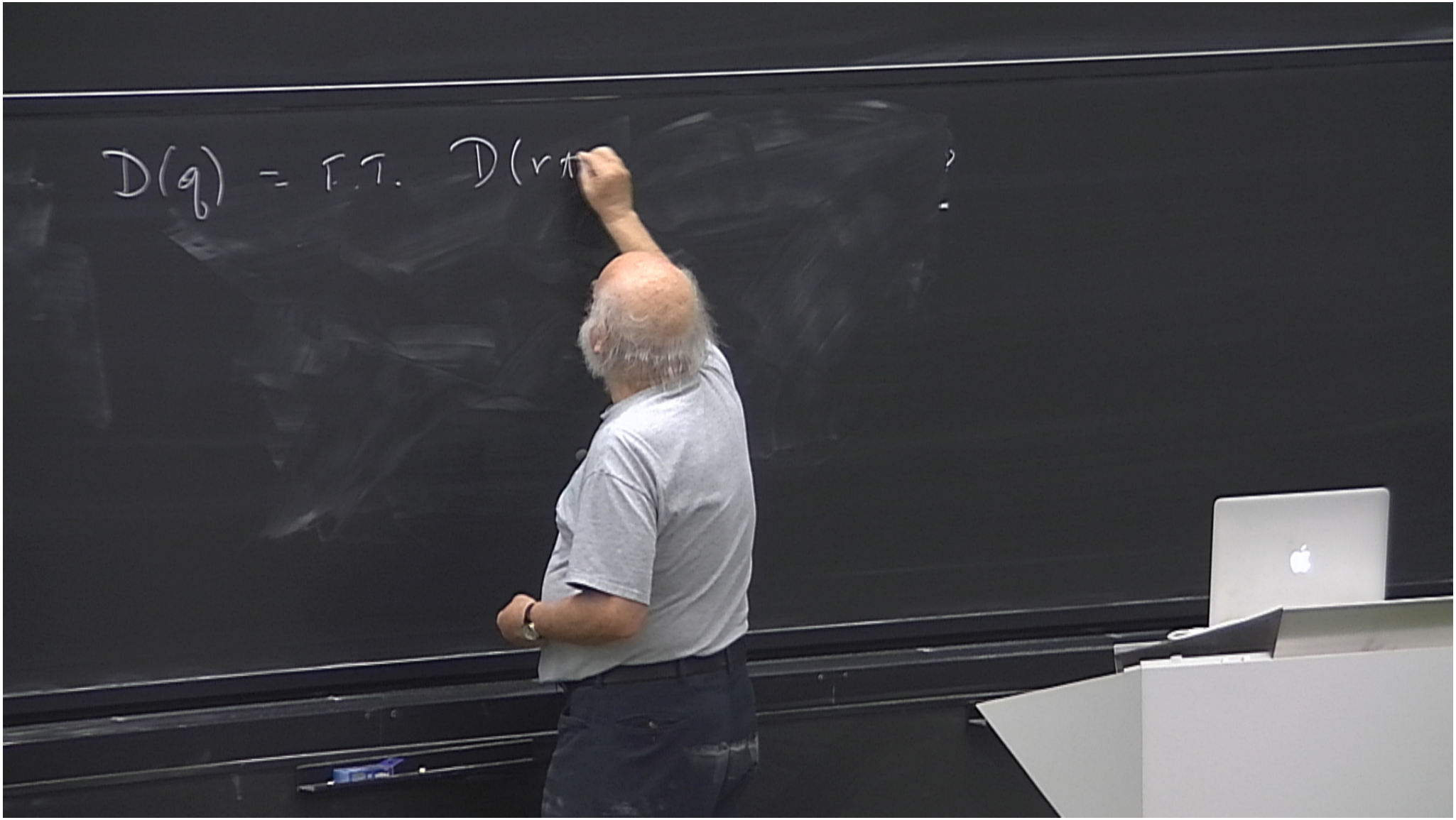
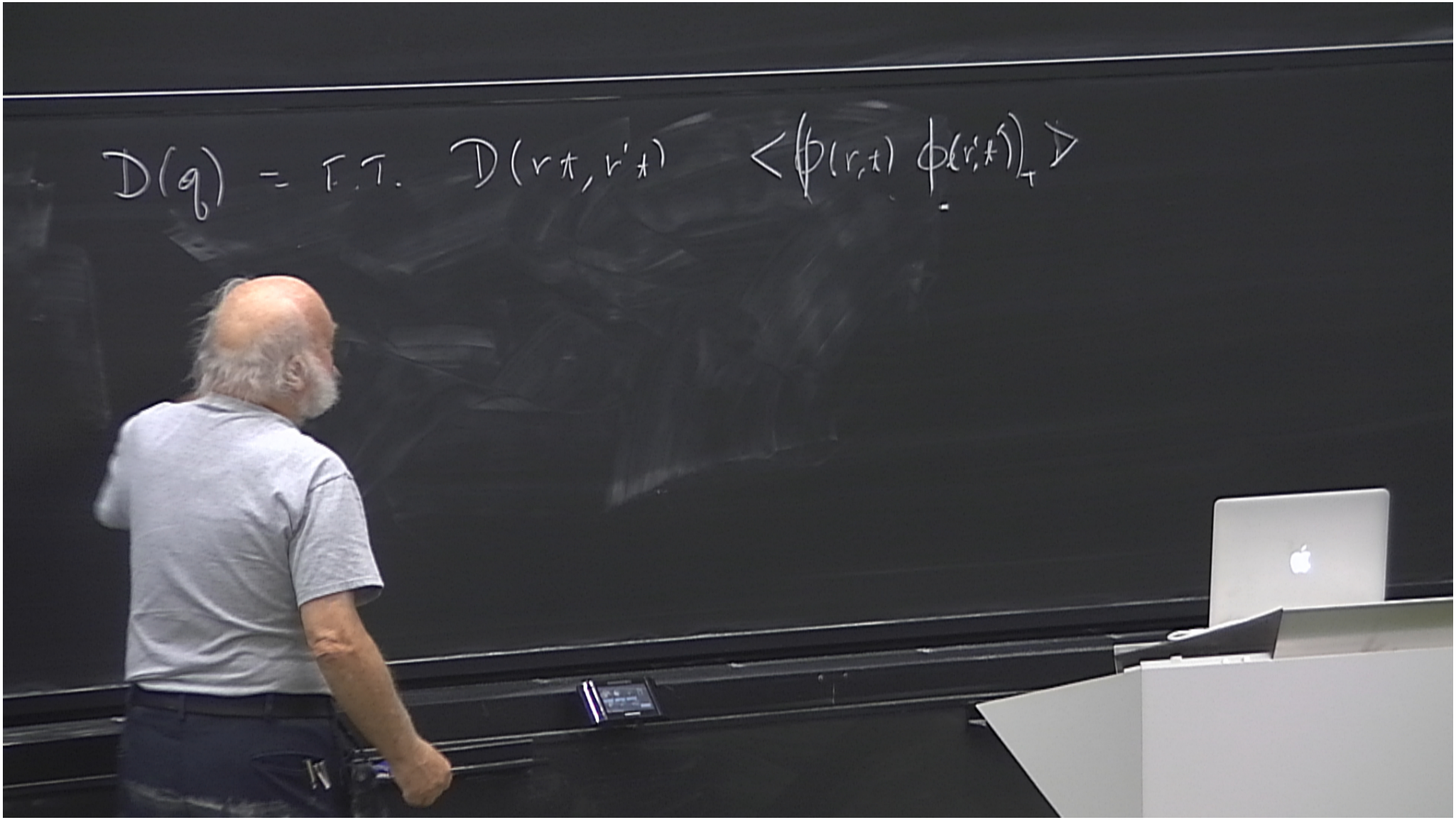
Title: Statistical Mechanics - Lecture 12

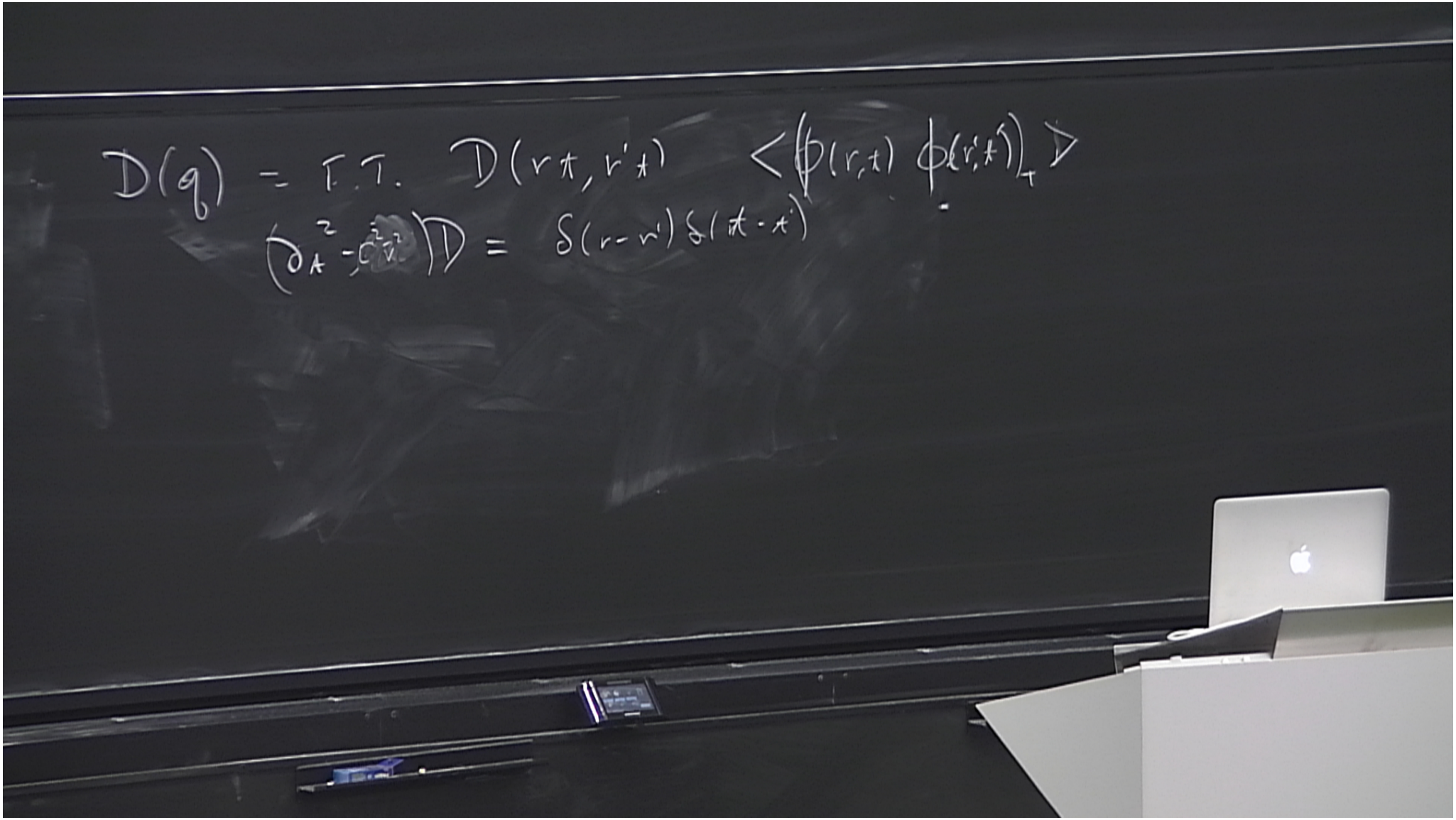
Date: Oct 19, 2011 10:30 AM

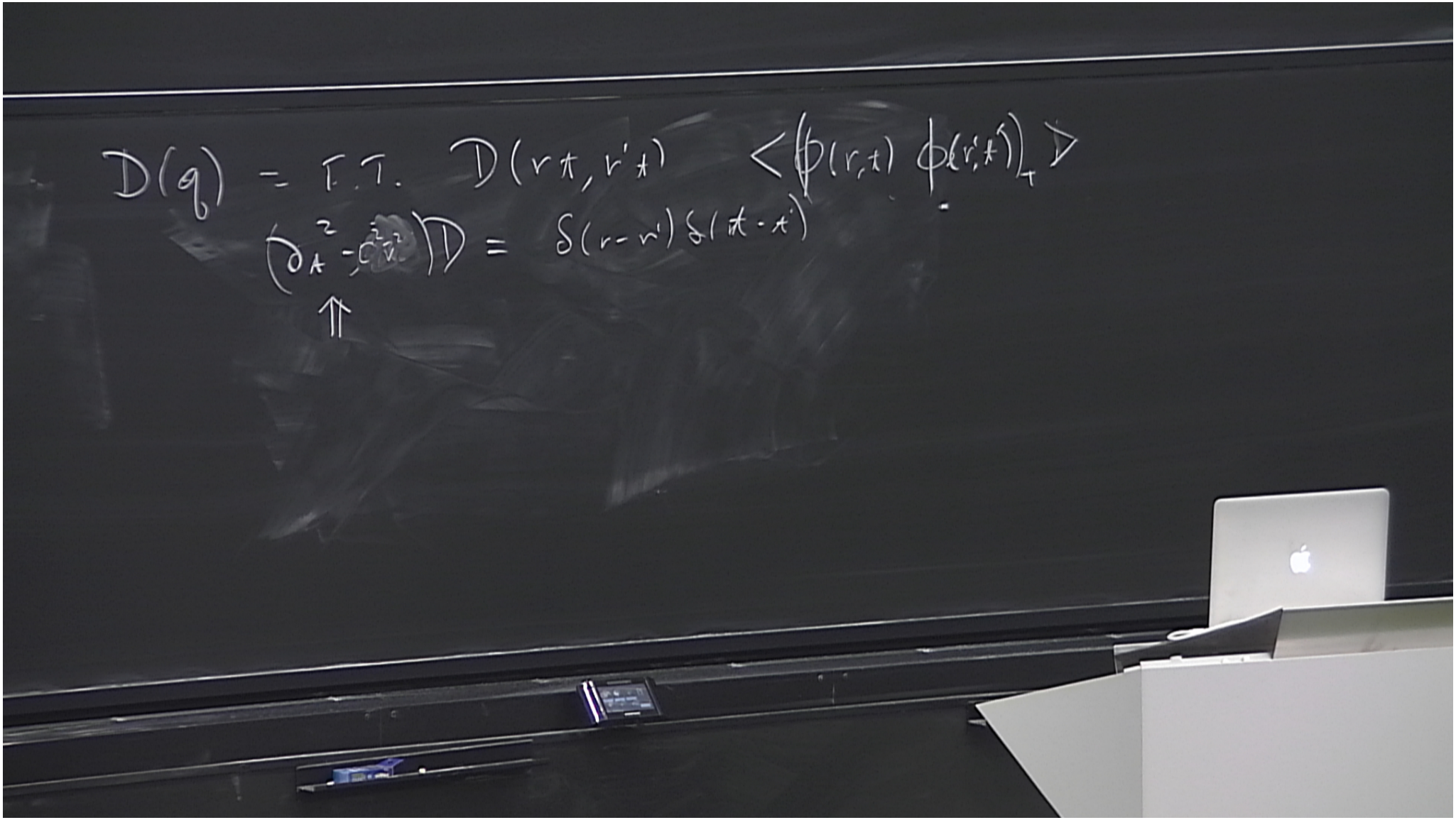
URL: http://pirsa.org/11100041

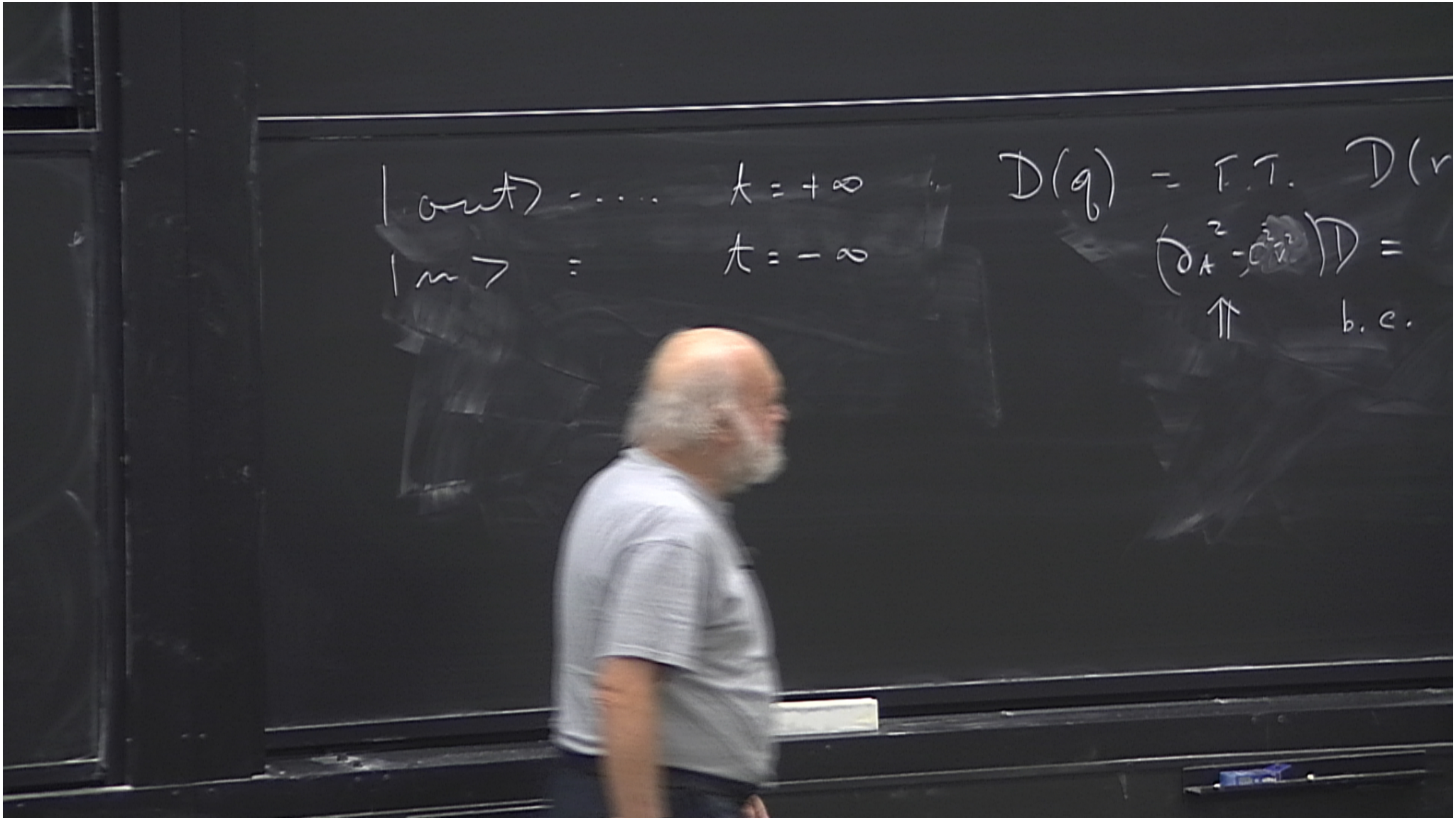
Abstract:

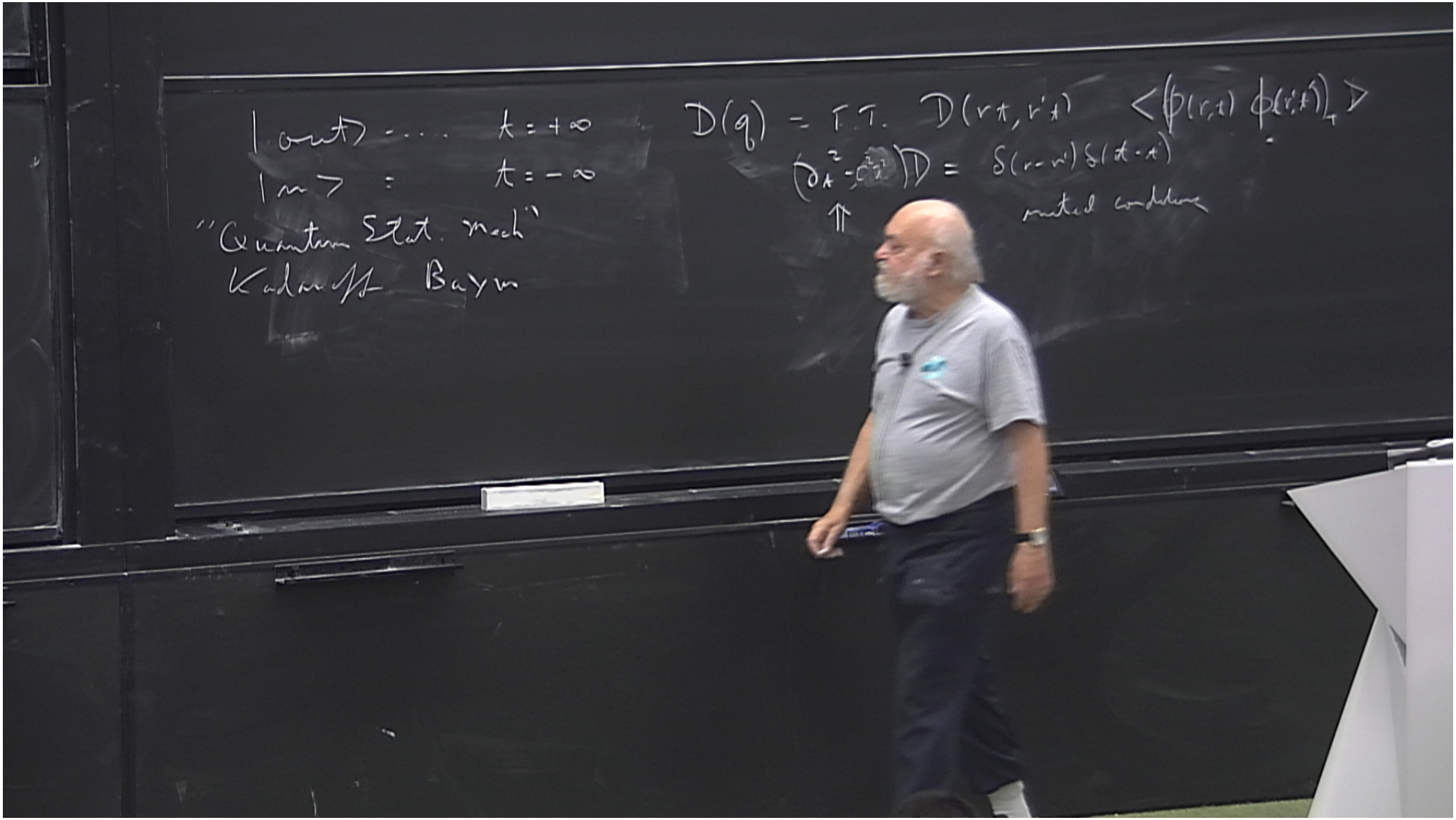

D(q) = F.T. D(r

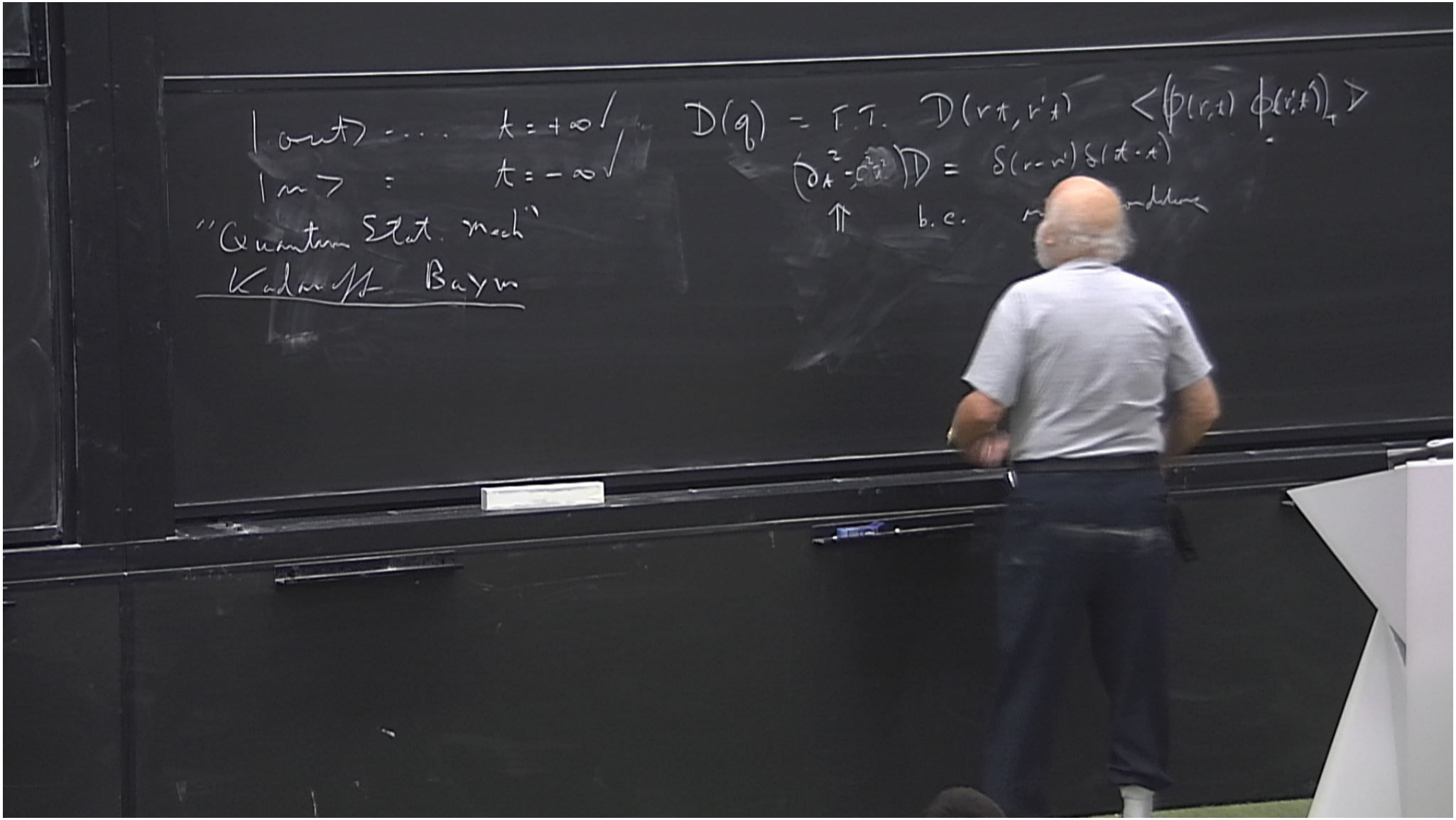

D(q) = F.T. D(r-r', t-t') <φ(r,t) φ(r',t')>_T

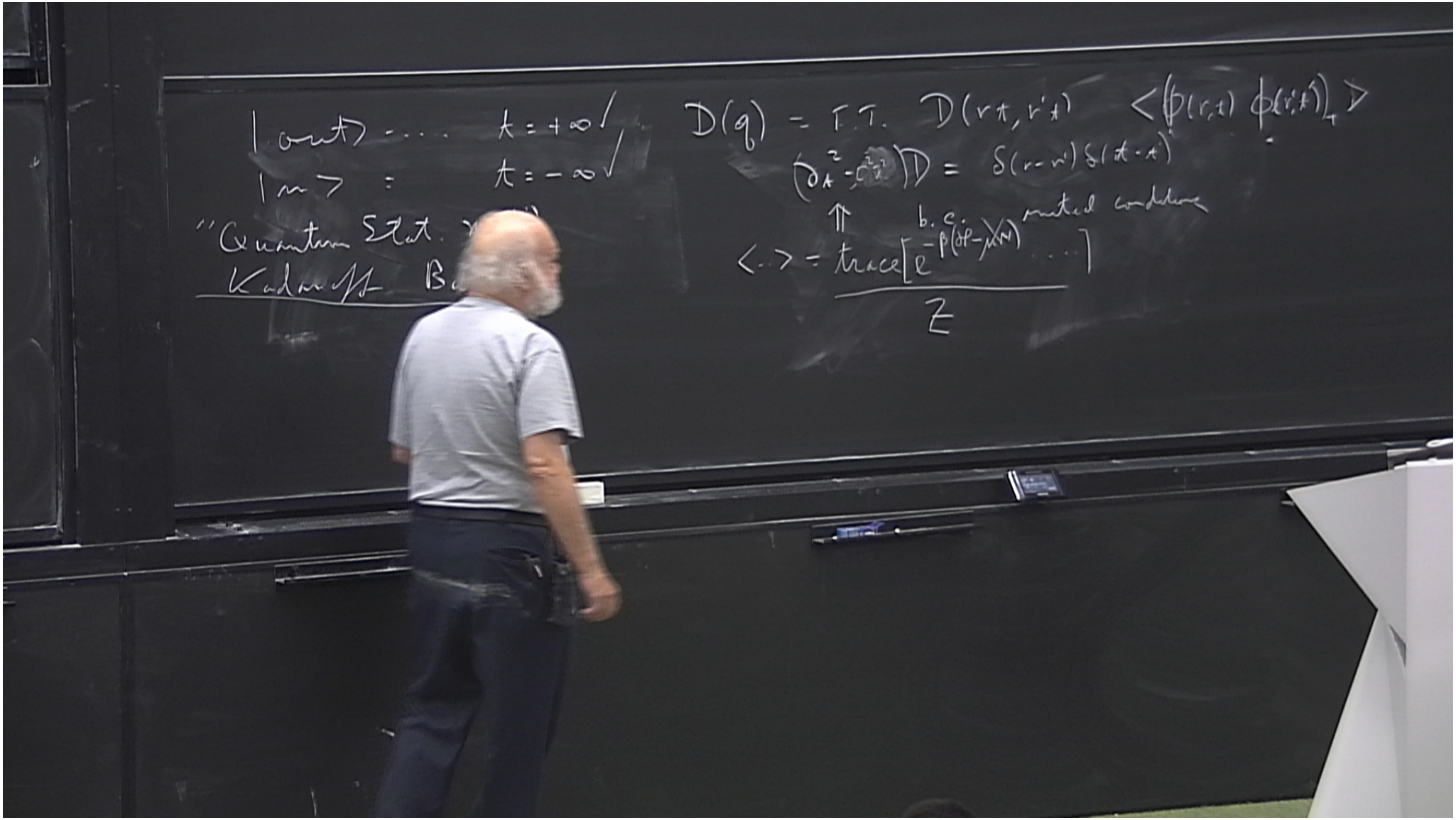

D(q) = F.T. D(r t, r' t')
<(φ(r,t) φ(r',t'))_+ >
(∂_t^2 - c^2 ∇^2) D = δ(r - r') δ(t - t')

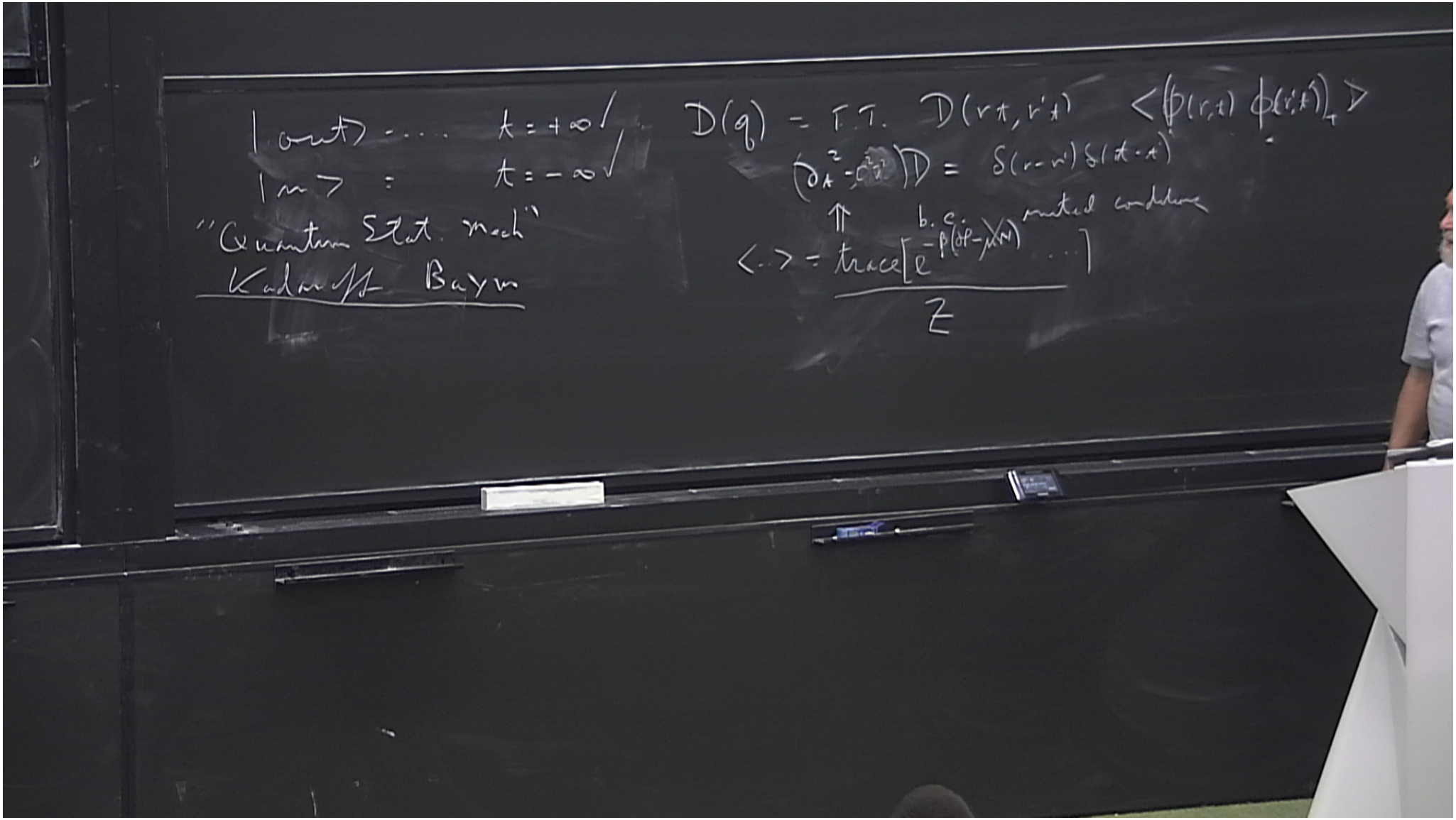

D(q) = F.T. D(r t, r' t')
<φ(r,t) φ(r',t')>
(∂t² - c²∇²) D = δ(r - r') δ(t - t')

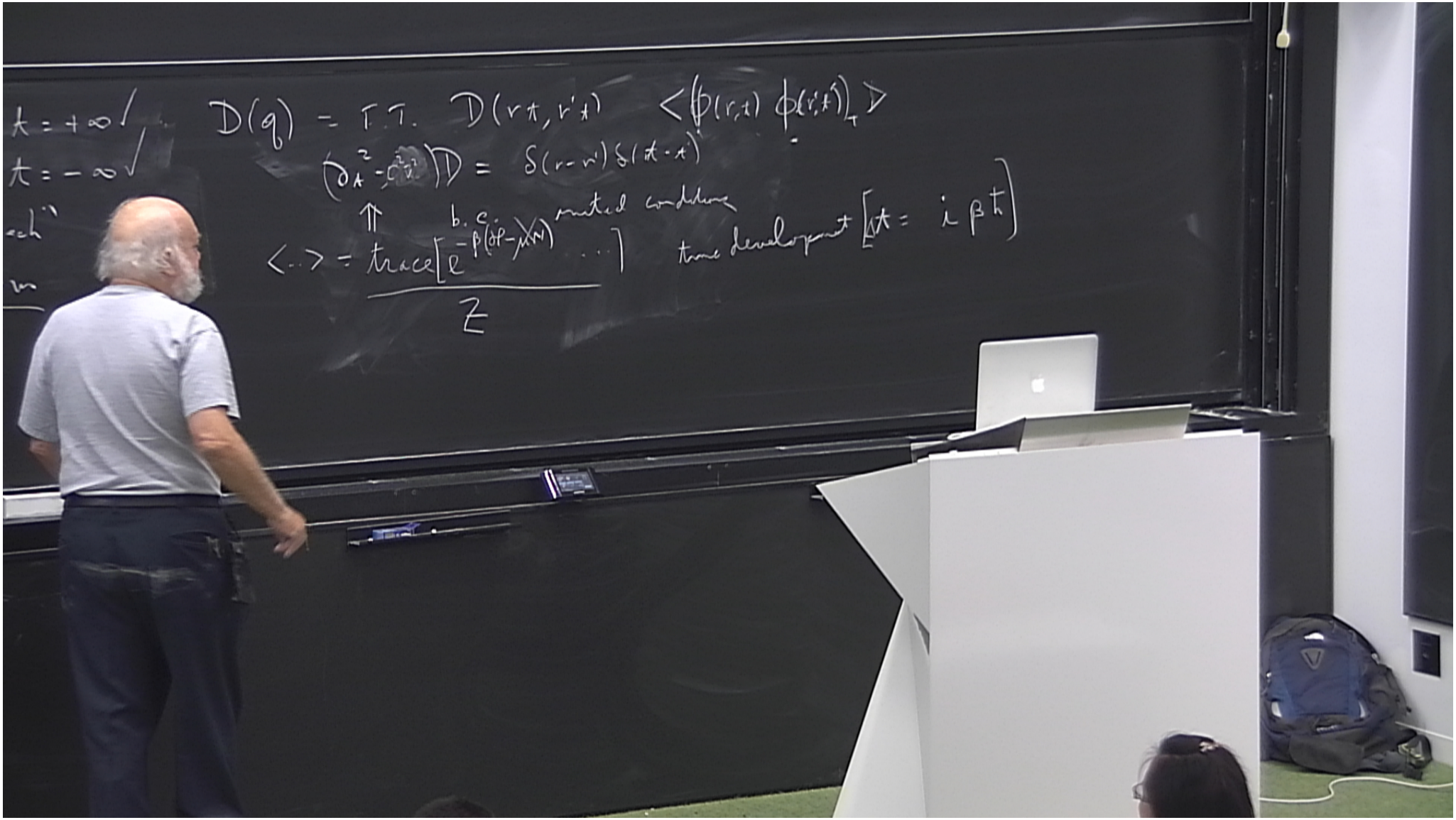

|out> .... t = +∞
|in> = t = −∞
D(q) = F.T. D(
(∂t² − c²∇²) D =
⇑ b.c.

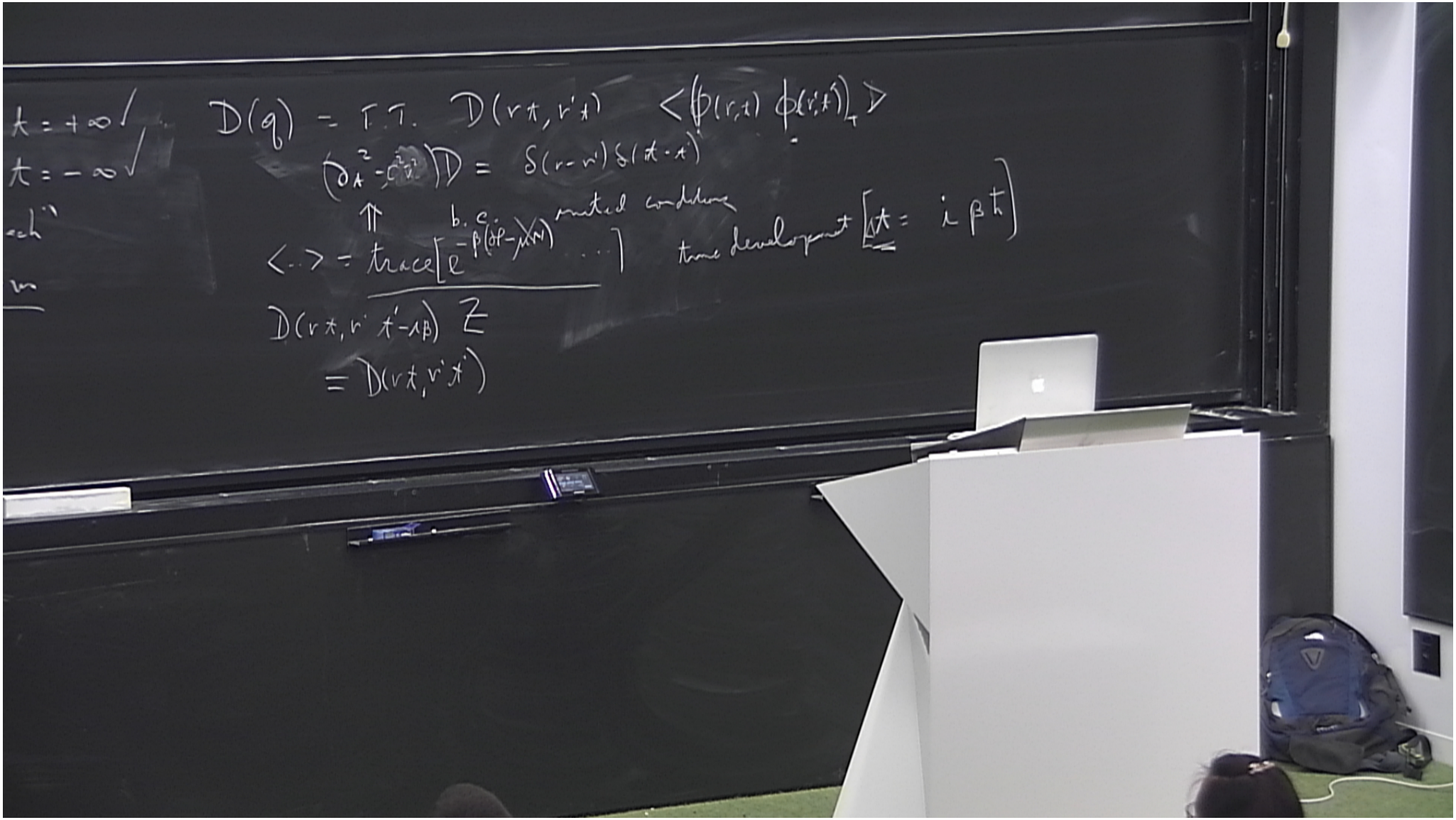

|out> .... t = +∞
|in> : t = −∞
"Quantum Stat. mech"
Kadanoff Baym
D(q) = F.T. D(rt, r't)
D = δ(r−r')δ(t−t')

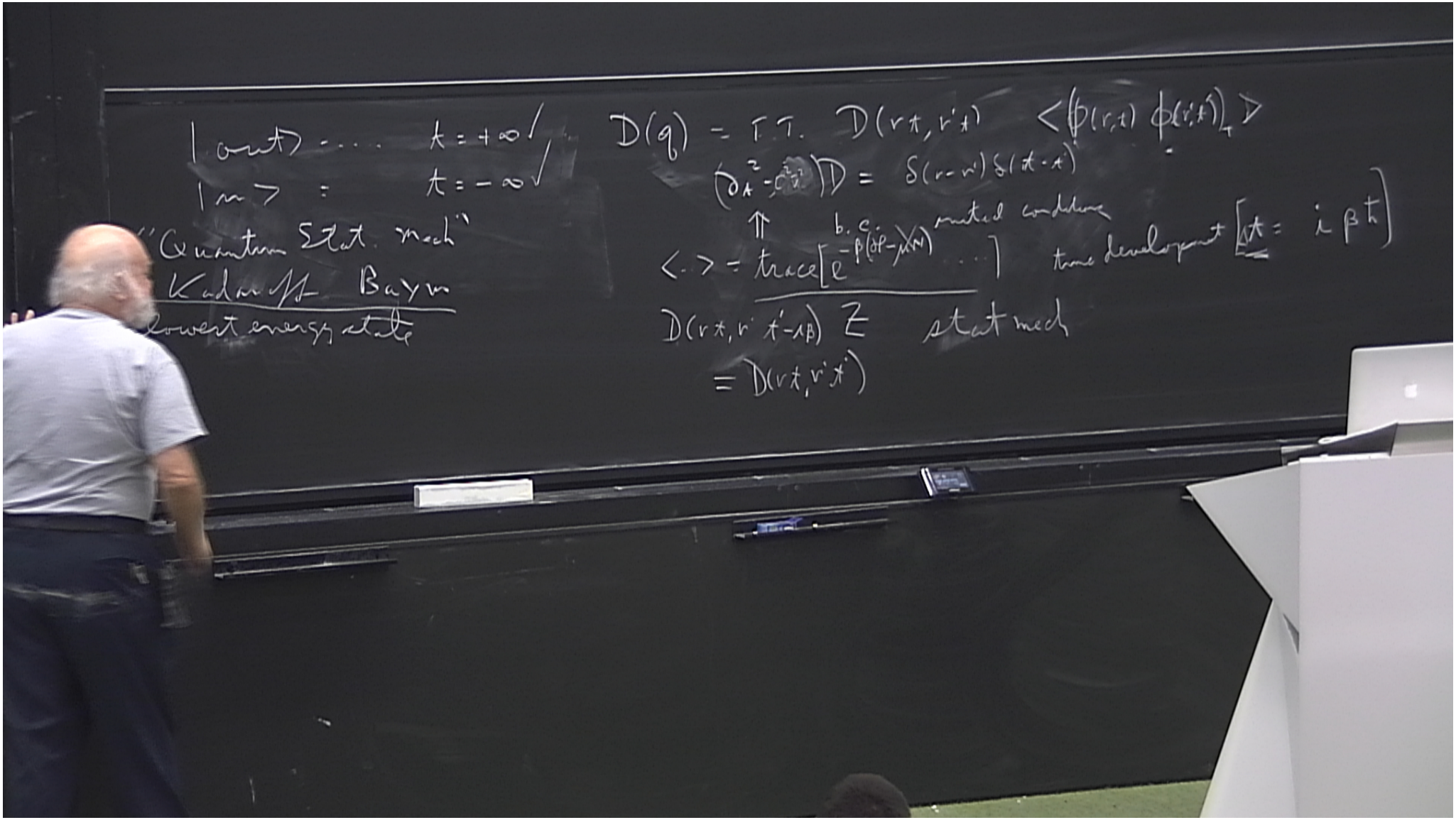

$|\text{out}\rangle$ .... $t = +\infty$
$|\text{in}\rangle$: $t = -\infty$
"Quantum Stat. mech"
Kadanoff Baym
$D(q) = T.T.\ D(r t, r' t')$ $\langle \phi(r,t)\ \phi(r',t') \rangle$
$(\partial_t^2 - c^2 \nabla^2) D = \delta(r-r')\delta(t-t')$
b.c.

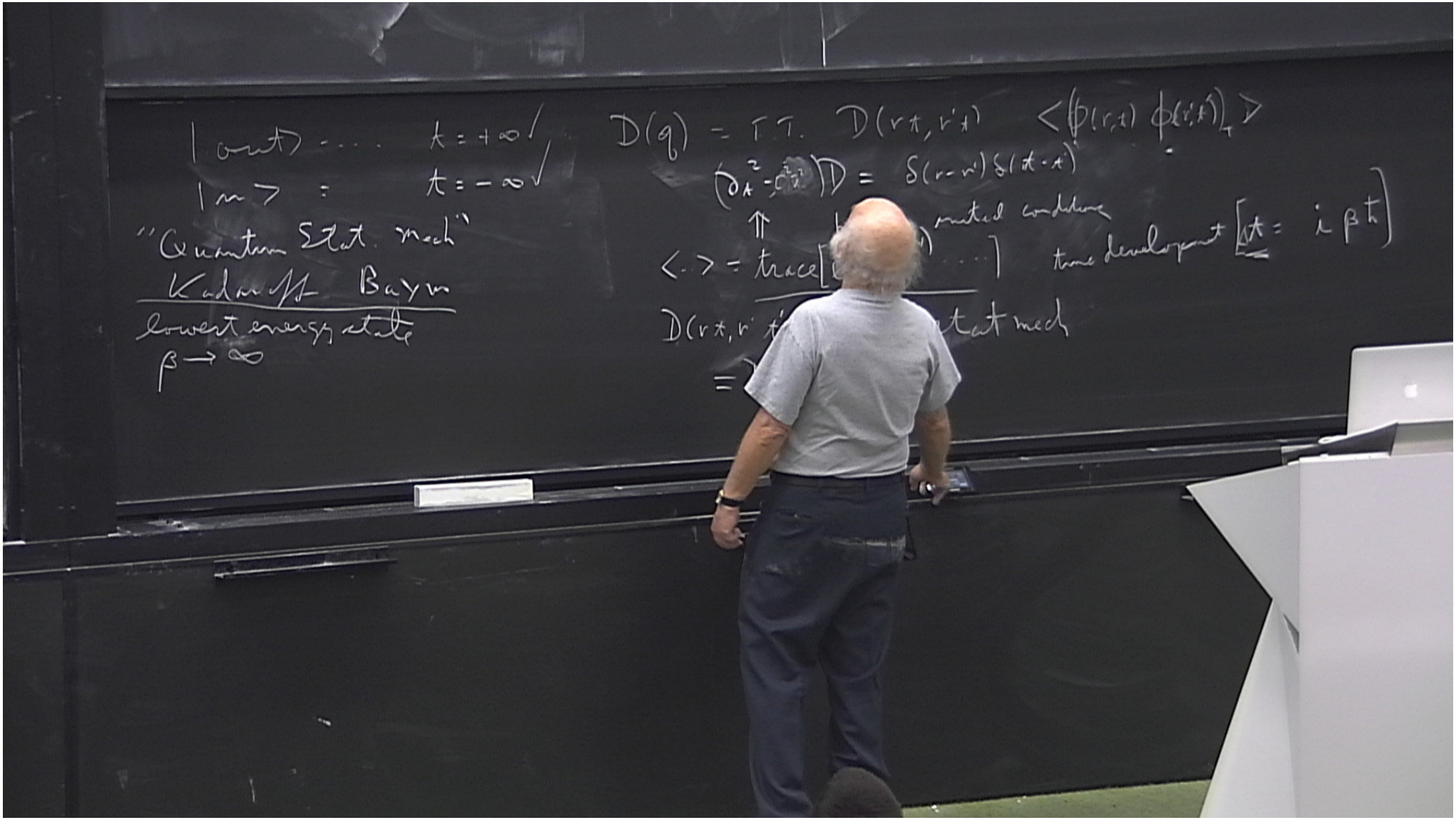

|out> .... t = +∞
|in> : t = −∞
"Quantum Stat.
Kadanoff
D(q) = F.T. D(rt, r't)
b.c.
Z

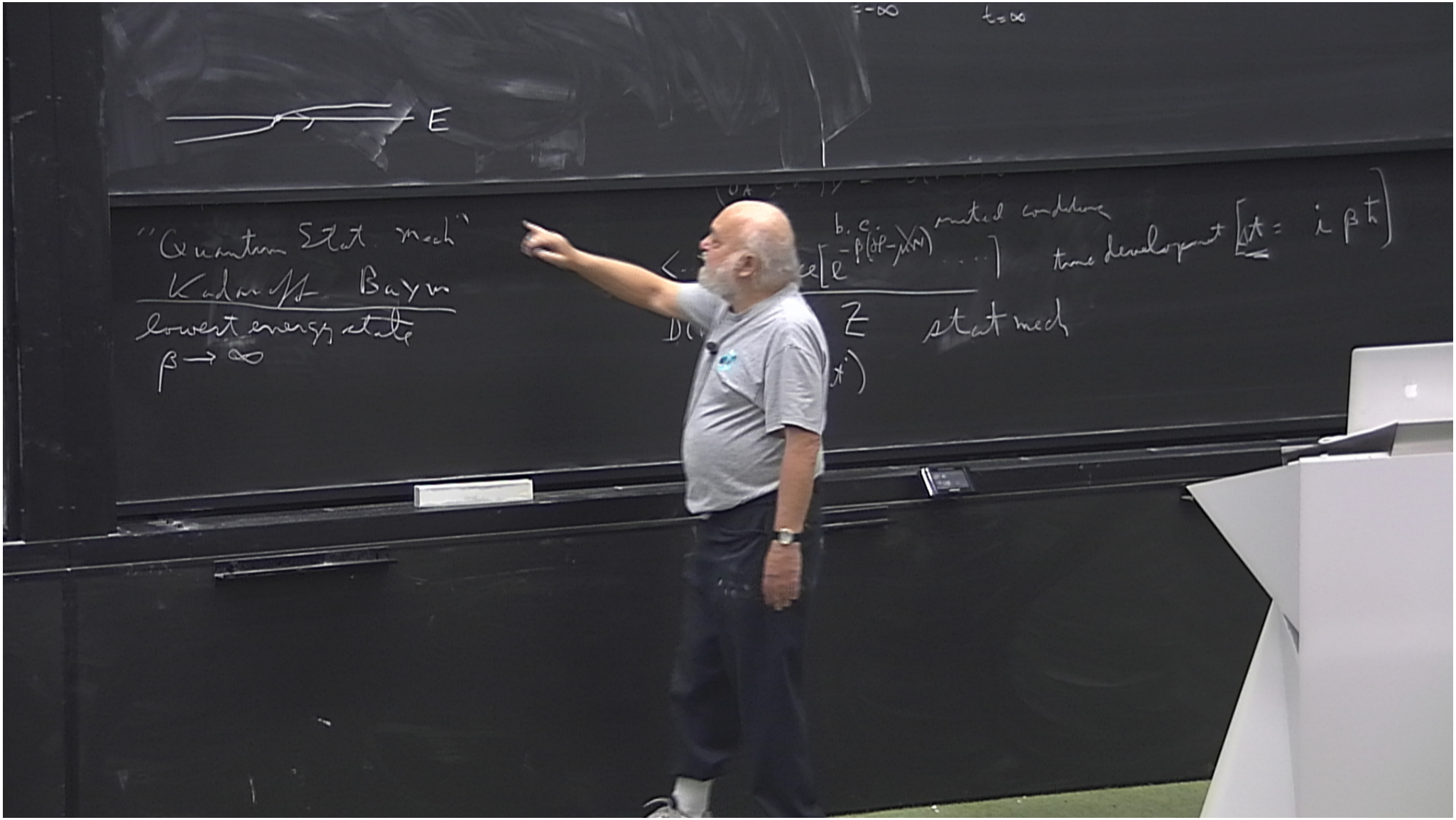

$|\text{out}\rangle$ .... $t = +\infty$
$|n\rangle$: $t = -\infty$
"Quantum Stat. mech"
Kadanoff Baym
$D(q) = T.T.\ D(r t, r' t')$ $\langle \phi(r,t)\ \phi(r',t') \rangle$
$(\partial_t^2 - c^2 \nabla^2) D = \delta(r-r')\delta(t-t')$
b.c.
$\langle .. \rangle = \frac{\text{trace}[e^{-\beta(\hat{H}-\mu\hat{N})} ...]}{Z}$
initial conditions

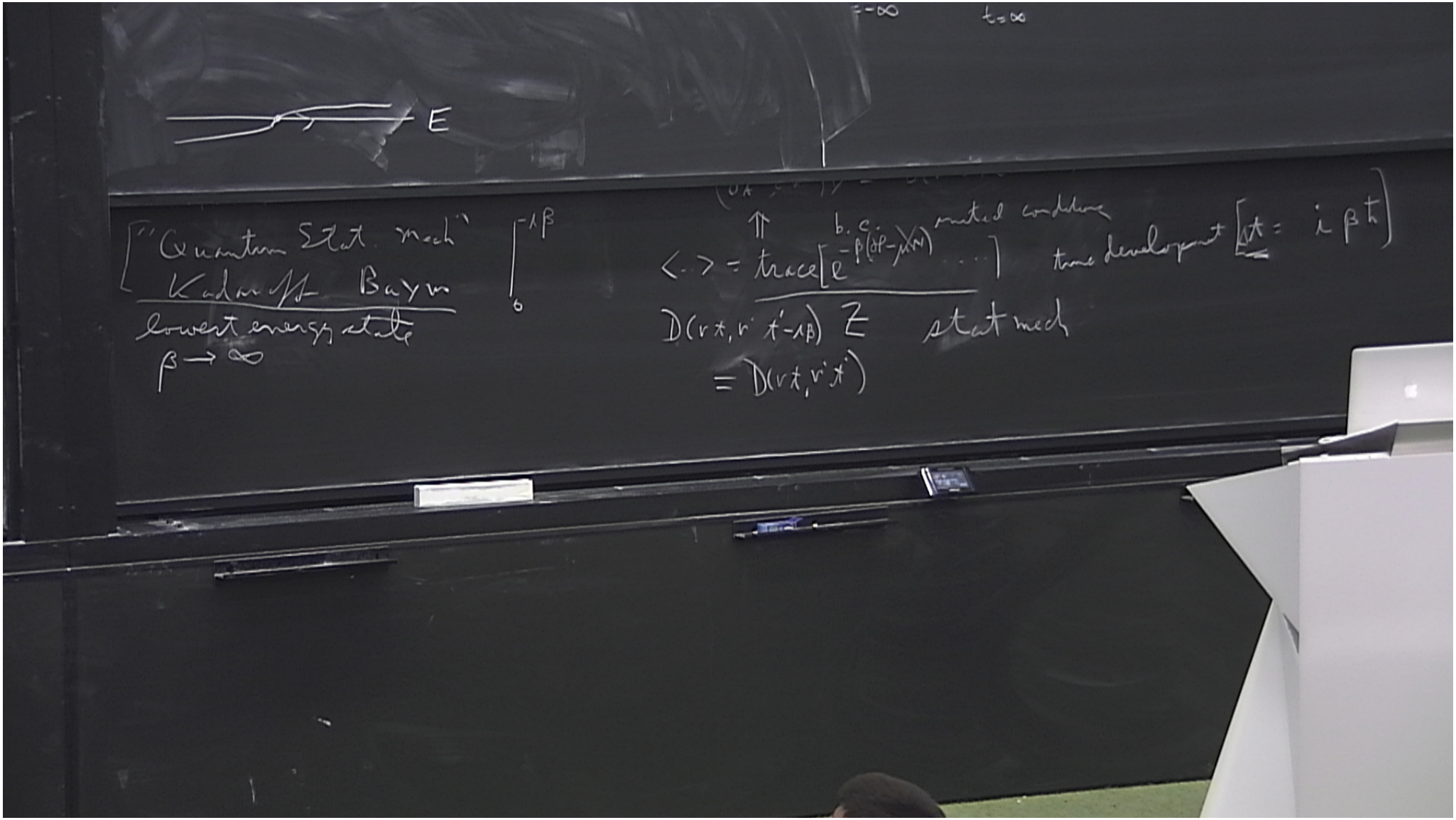

t = +∞
t = −∞
D(q) = F.T. D(rt, r't)
b.c.
initial conditions
trace
Z
time development

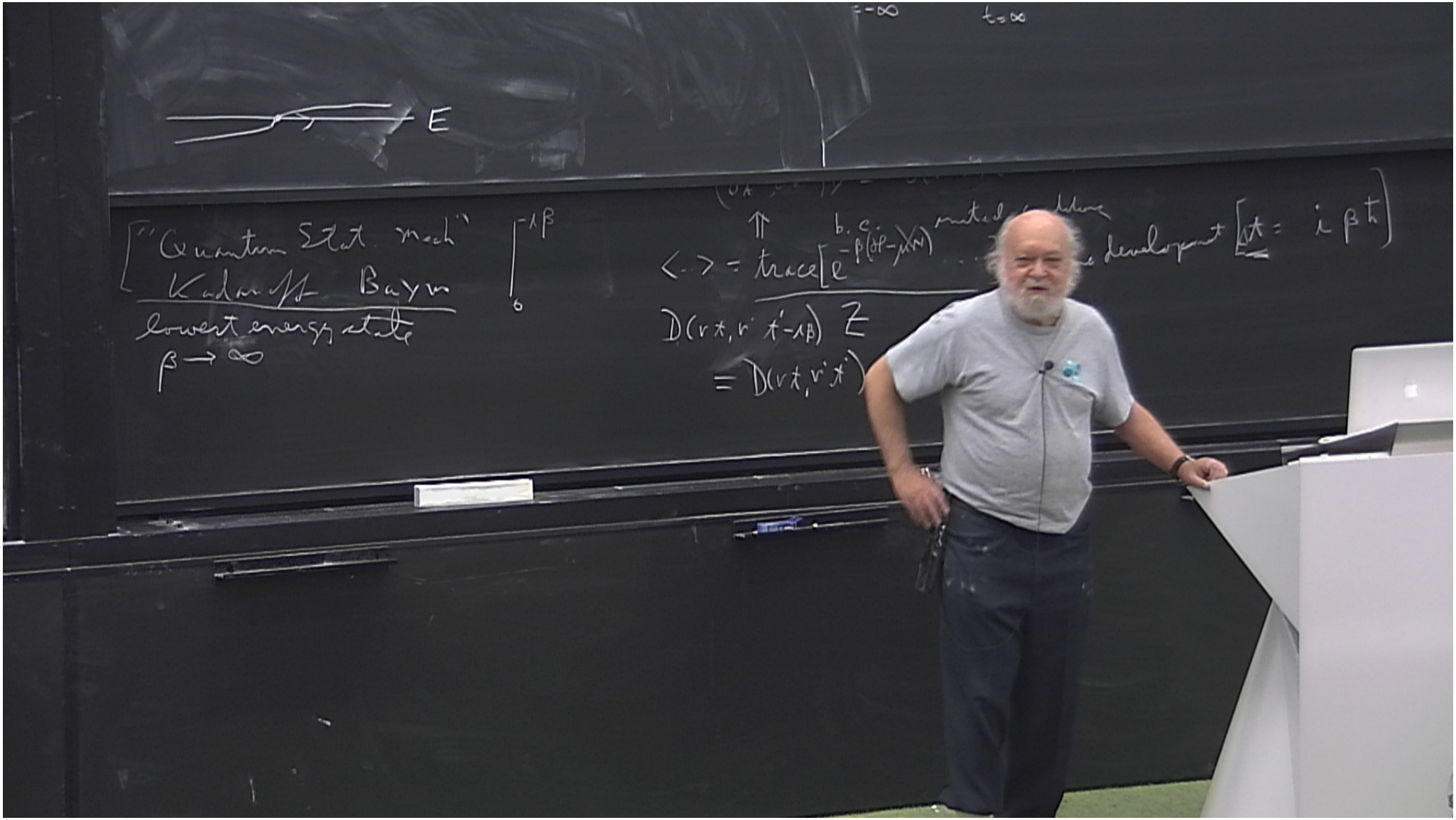

$t = +\infty$
$t = -\infty$
$D(q) = T.T.\ D(r\,t, r'\,t')$
$\langle \phi(r,t)\ \phi(r',t') \rangle_+$
$(\partial_t^2 - c^2 \nabla^2) D = \delta(r-r')\,\delta(t-t')$
b.c.
$\langle \ldots \rangle = \mathrm{trace}[e^{-\beta(\mathcal{H}-\mu N)} \ldots]$
mixed conditions
time development $[\Delta t = i\beta\hbar]$
$D(r\,t, r'\,t'-i\beta)\ Z$
$= D(r\,t, r'\,t')$


|out> ... t = +∞
|in> : t = −∞
"Quantum Stat mech"
Kadanoff Baym
lowest energy state
D(q) = T.T. D(rt, r't') <φ(r,t) φ(r',t')>
(∂t² − c²∇²) D = δ(r − r') δ(t − t')
b.c.
<.> = trace[e^{−β(H−μN)} ...]
D(rt, r't' − iβ) Z
= D(rt, r't')
stat mech
initial condition
time development
Δt = iβħ


|out> .... t = +∞
|in> : t = −∞
"Quantum Stat. mech"
Kadanoff Baym
lowest energy state
β → ∞
D(q) = F.T. D(rt, r't)
time development
stat mech


E
"Quantum Stat mech"
Kadanoff Baym
lowest energy state
β → ∞
b.c.
initial conditions
time development
Z
stat mech


E
"Quantum Stat mech"
Kadanoff Baym
lowest energy state
$\beta \to \infty$
$\int_0^{-i\beta}$
$t = -\infty$
$t = \infty$
b. c.
initial condition
$\langle \cdot \rangle = \mathrm{trace}[e^{-\beta(\hat{H}-\mu\hat{N})} \cdots]$
time development $[\Delta t = i\beta\hbar]$
$D(r t, r' t' - i\beta)$ Z stat mech
$= D(r t, r' t')$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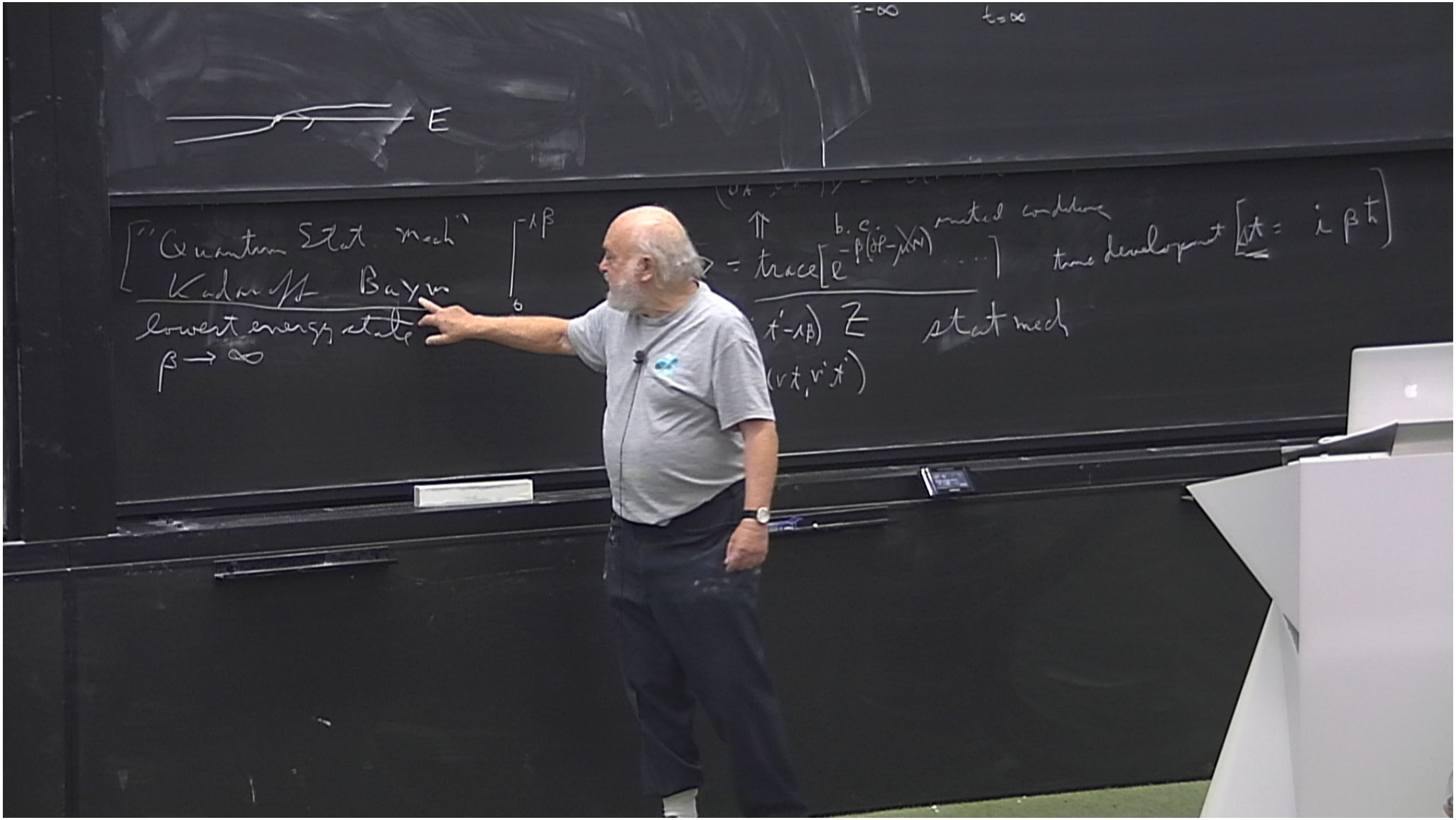
β → ∞
b.c.
trace
D(rt, r't' − iβ) Z
= D(rt, r't')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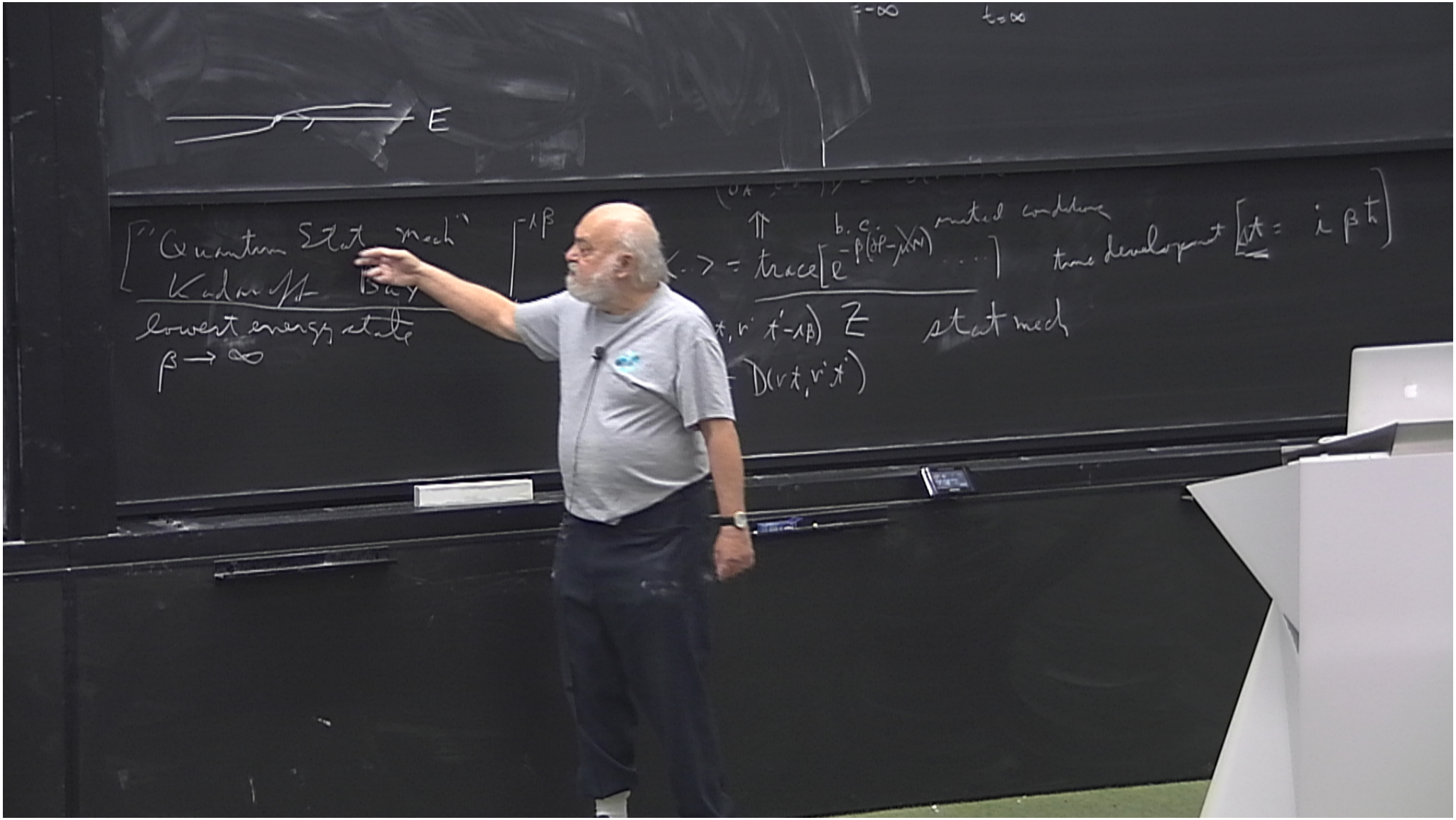
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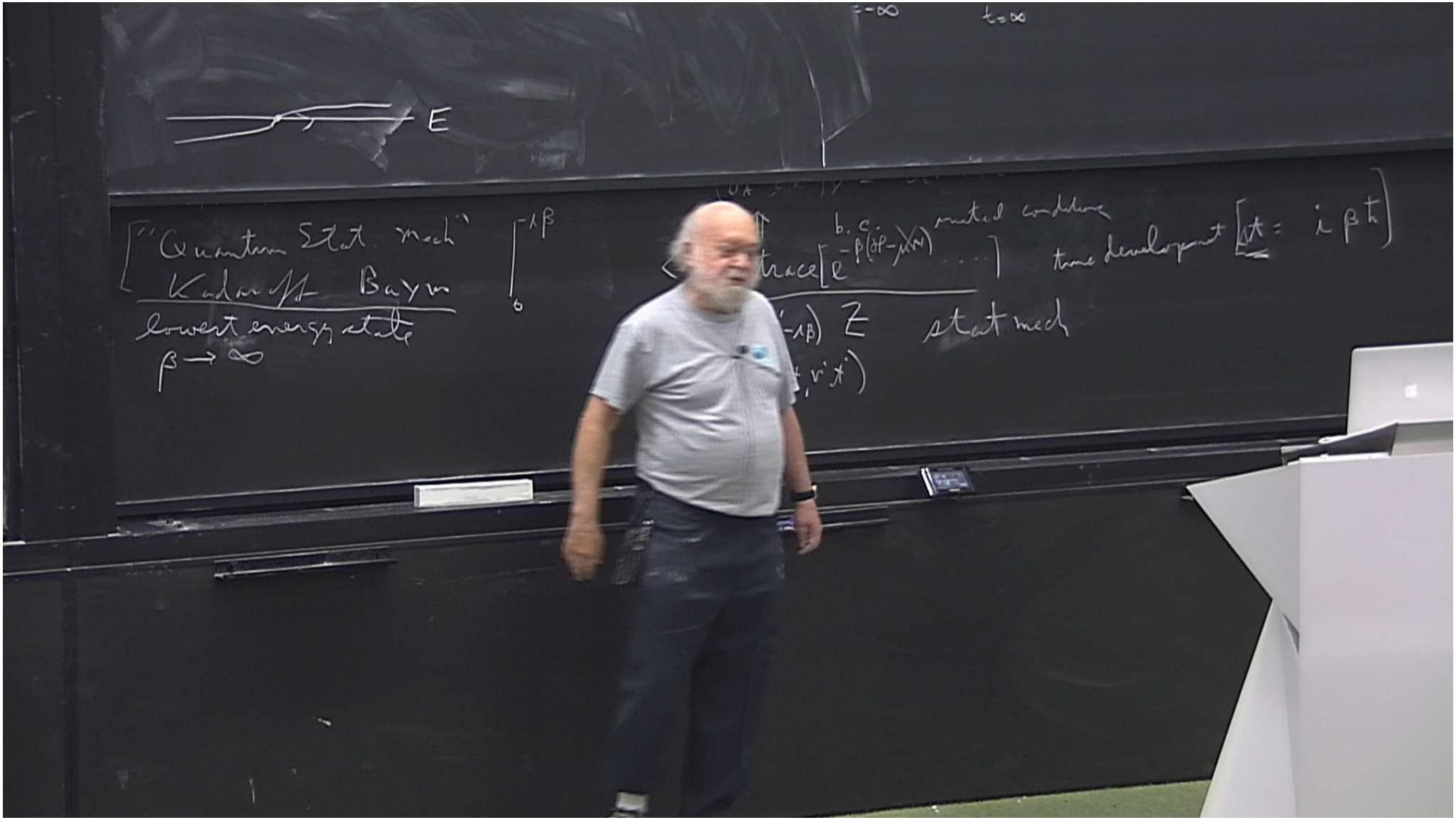
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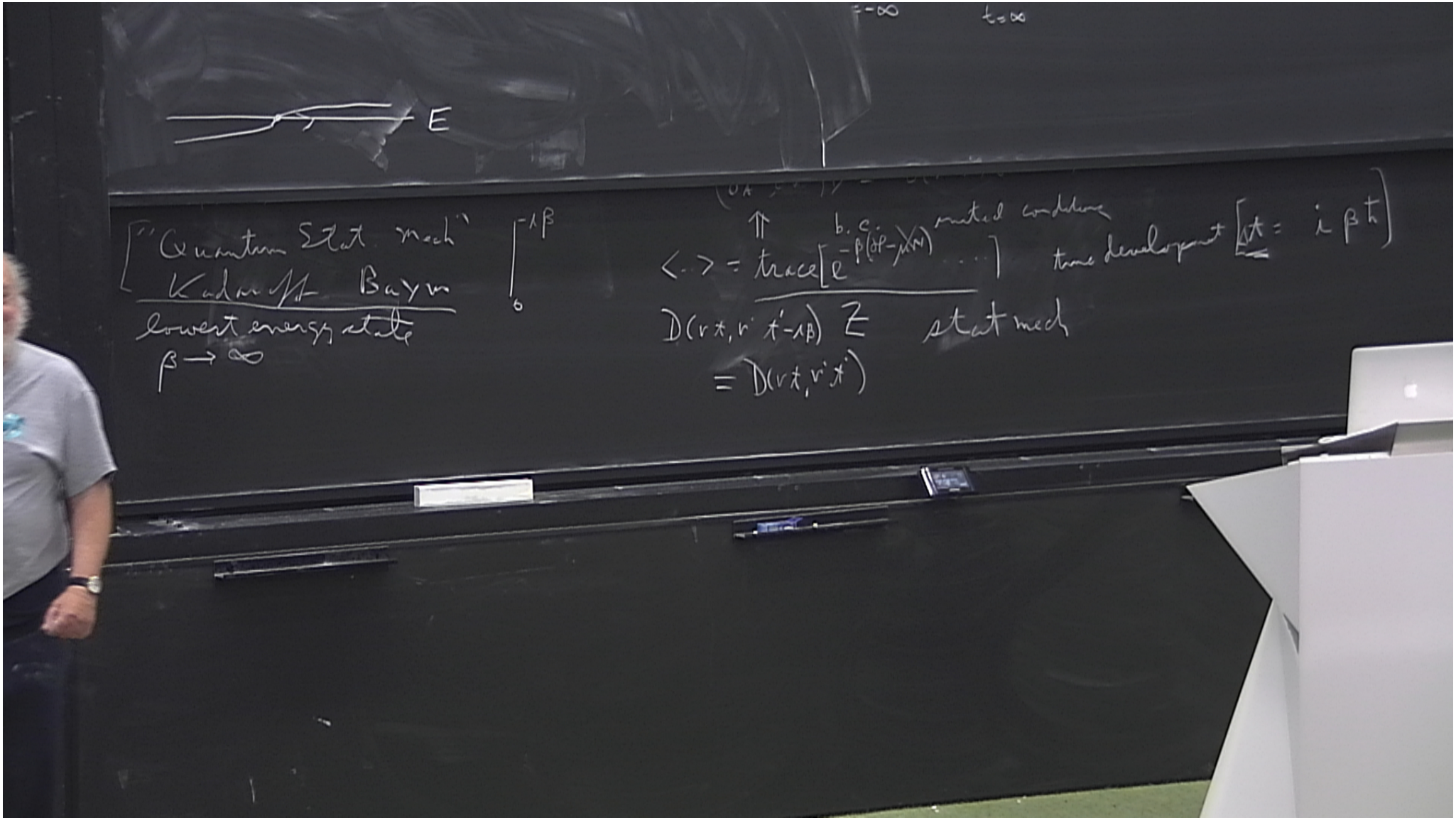
stat mech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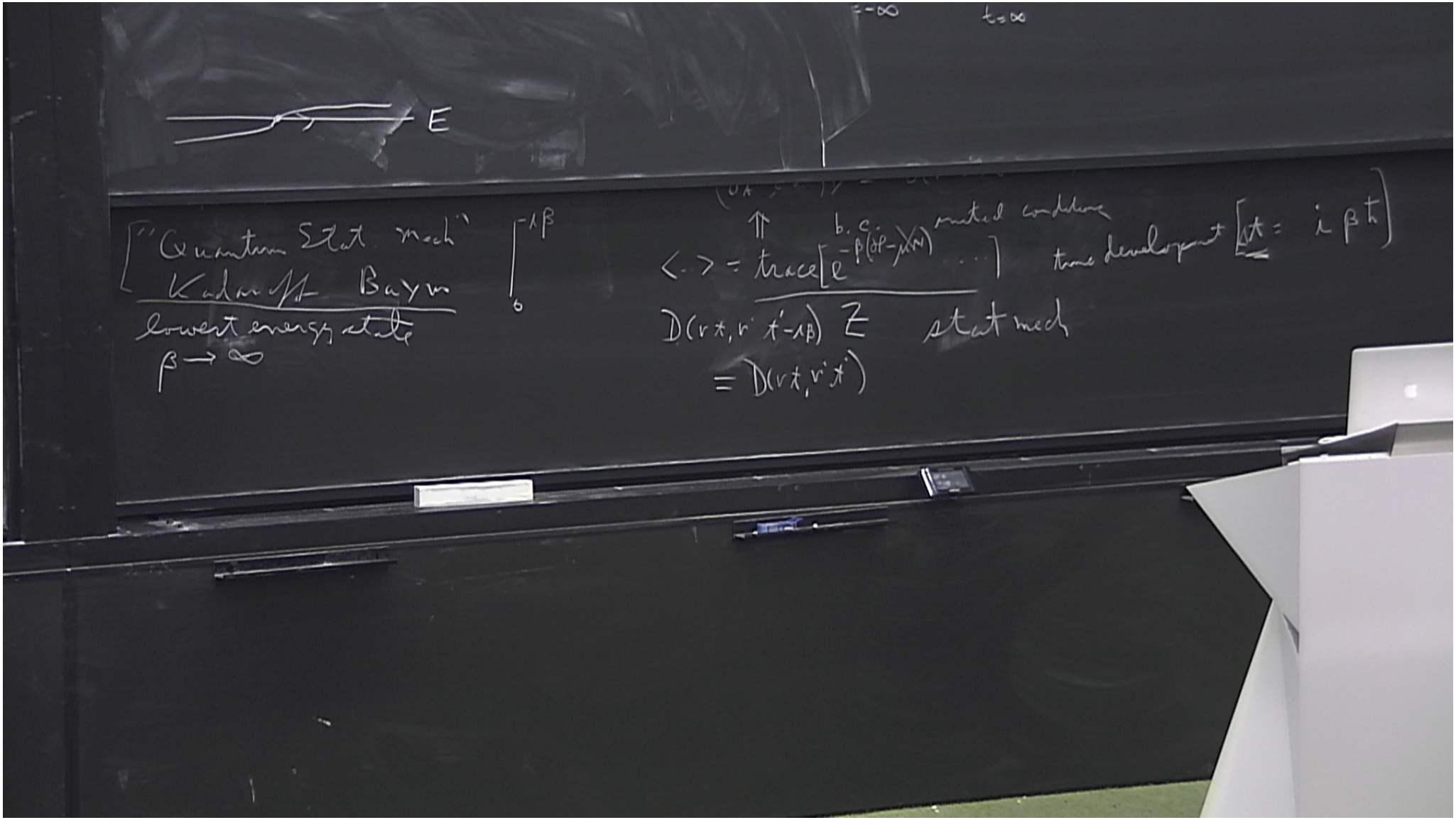
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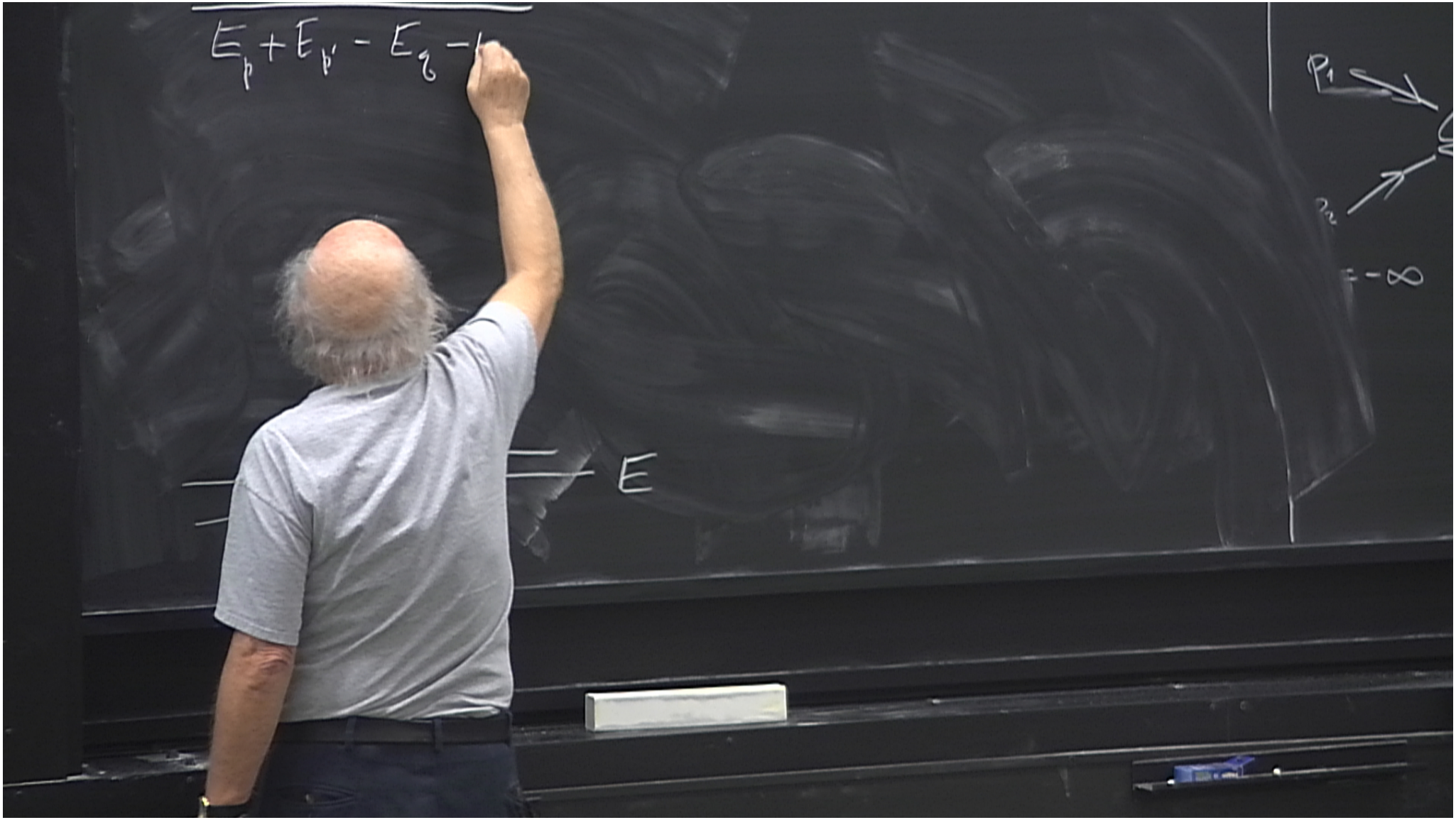
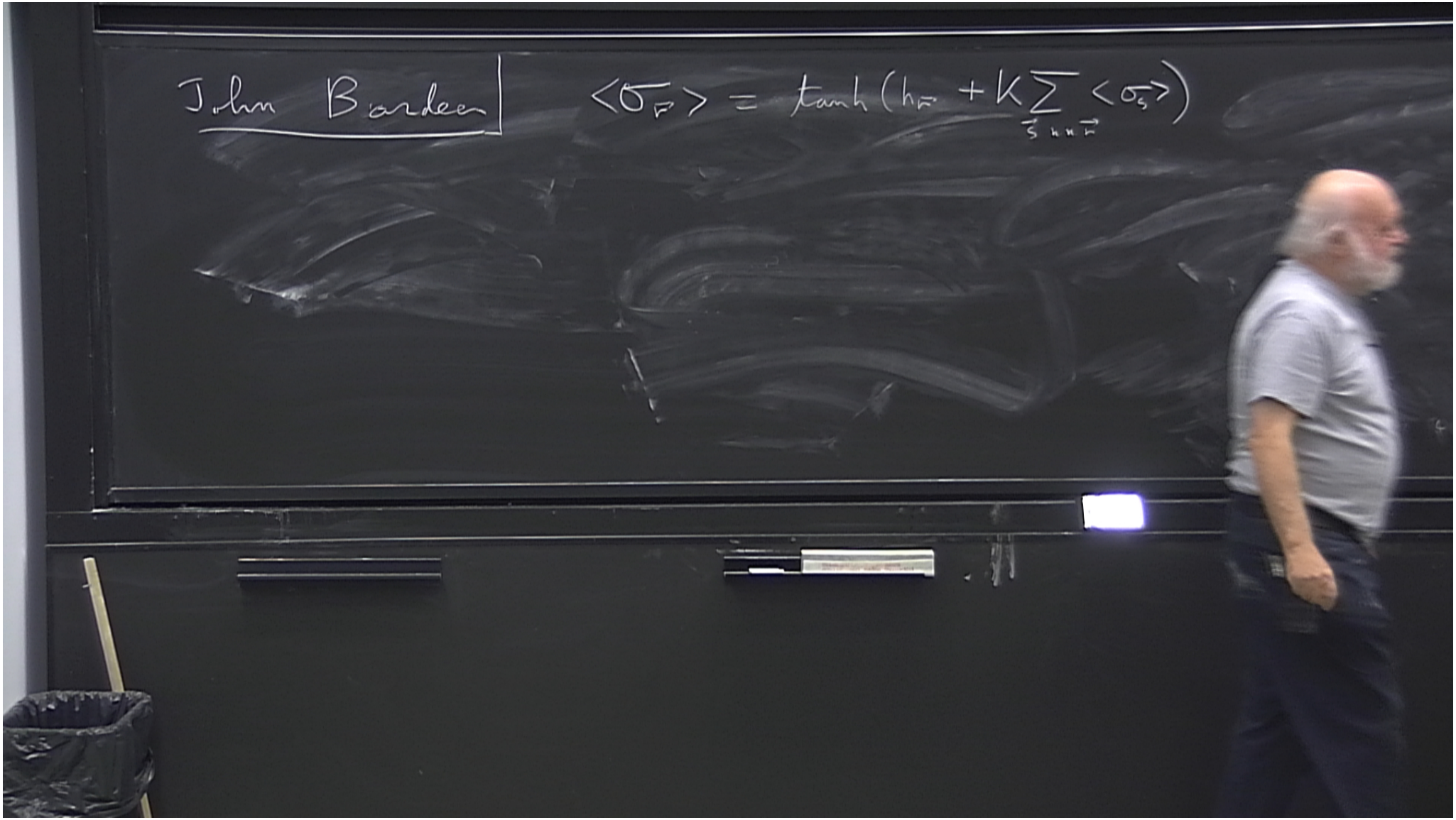
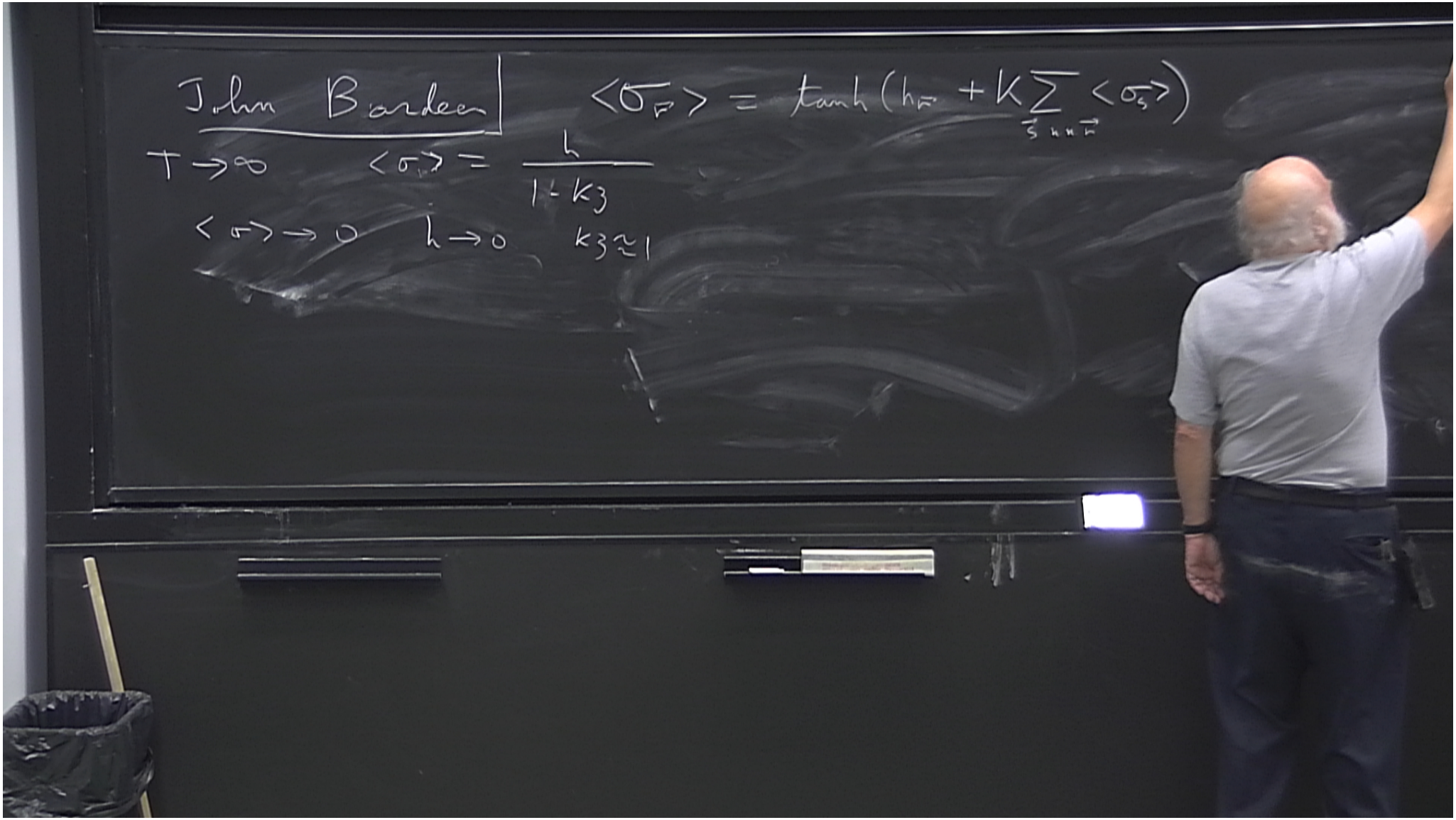
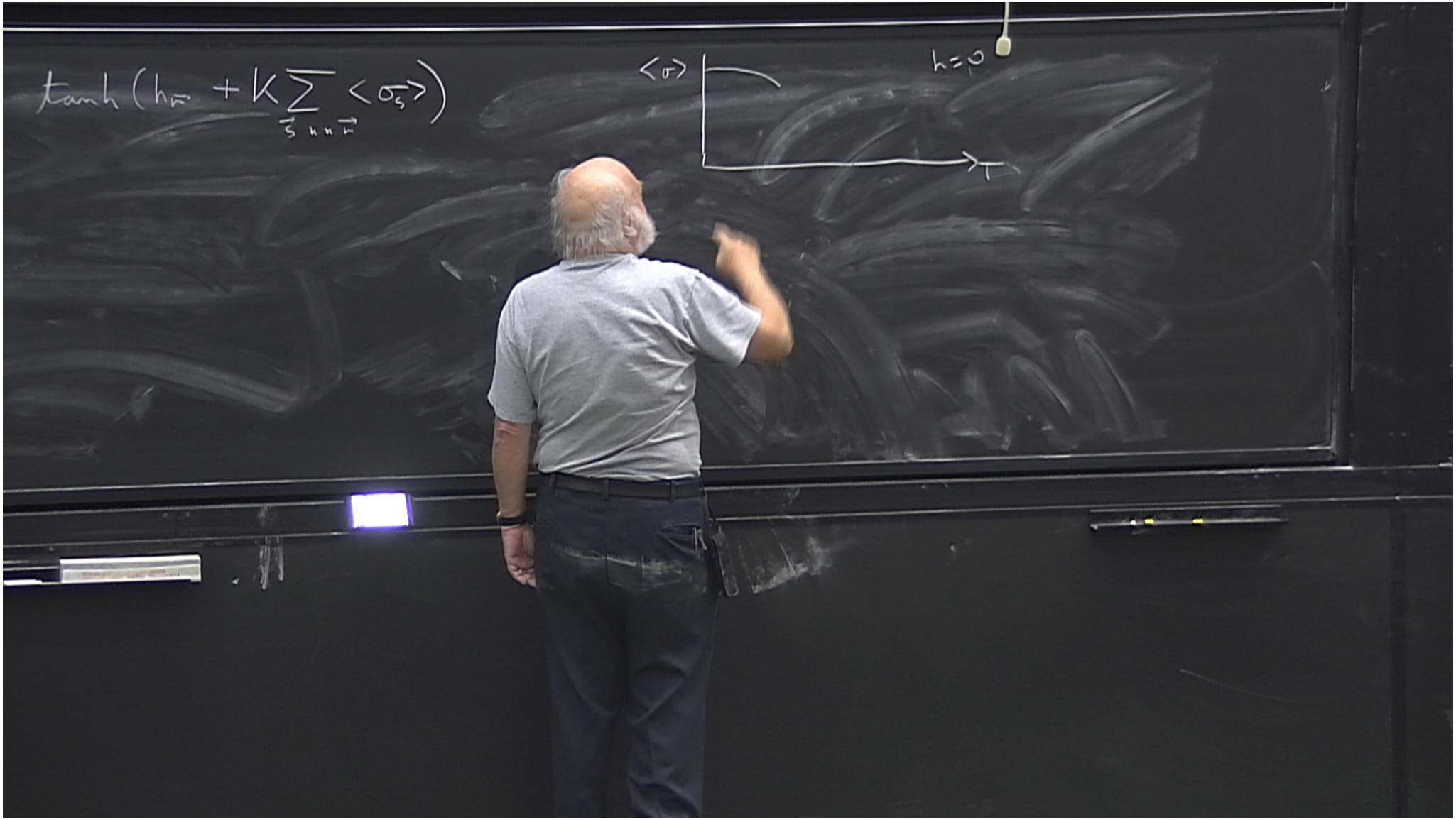
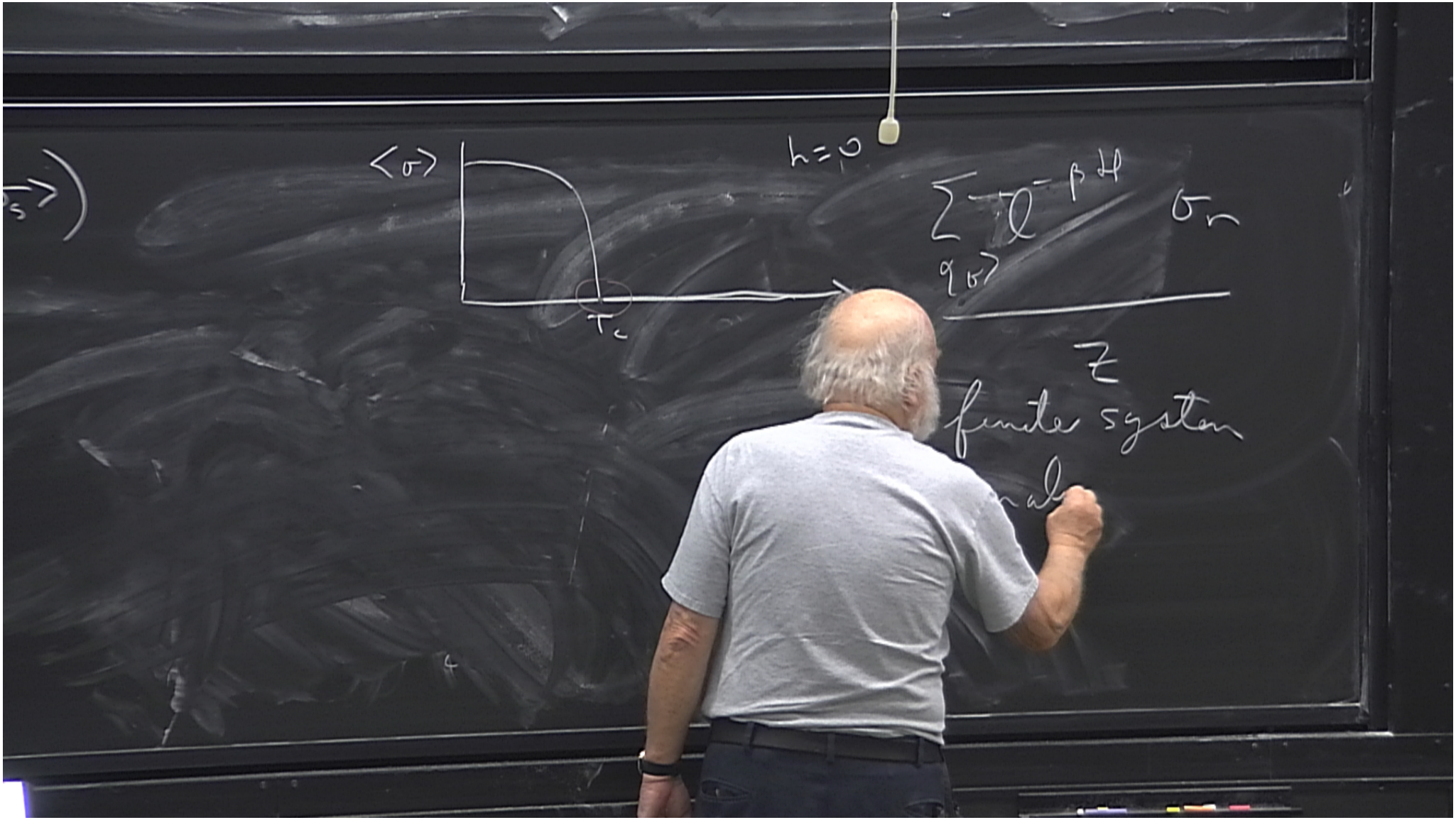

$E_p + E_{p'} - E_q -$
E
P_1
P_2
$= -\infty$

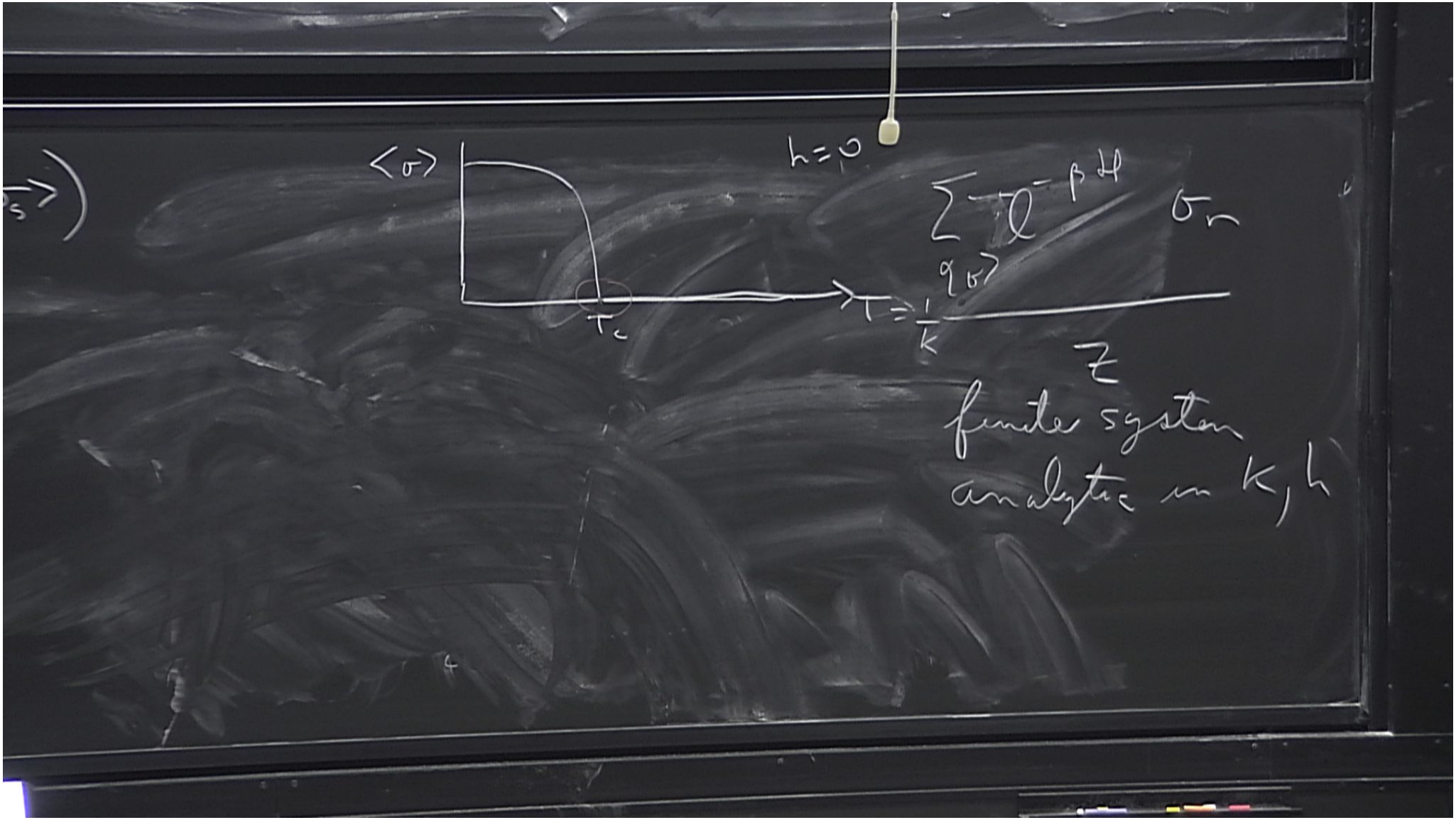
$\frac{1}{(E_i+E_{i'}-E_f-E_{f'})}$

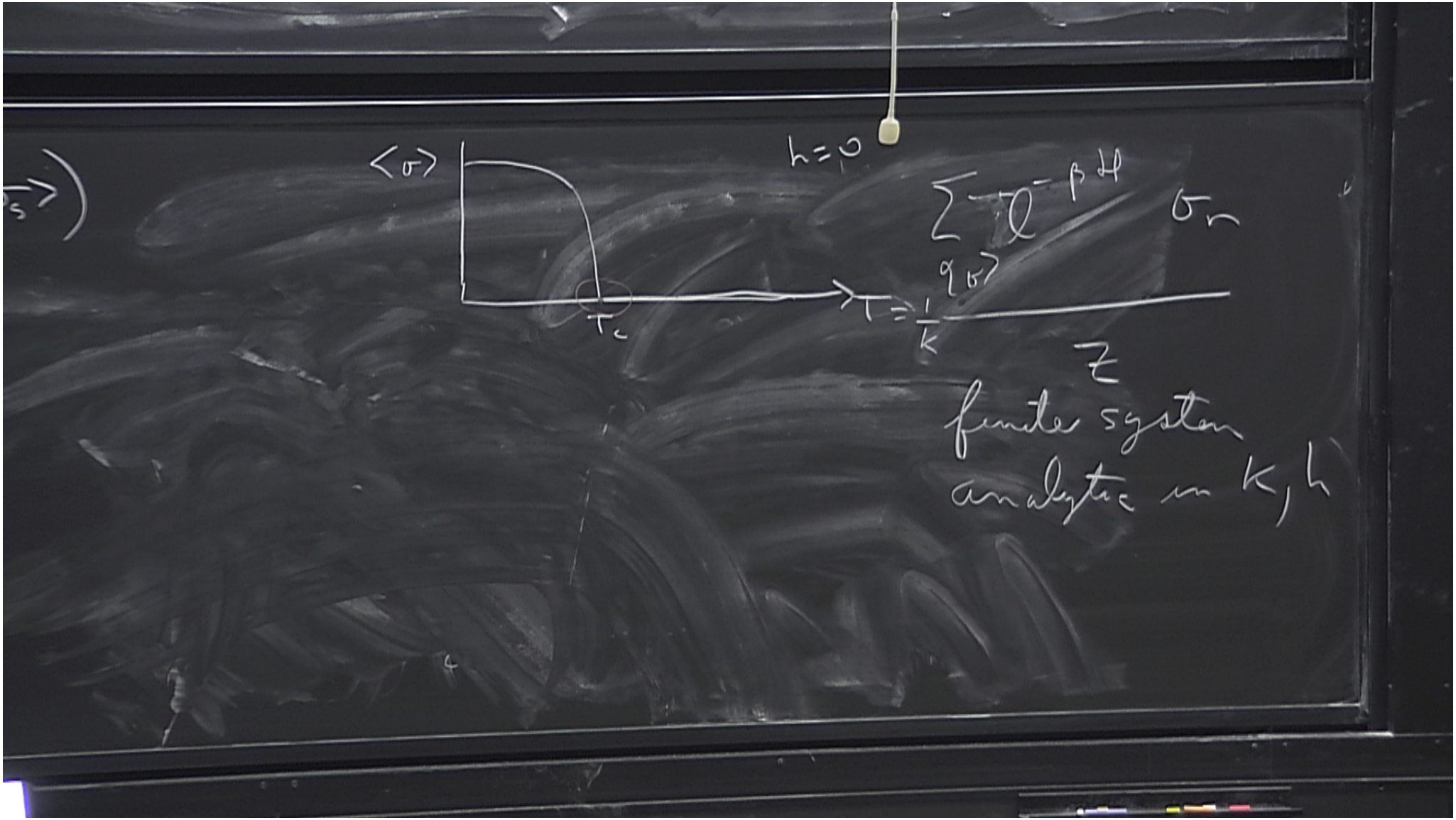

John Bardeen
$\langle \sigma_{\vec{r}} \rangle = \tanh\left(h_{\vec{r}} + K \sum_{\vec{s}\ \text{nn}\ \vec{r}} \langle \sigma_{\vec{s}} \rangle\right)$

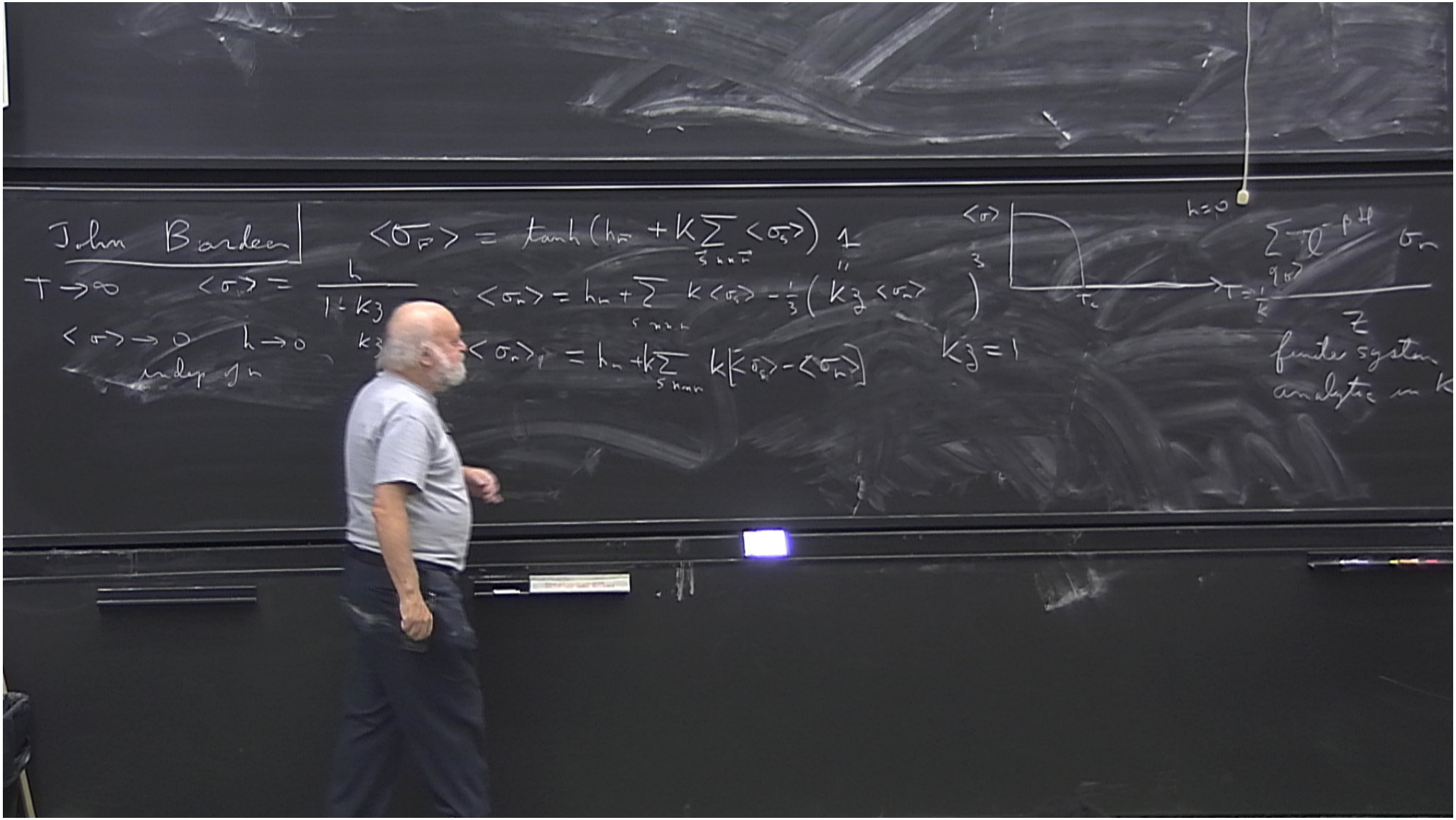

John Bardeen
$\langle \sigma_r \rangle = \tanh\left(h_r + K \sum_{\vec{s}\ nn\ \vec{r}} \langle \sigma_s \rangle\right)$
$T \to \infty \quad \langle \sigma \rangle = \frac{h}{1 - k_3}$
$\langle \sigma \rangle \to 0 \quad h \to 0 \quad k_3 \simeq 1$

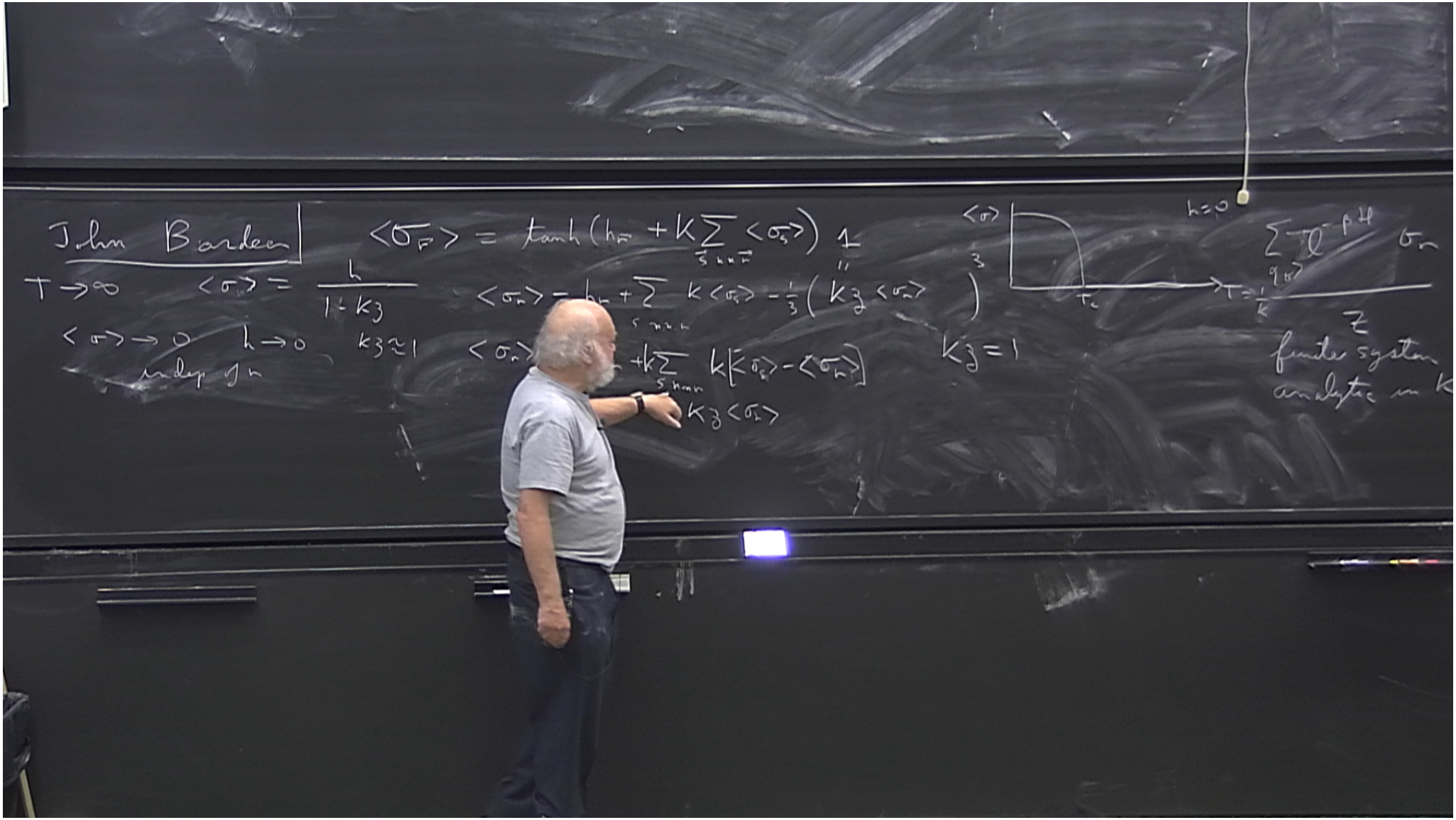

$\tanh\left(h_{\vec{n}} + K \sum_{\vec{s}\ \text{n.n.}\ \vec{n}} \langle \sigma_{\vec{s}} \rangle\right)$
$\langle \sigma \rangle$
$h=0$
T

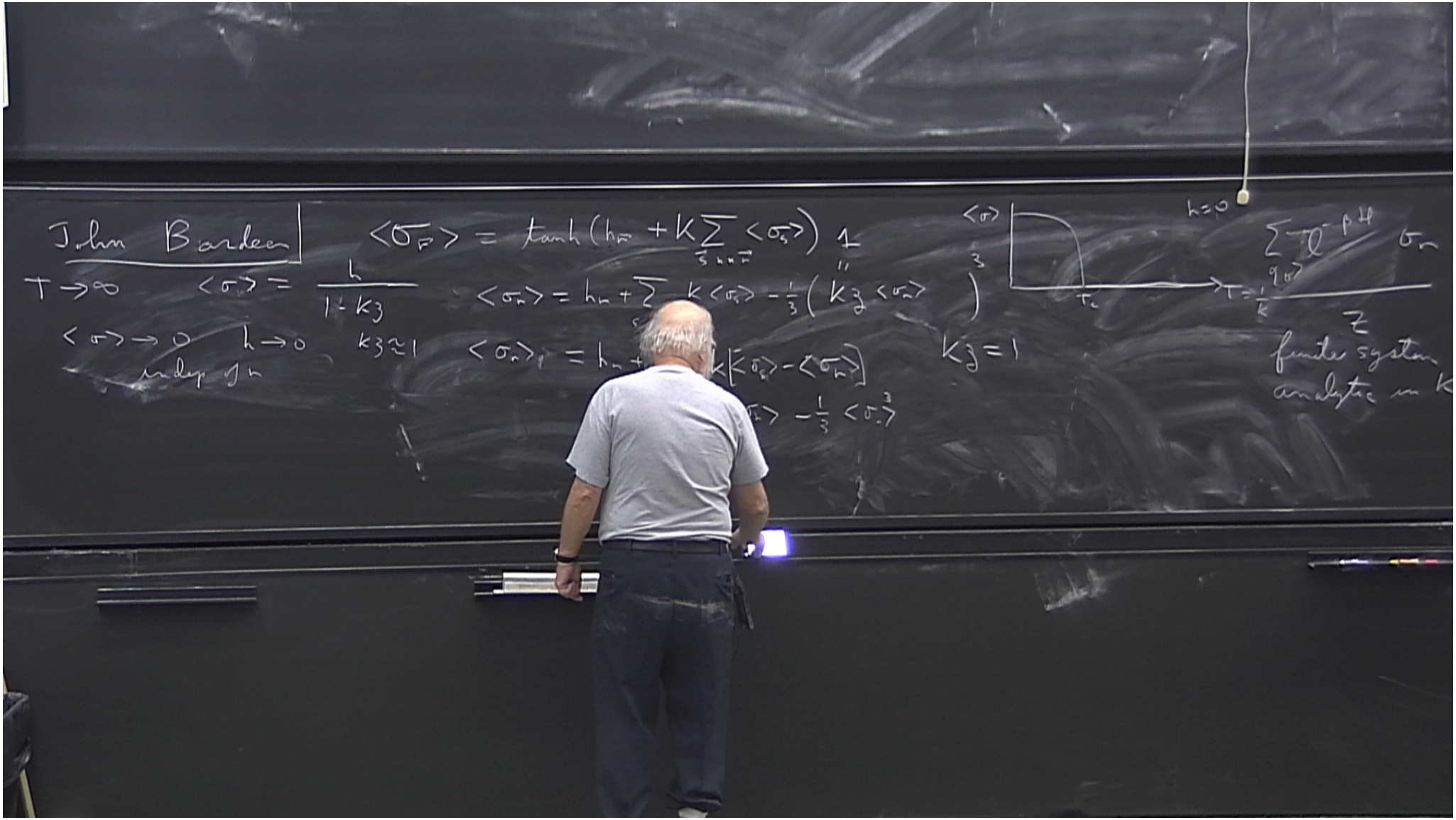

h=0
finite system

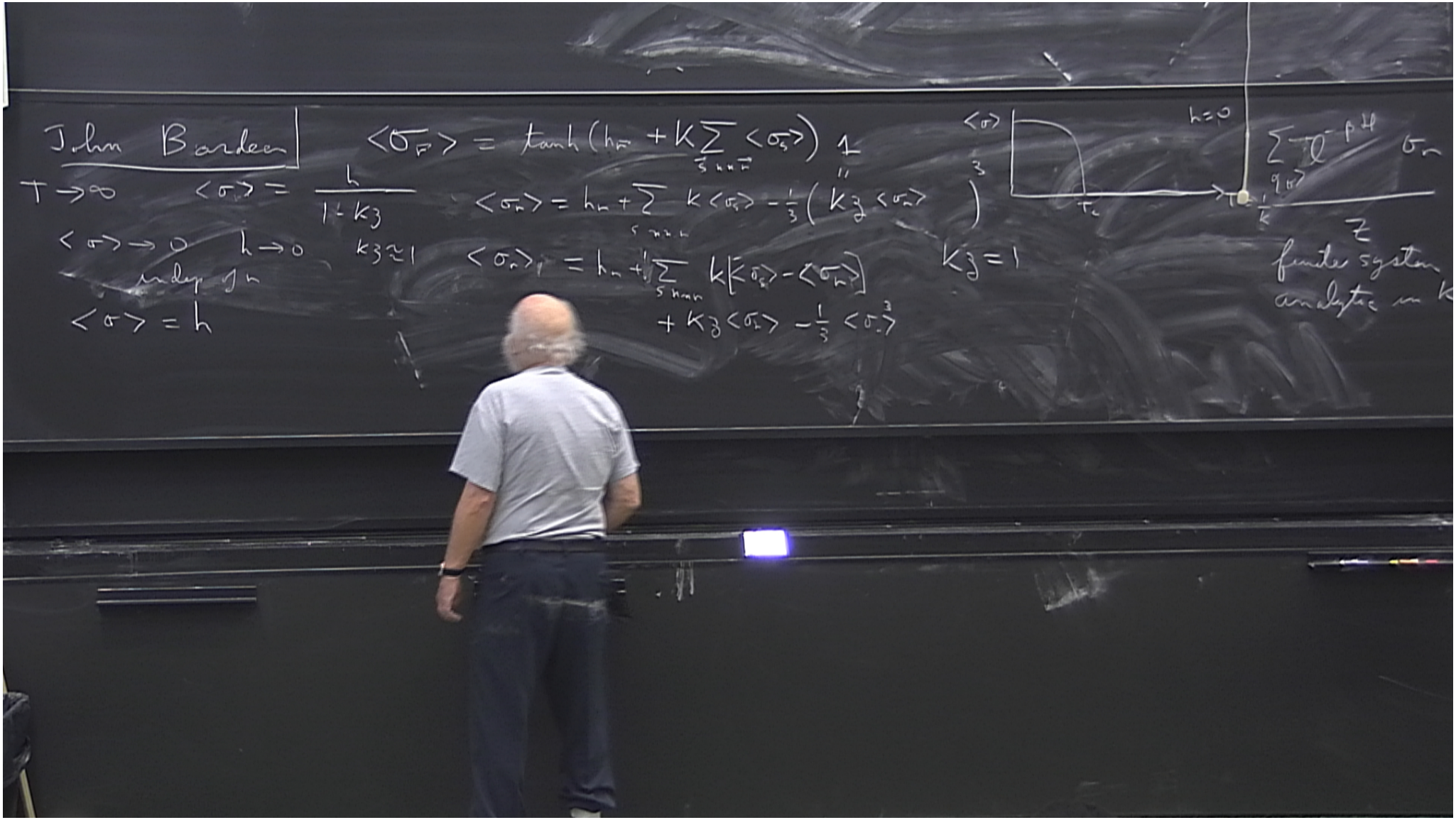

⟨σ⟩
h=0
T_c
T = 1/k
Z
finite system
analytic in k, h

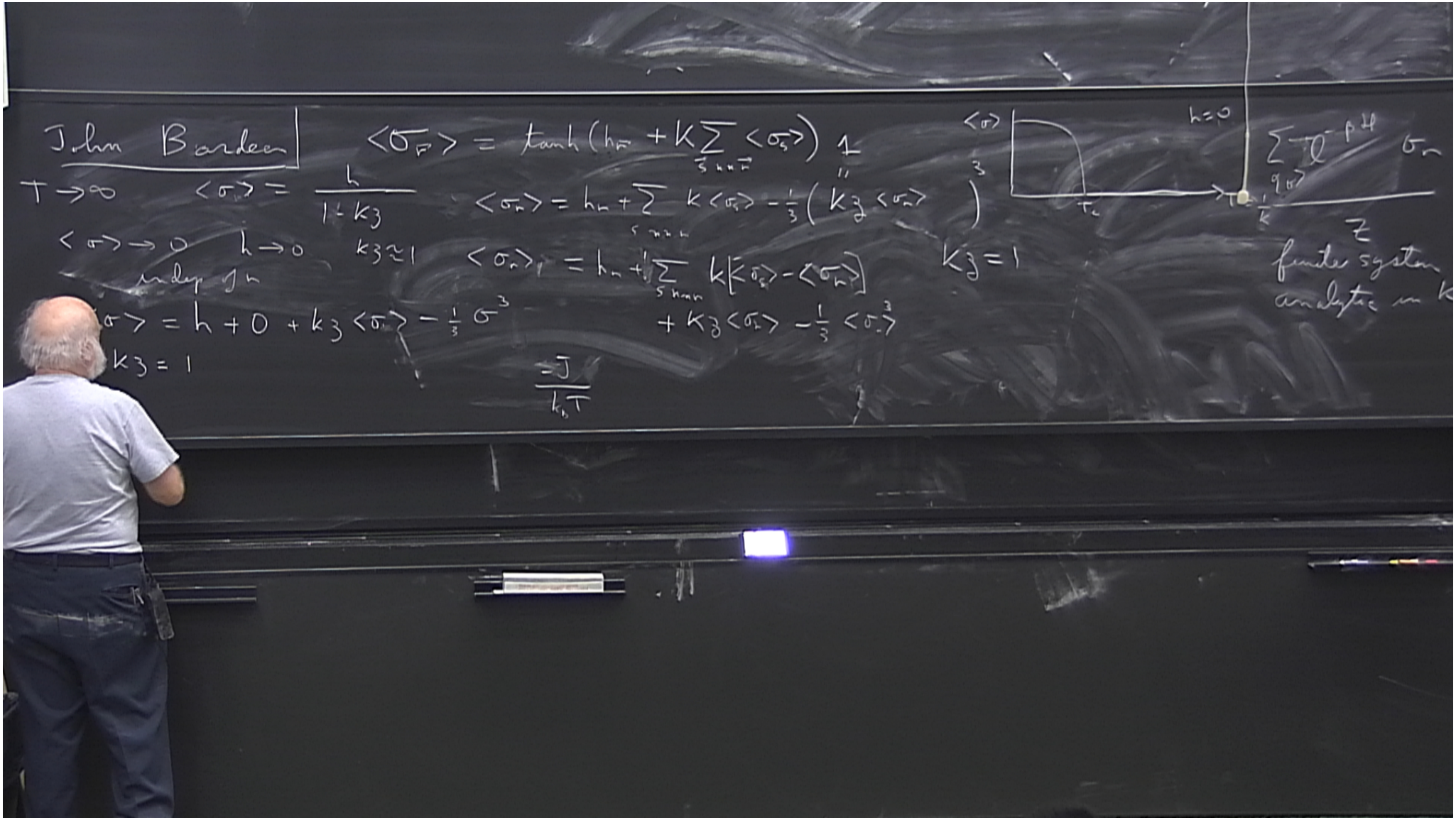

$\langle \sigma \rangle$
$h=0$
T_c
$T = \frac{1}{k}$
$\sum e^{-\beta H} \sigma_n$
$q\sigma$
Z
finite system
analytic in k, h

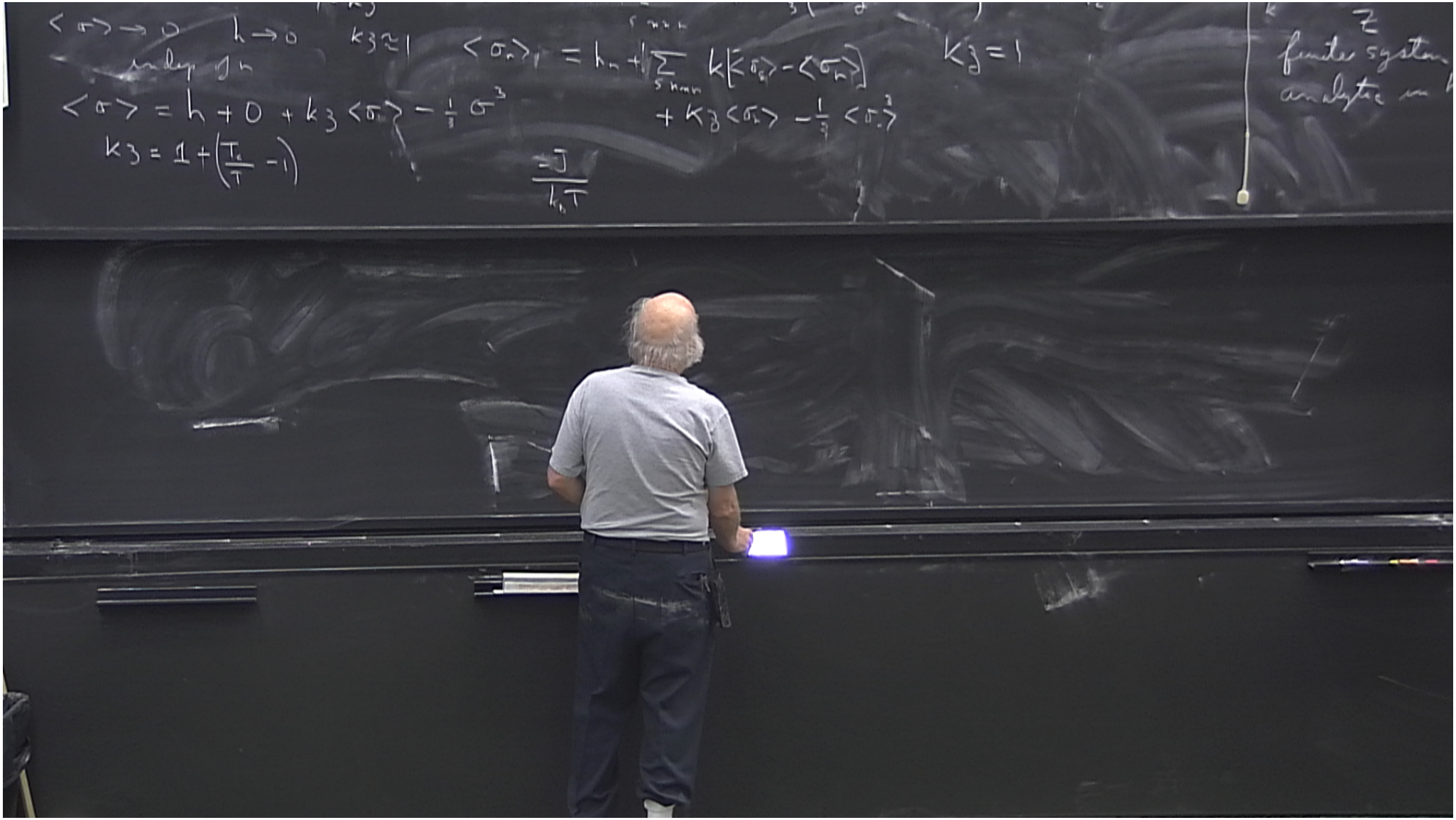

John Bardeen
T → ∞
⟨σ⟩ → 0
h → 0
indep of n
Kz = 1
h = 0
finite system
analytic in K

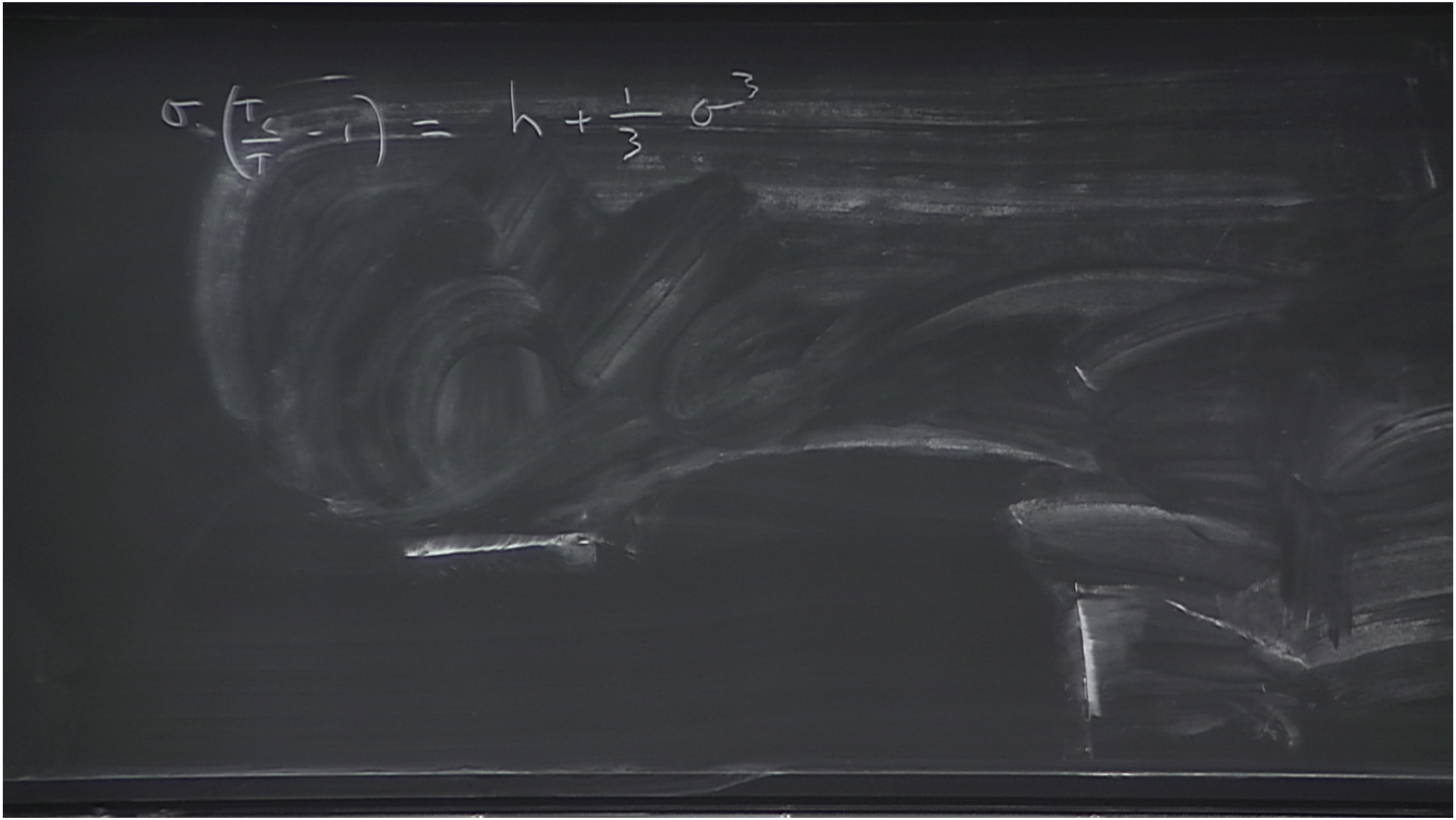

John Bardeen
T → ∞
indep of n
Kz = 1
h = 0
finite system
analytic in K

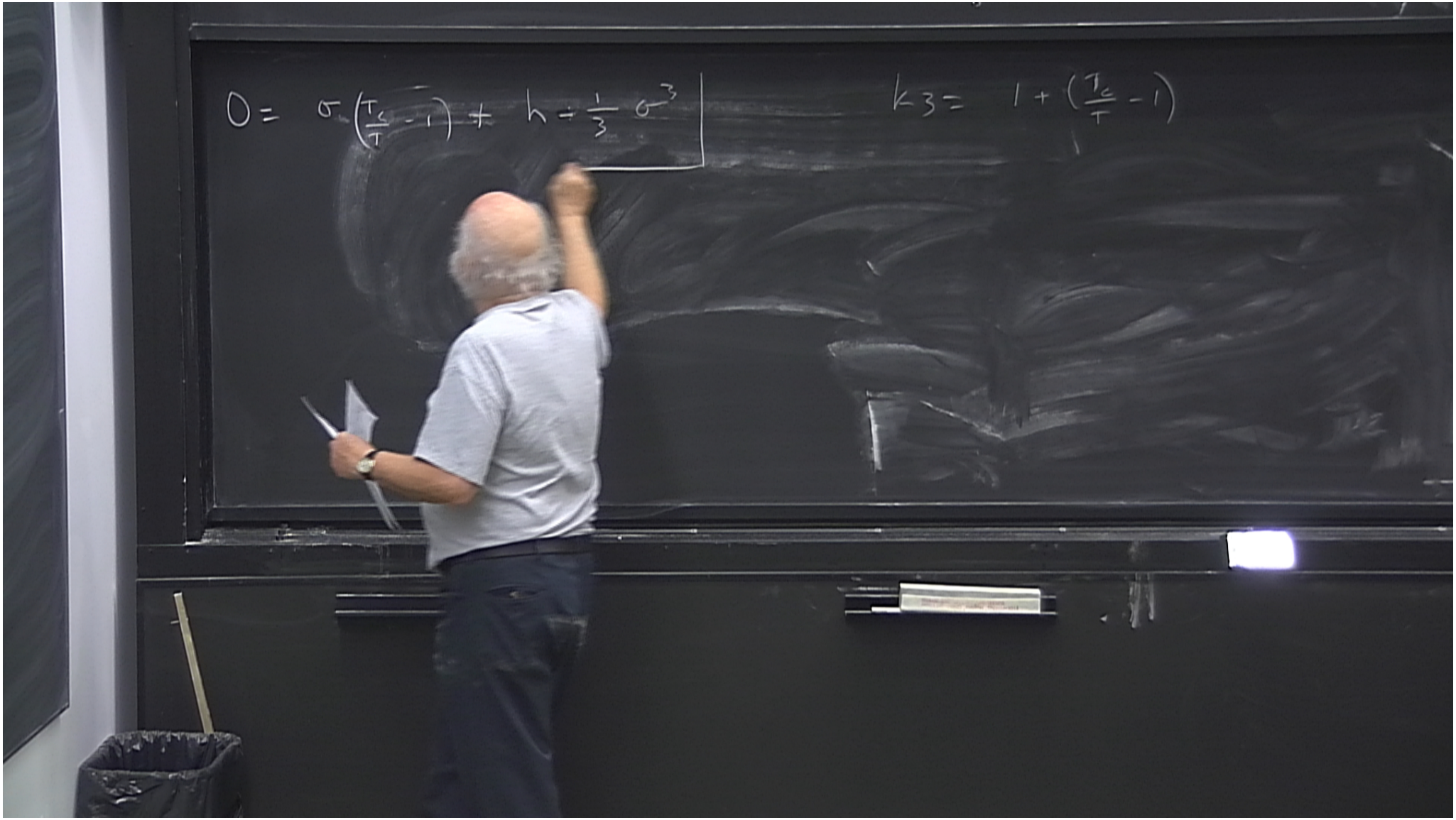

John Bardeen
T → ∞
⟨σ⟩ → 0
h → 0
indep of n
kz ≈ 1
kz = 1
h = 0
finite system
analytic in K

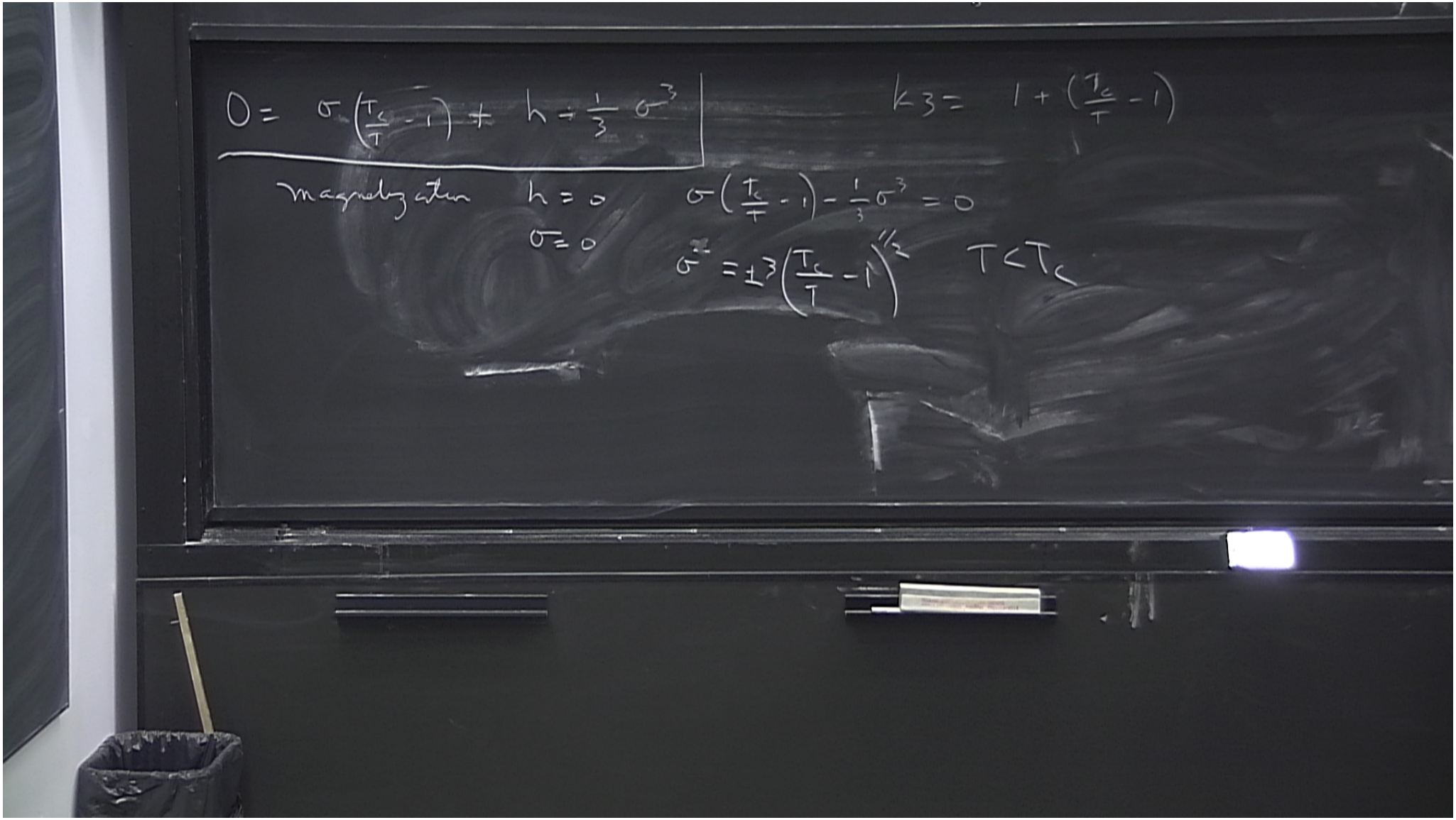

John Bardeen
T → ∞
⟨σ⟩ → 0
h → 0
indep of n
⟨σ⟩ = h
kz ≈ 1
kz = 1
h = 0
finite system
analytic in k

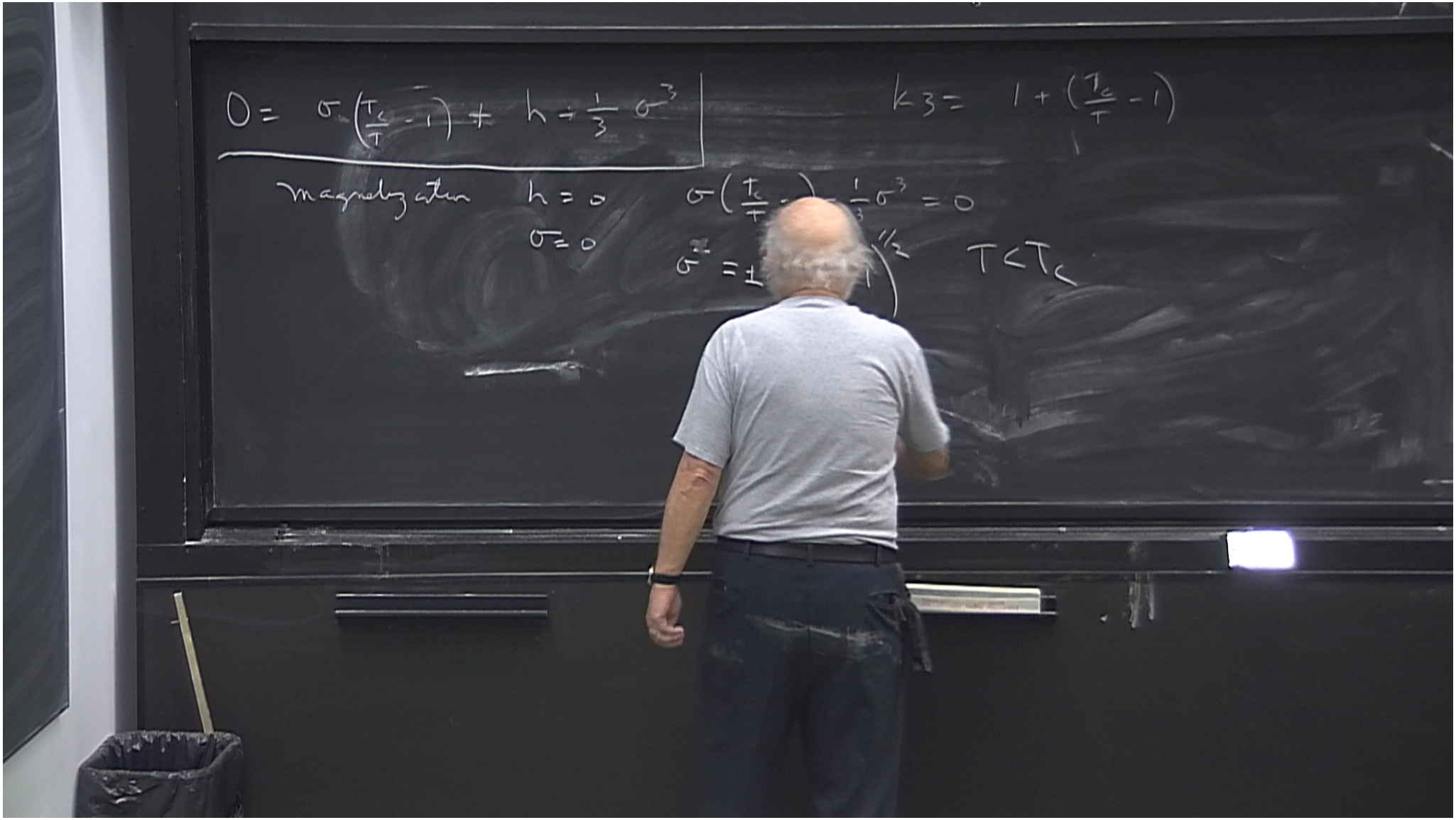

John Bardeen
T → ∞
⟨σ⟩ → 0
h → 0
kz ≈ 1
indep of n
kz = 1
h = 0
finite system
analytic in k

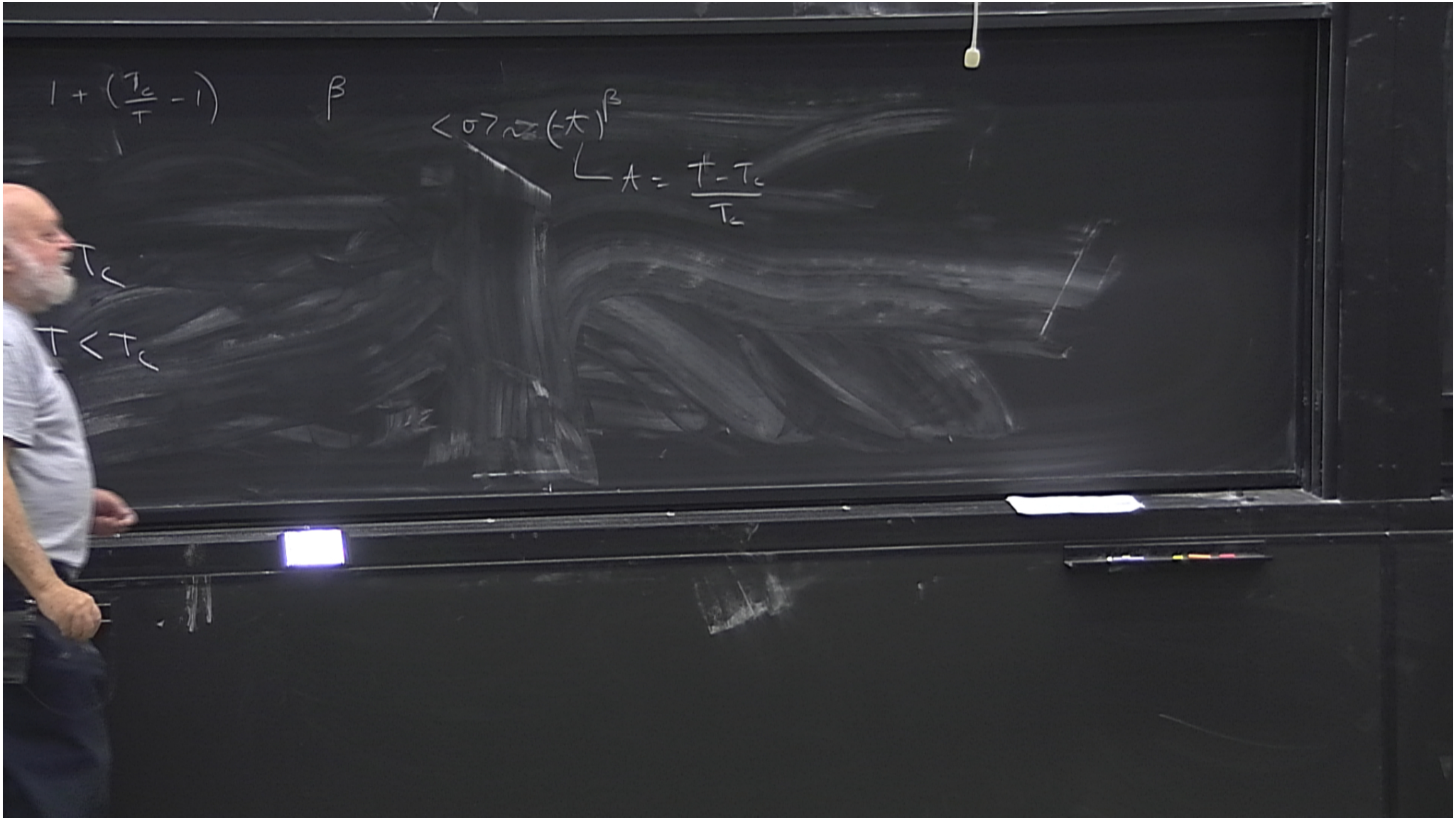

$\langle\sigma\rangle \to 0 \quad h \to 0 \quad k_3 \approx 1$
$\langle\sigma\rangle = h + 0 + k_3\langle\sigma\rangle - \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{zJ}{k_B T}$
$\langle\sigma_n\rangle = h_n + \sum_{s\,near\,n} k[\langle\sigma_s\rangle - \langle\sigma_n\rangle]$
$+ k_3\langle\sigma_n\rangle - \frac{1}{3}\langle\sigma_n^3\rangle$
$k_3 = 1$
z

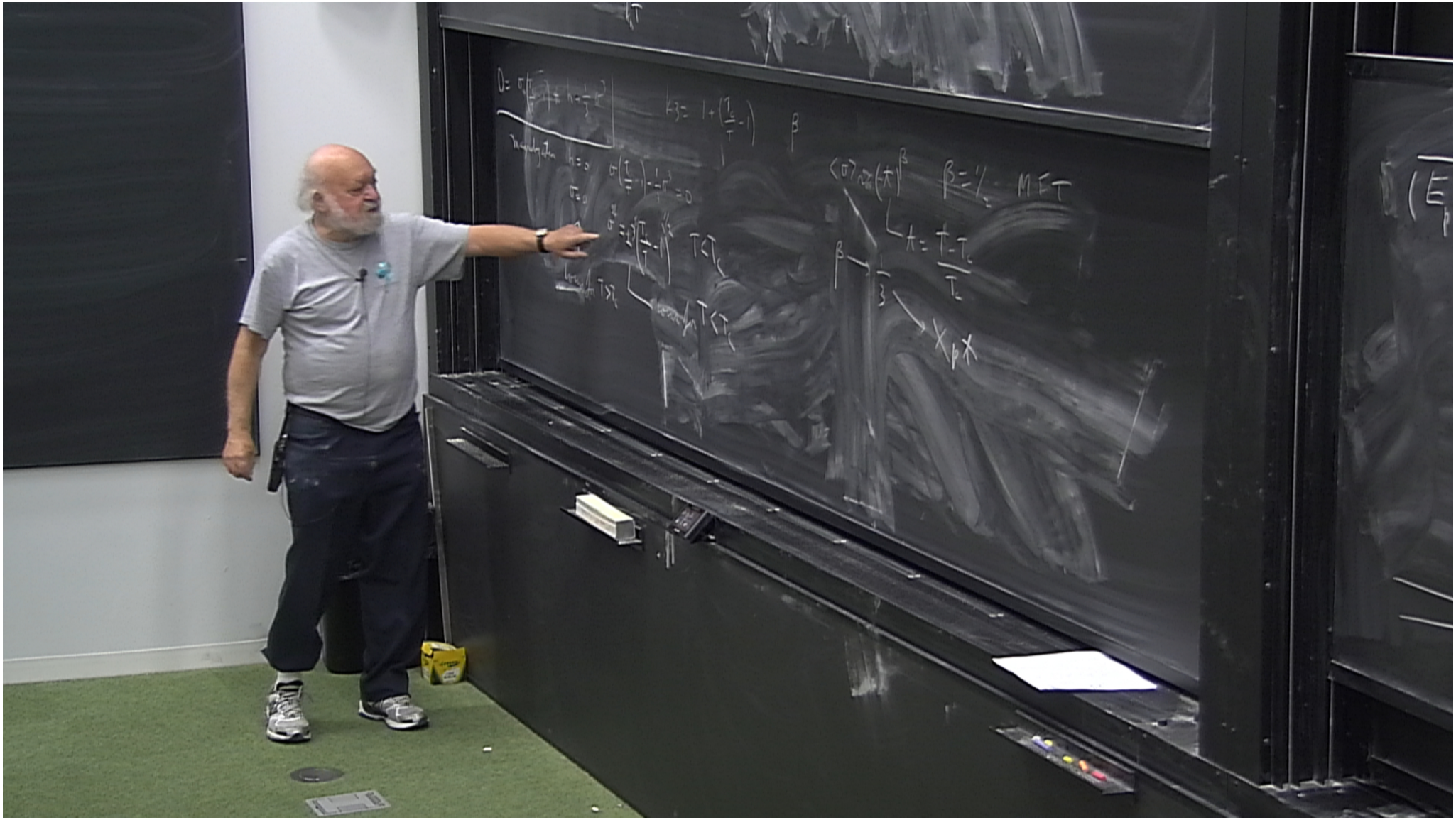

$\sigma\left(\frac{T_s}{T}-1\right) = h + \frac{1}{3}\sigma^3$

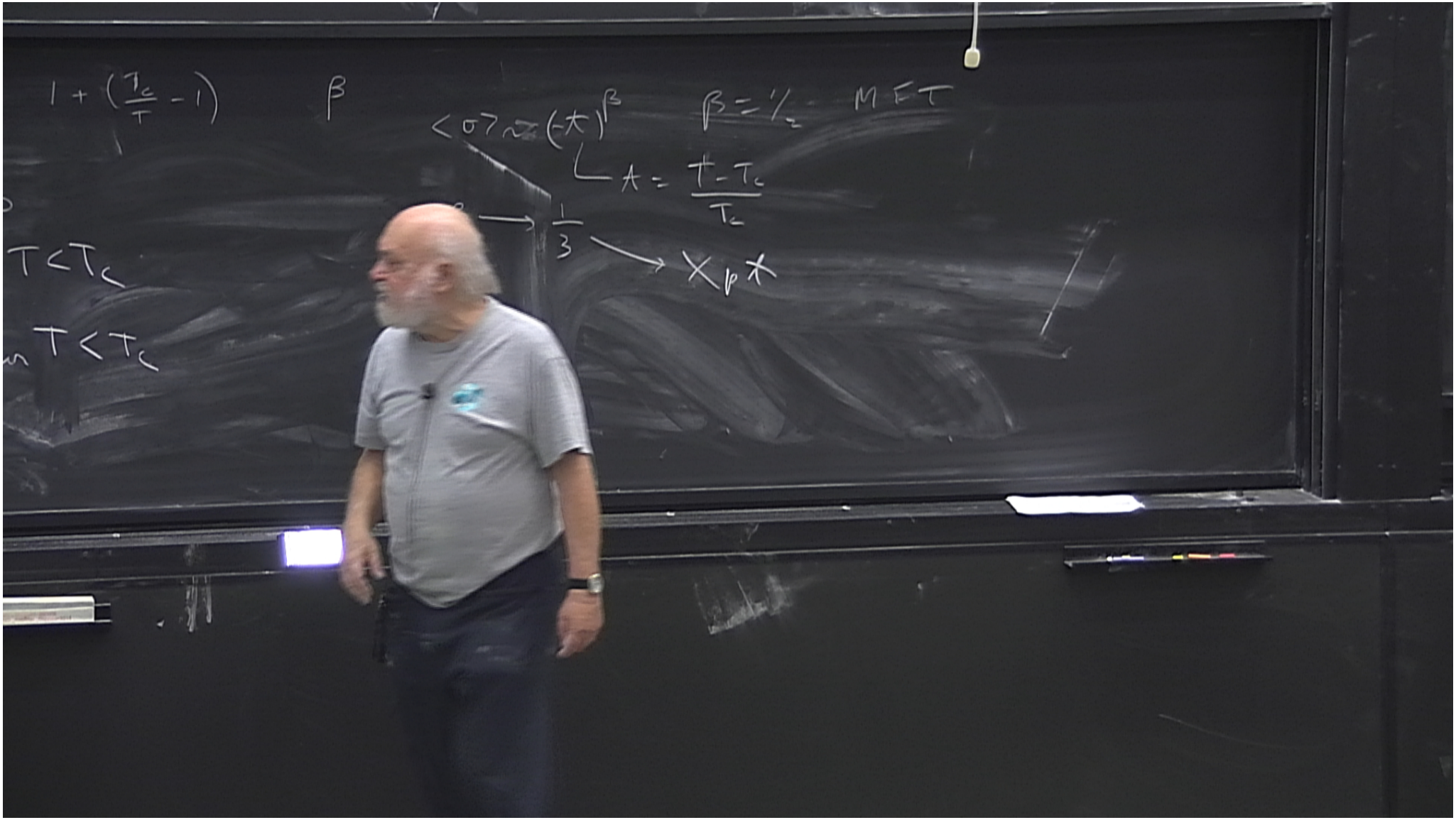

$0 = \sigma\left(\frac{T_c}{T} - 1\right) + h + \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$

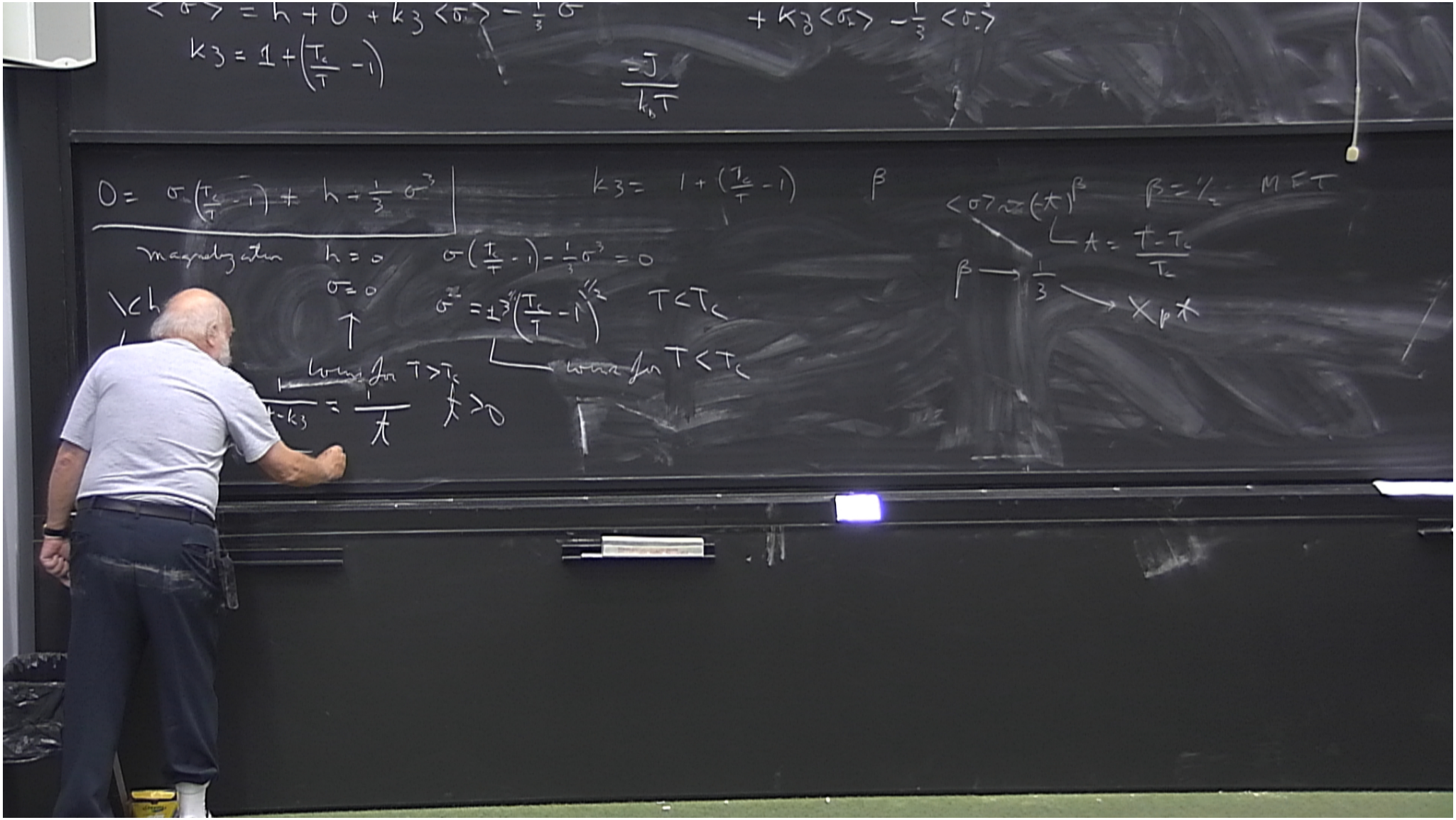

$0 = \sigma\left(\frac{T_c}{T} - 1\right) + h + \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
magnetization
$h = 0$
$\sigma = 0$
$\sigma\left(\frac{T_c}{T} - 1\right) - \frac{1}{3}\sigma^3 = 0$
$\sigma^2 = \pm 3\left(\frac{T_c}{T} - 1\right)^{1/2}$
$T < T_c$

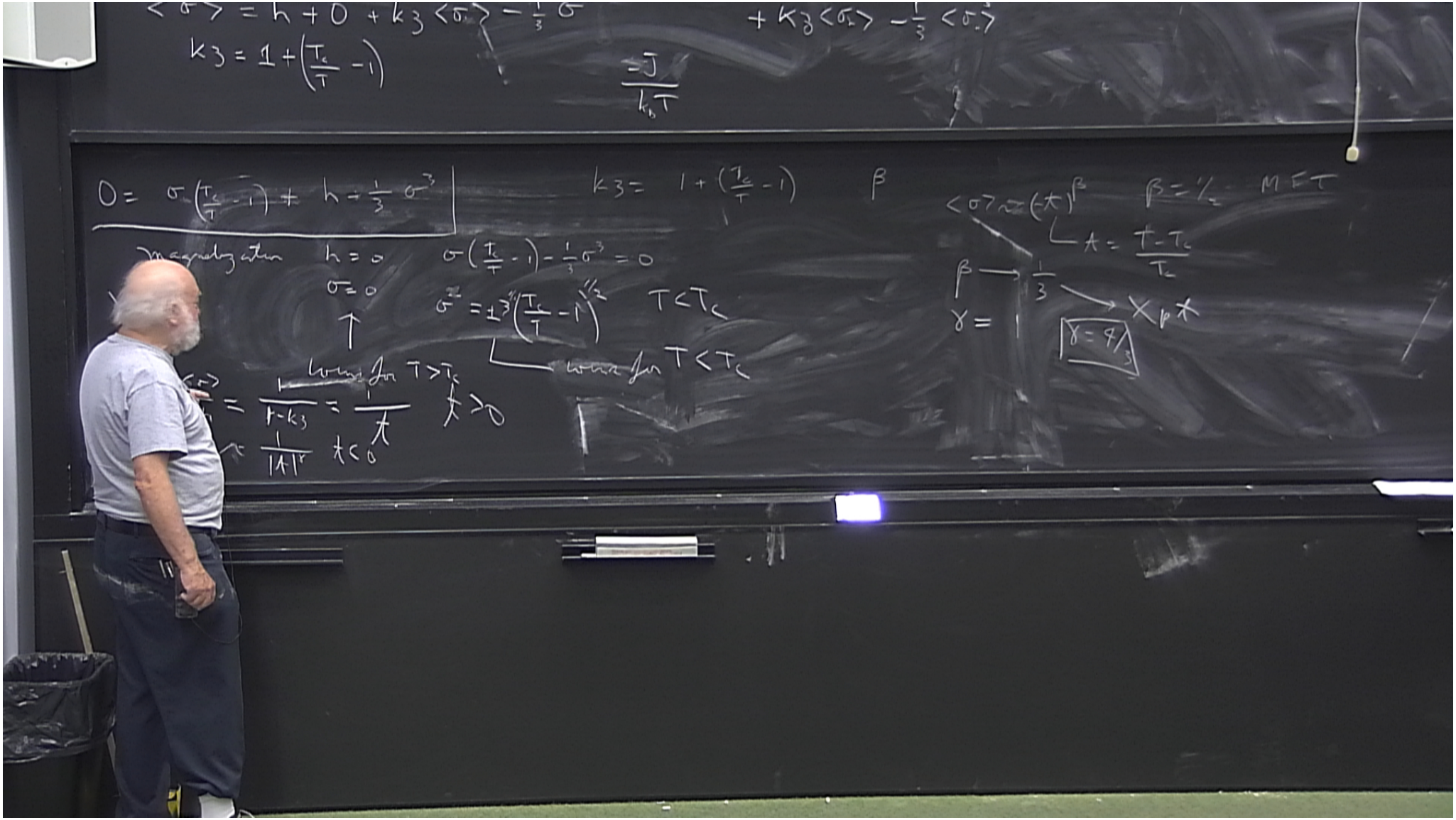

$0 = \sigma\left(\frac{T_c}{T} - 1\right) + h + \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
magnetization
$h = 0$
$\sigma = 0$
$\sigma\left(\frac{T_c}{T} - \right) - \frac{1}{3}\sigma^3 = 0$
$\sigma^2 = \pm$
$T < T_c$


$1 + \left(\frac{T_c}{T} - 1\right)^{\beta}$
$\langle \sigma \rangle \sim (-t)^{\beta}$
$t = \frac{T - T_c}{T_c}$
T_c
$T < T_c$

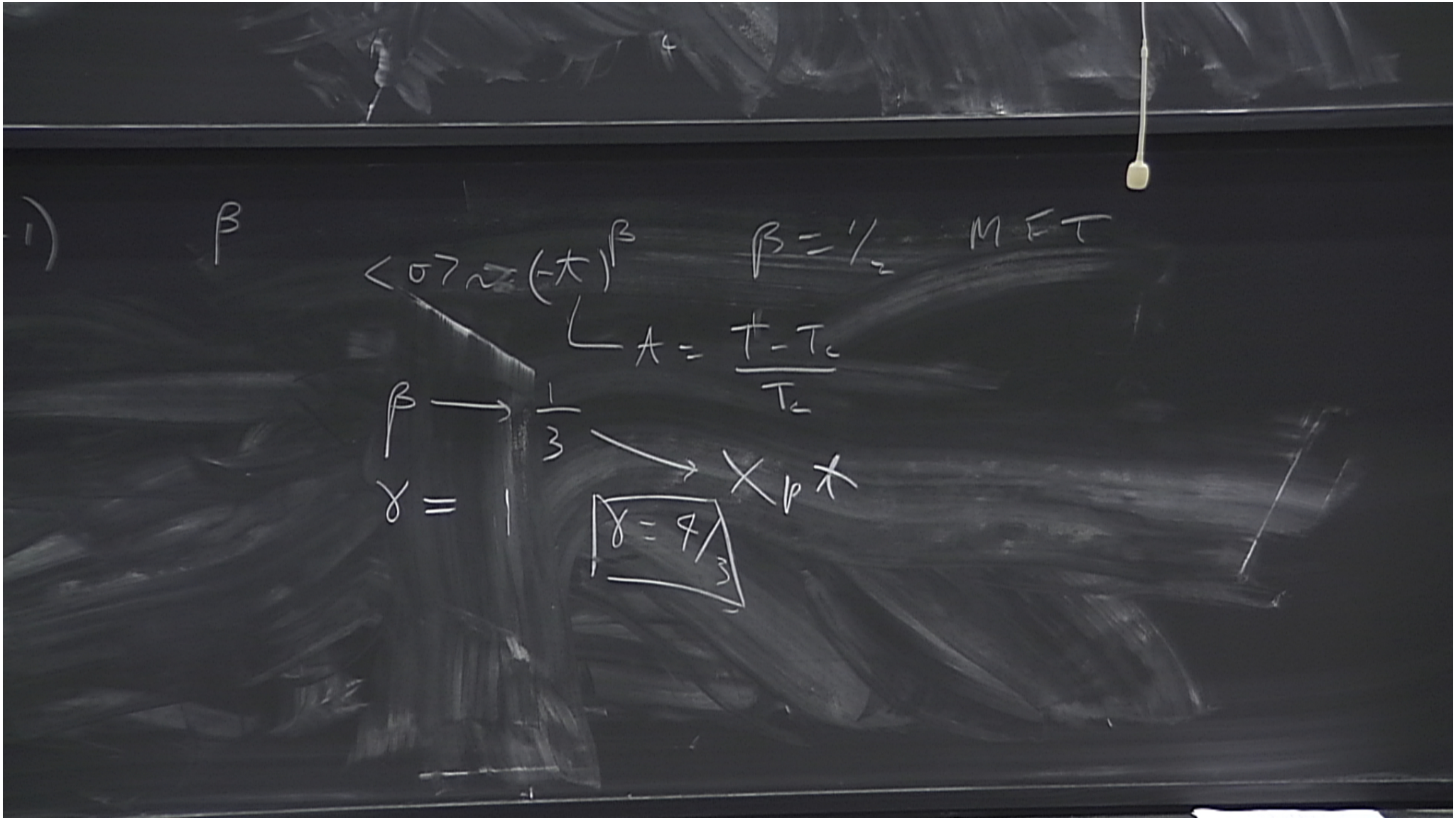


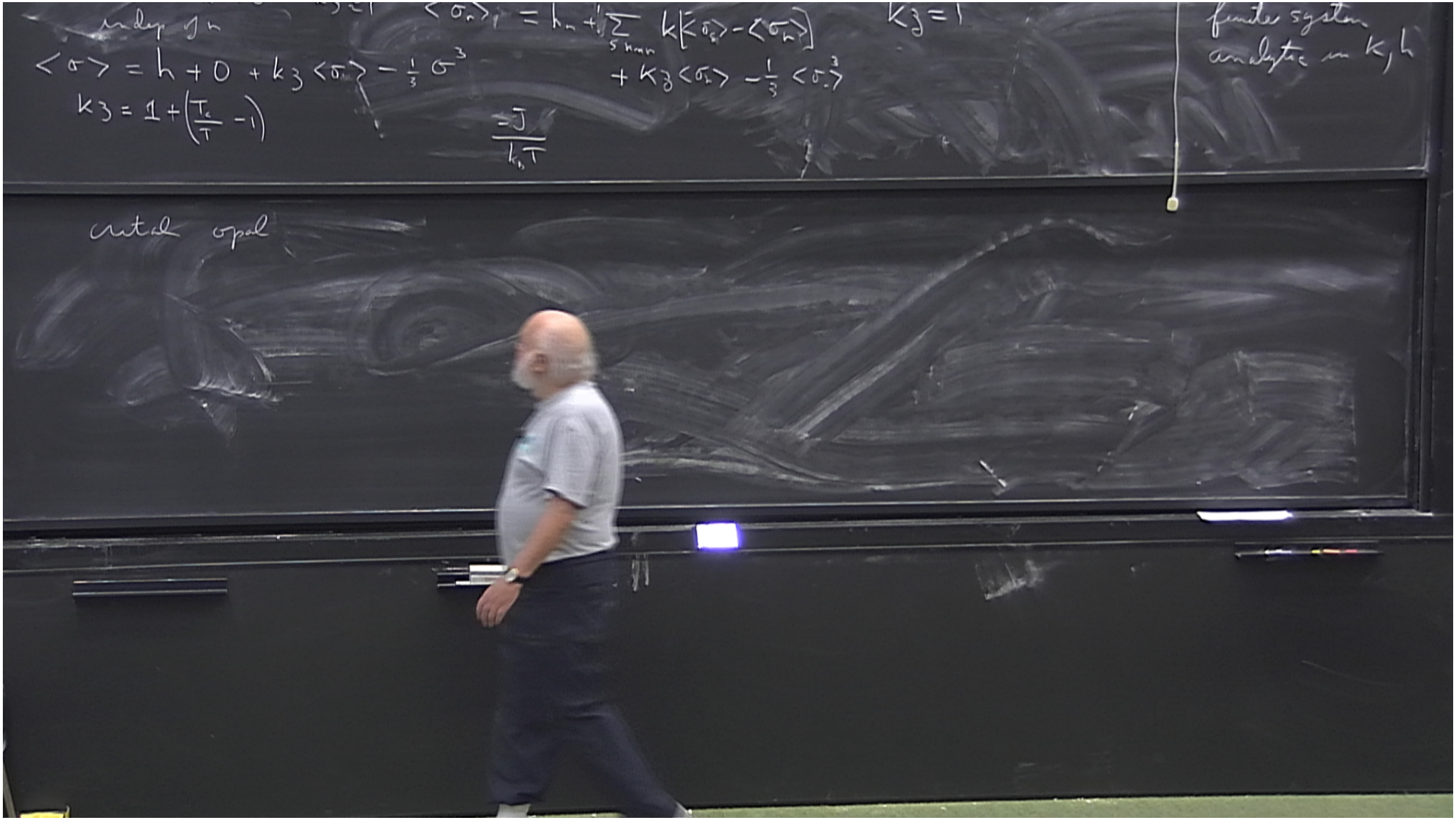

$1+\left(\frac{T_c}{T}-1\right)^{\beta}$
$\langle\sigma\rangle \sim (-t)^{\beta}$
$\beta = 1/2$ MFT
$t = \frac{T-T_c}{T_c}$
$T < T_c$
$T < T_c$
$\frac{1}{3}$
χ_p

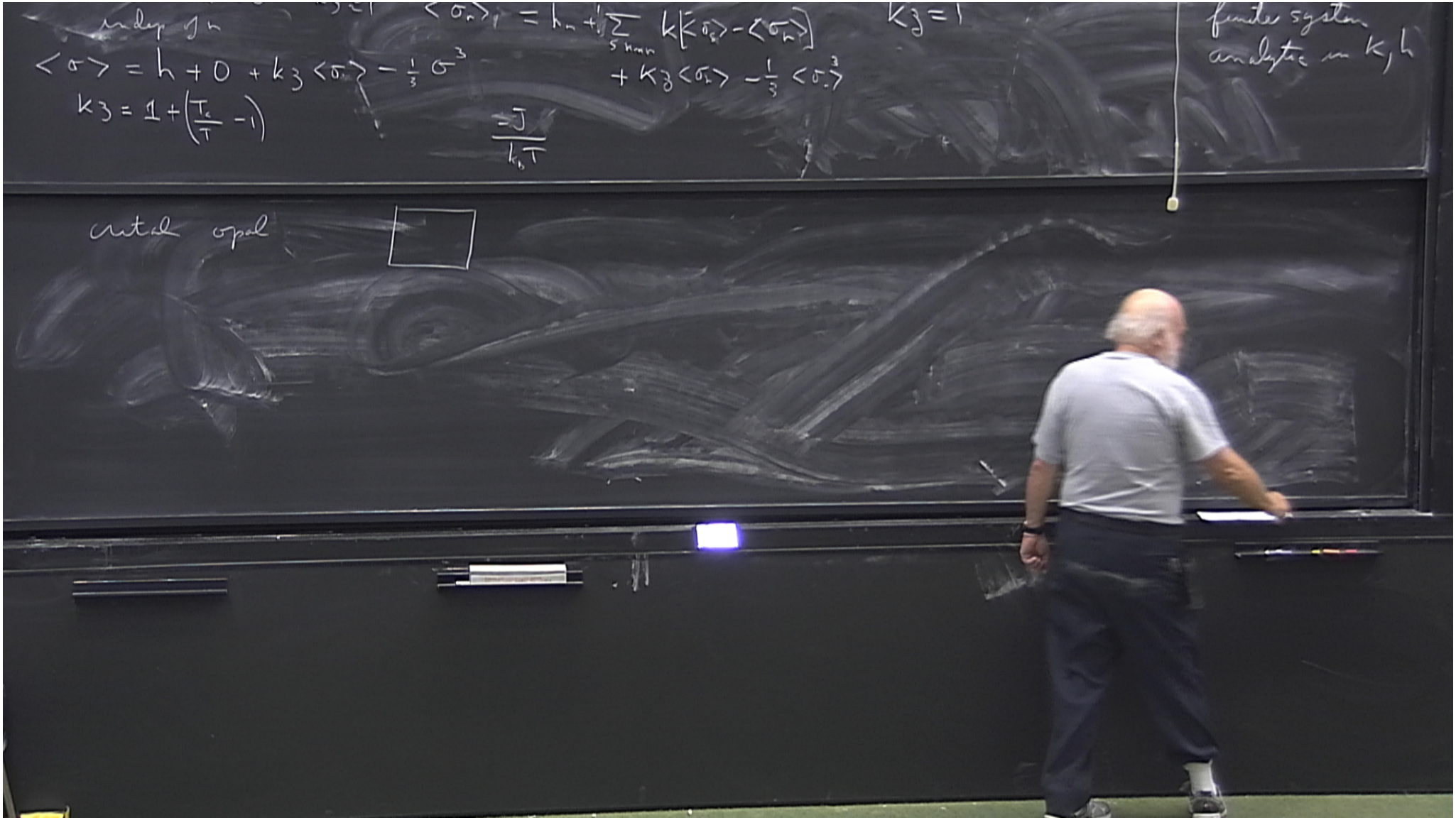

$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$= \frac{J}{k_B T}$
$0 = \sigma\left(\frac{T_c}{T} - 1\right) + h - \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
β
$\langle\sigma\rangle \sim (-t)^\beta$
$\beta = 1/2$ MFT
$t = \frac{T - T_c}{T_c}$
$\beta \to \frac{1}{3}$
magnetization
$h = 0$
$\sigma\left(\frac{T_c}{T} - 1\right) - \frac{1}{3}\sigma^3 = 0$
$\sigma = 0$
$\sigma^2 = \pm 3\left(\frac{T_c}{T} - 1\right)$
$T < T_c$
$T > T_c$
$T < T_c$
$t > 0$

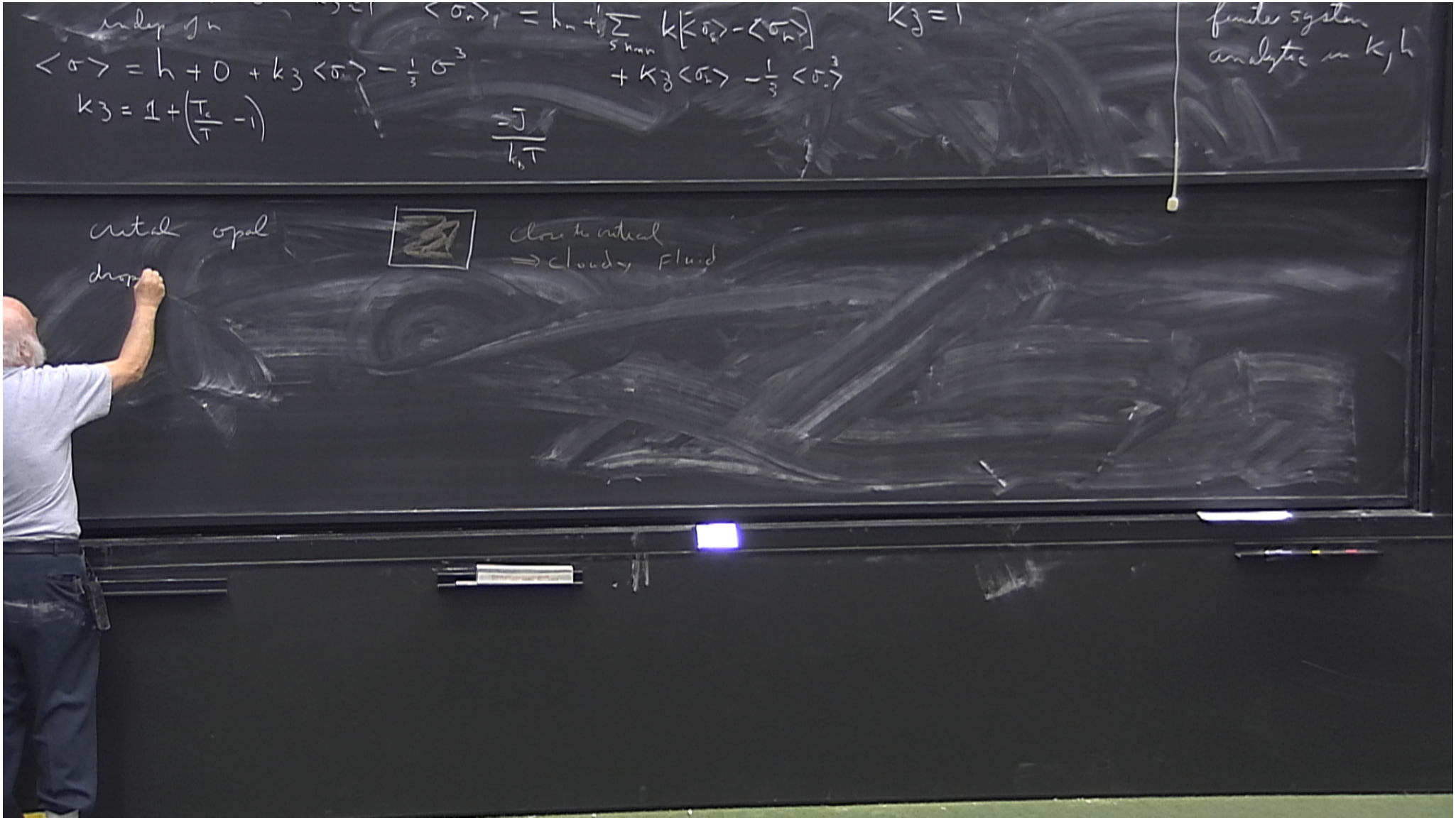


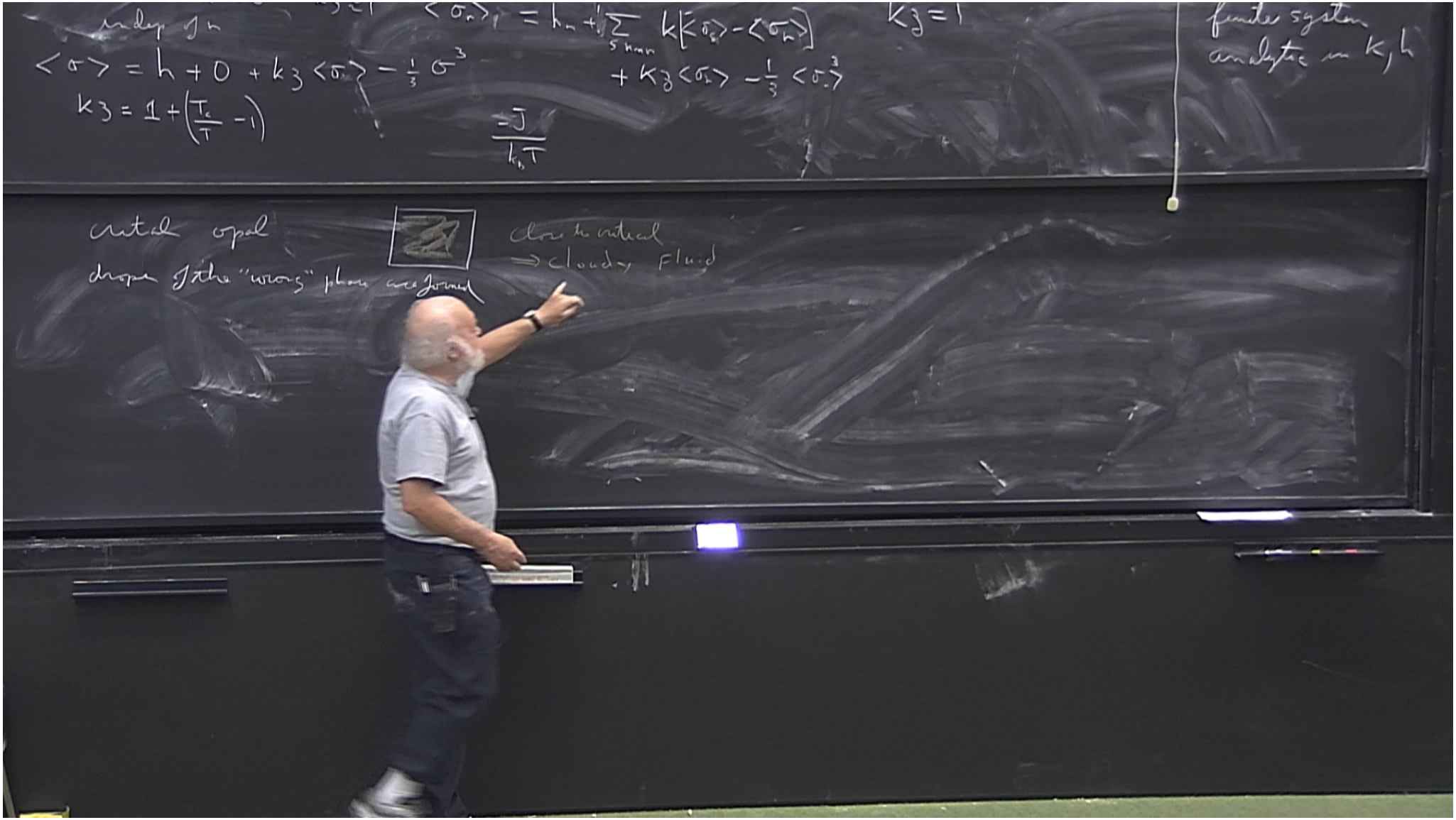
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$0 = \sigma\left(\frac{T_c}{T} - 1\right) + h - \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
β
$\langle\sigma\rangle \sim (-t)^\beta$
$\beta = 1/2$
MFT
$t = \frac{T - T_c}{T_c}$
magnetization
$h = 0$
$\sigma = 0$
$\sigma\left(\frac{T_c}{T} - 1\right) - \frac{1}{3}\sigma^3 = 0$
$\sigma^2 = \pm 3^{1/2}\left(\frac{T_c}{T} - 1\right)^{1/2}$
$T < T_c$
$\beta \to \frac{1}{3}$
$\gamma = 1$
$\gamma = 4/3$
$t > 0$
$t < 0$

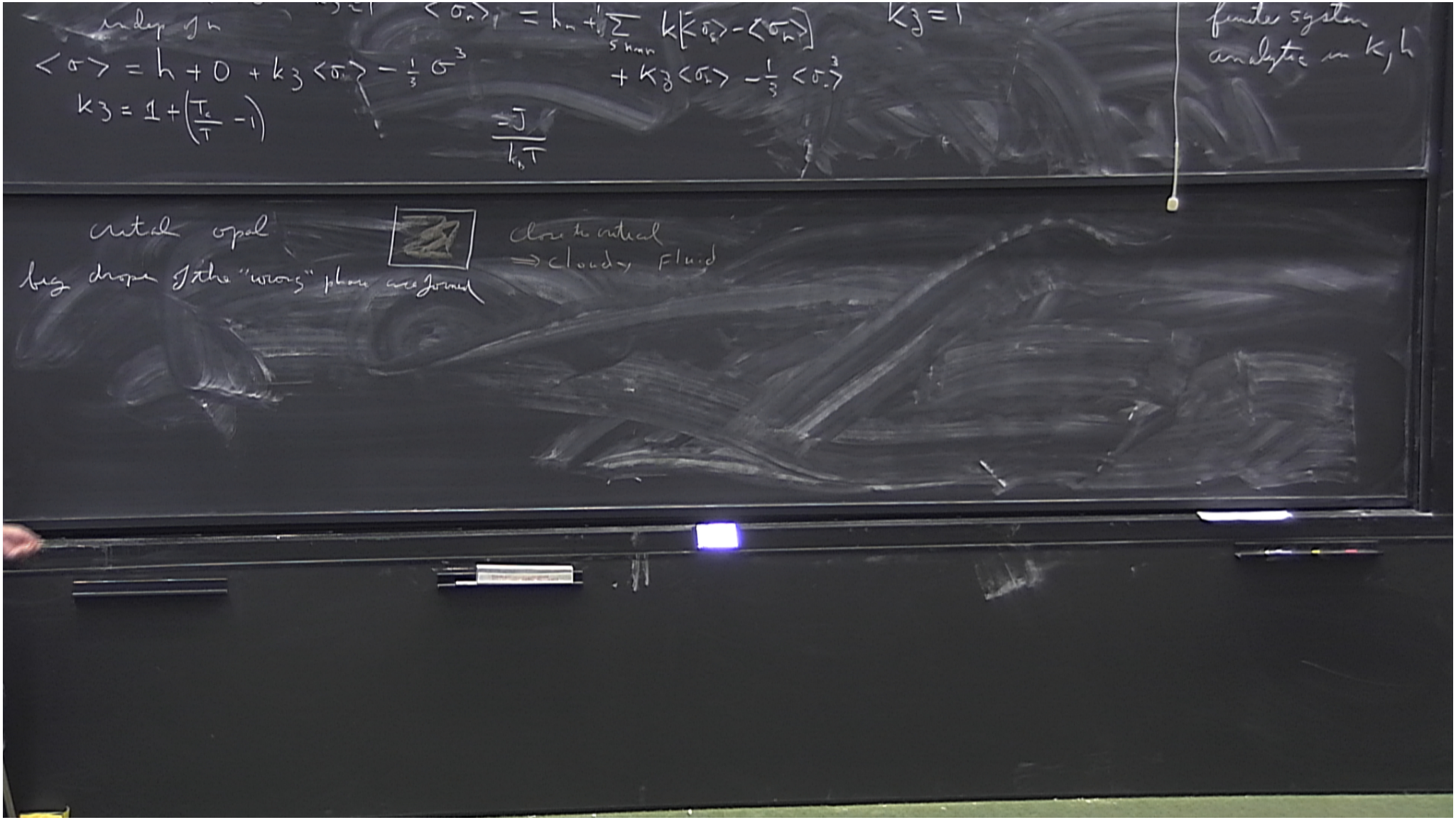

β
$\langle \sigma \rangle \sim (-t)^{\beta}$
$\beta = 1/2$ MFT
$t = \frac{T - T_c}{T_c}$
$\beta \to \frac{1}{3}$
χ_p
$\gamma = 1$
$\gamma = 4/3$


$\langle\sigma\rangle = h + 0 + k_3\langle\sigma\rangle - \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$k_3 = 1$
finite system
analytic in k, h
mutual equal


indep of n
$\langle\sigma\rangle = h + 0 + kz\langle\sigma\rangle - \frac{1}{3}\sigma^3$
$kz = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$\langle\sigma_n\rangle = h_n + \sum_{s\,nmn} k[\langle\sigma_s\rangle - \langle\sigma_n\rangle]$
$+ kz\langle\sigma_n\rangle - \frac{1}{3}\langle\sigma_n\rangle^3$
$kz = 1$
finite system
analytic in k, h
critical opal


$\langle\sigma\rangle = h + 0 + k_3\langle\sigma\rangle - \frac{1}{3}\sigma^3$
$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$\langle\sigma_n\rangle = h_n + \sum_{s\,near\,n} k[\langle\sigma_s\rangle - \langle\sigma_n\rangle]$
$+ k_3\langle\sigma_n\rangle - \frac{1}{3}\langle\sigma_n^3\rangle$
$k_3 = 1$
finite system
analytic in k, h
critical opal
close to critical
⇒ cloudy Fluid


indep of n
$\langle\sigma\rangle = h + 0 + kz\langle\sigma\rangle - \frac{1}{3}\sigma^3$
$kz = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$\langle\sigma_n\rangle = h_n + \sum_{s\,nmn} k[\langle\sigma_s\rangle - \langle\sigma_n\rangle]$
$+ kz\langle\sigma_n\rangle - \frac{1}{3}\langle\sigma_n\rangle^3$
$kz = 1$
finite system
analytic in k, h
critical opal
drops of the "wrong" phase are formed
close to critical
⇒ cloudy fluid



indep of n

$\langle \sigma \rangle = h + 0 + kz\langle \sigma \rangle - \frac{1}{3}\sigma^3$

$kz = 1 + \left(\frac{T_c}{T} - 1\right)$

$\langle \sigma_n \rangle = h_n + \sum_{s\,nmn} k[\langle \sigma_s \rangle - \langle \sigma_n \rangle] + kz\langle \sigma_n \rangle - \frac{1}{3}\langle \sigma_n \rangle^3$

$\frac{-J}{k_B T}$

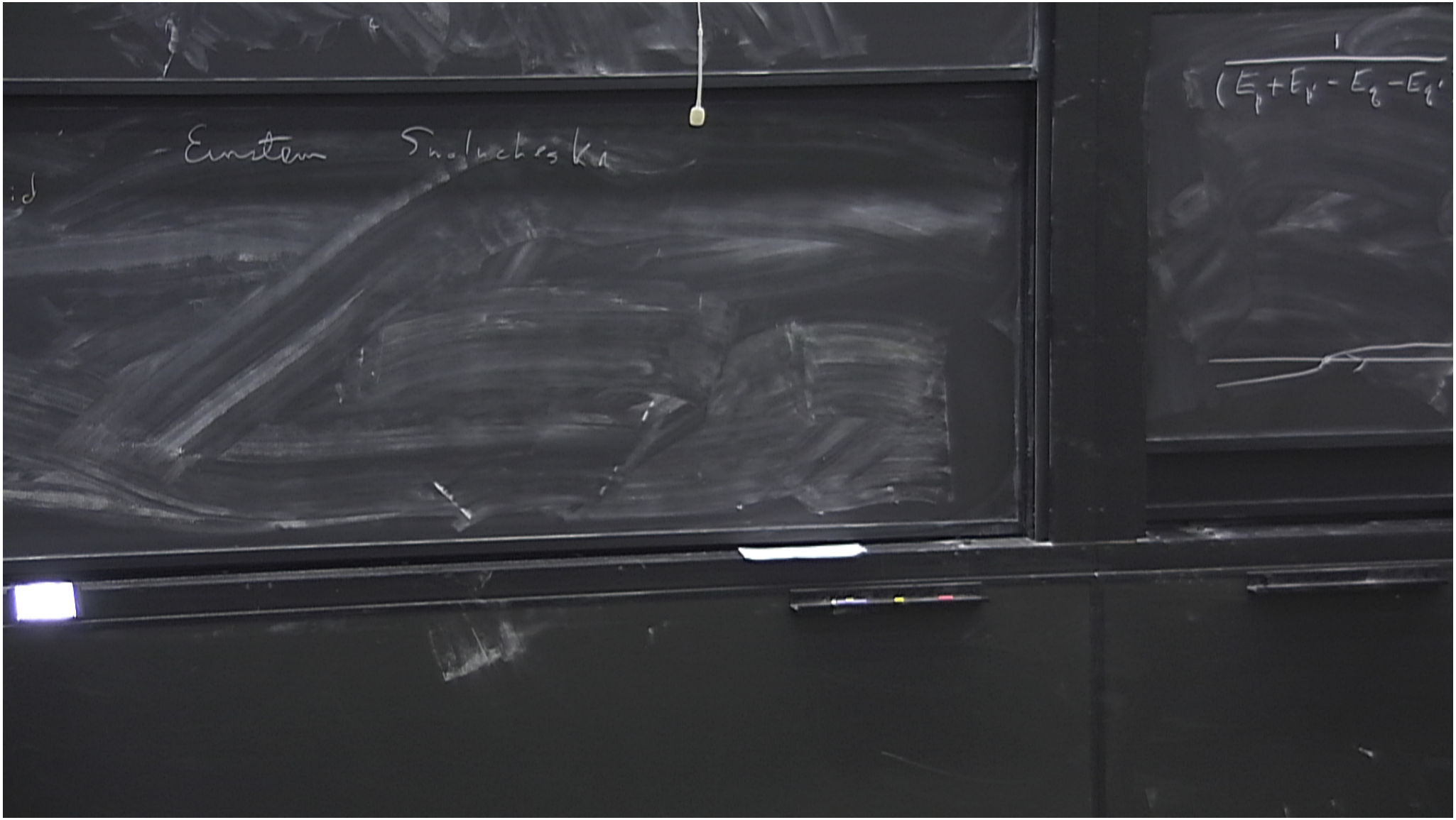
$kz = 1$

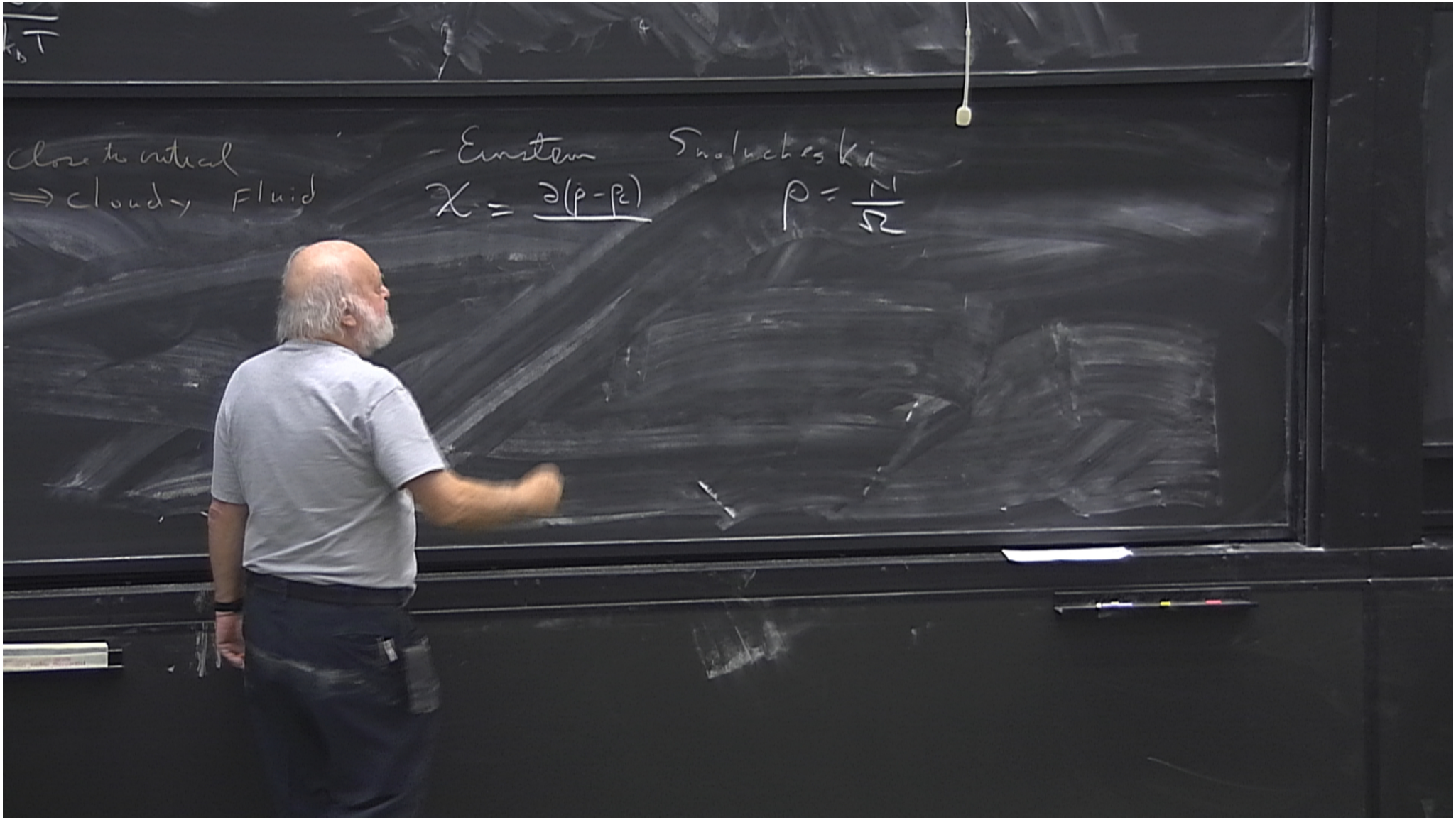
finite system
analytic in k, h

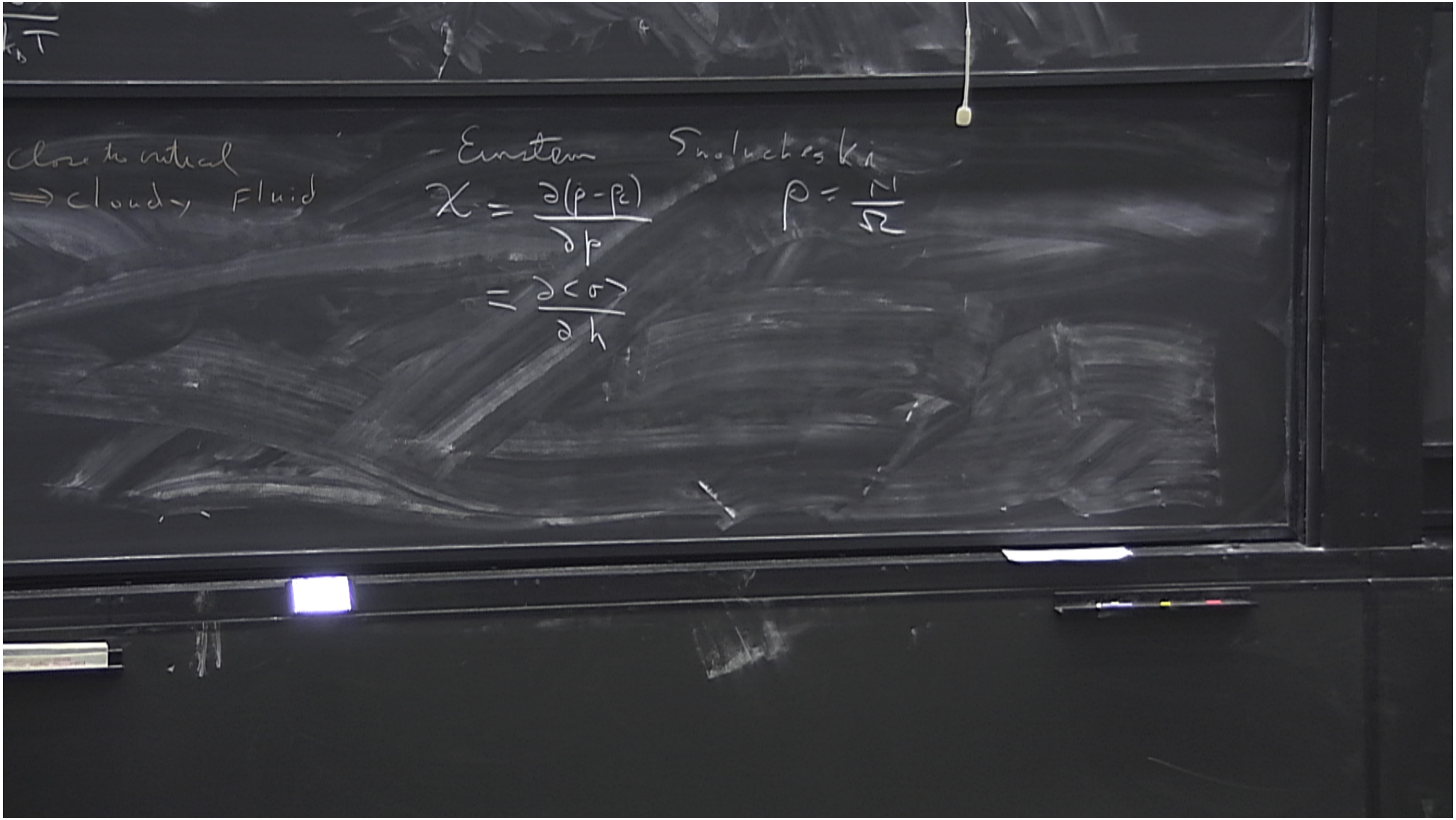
critical opal

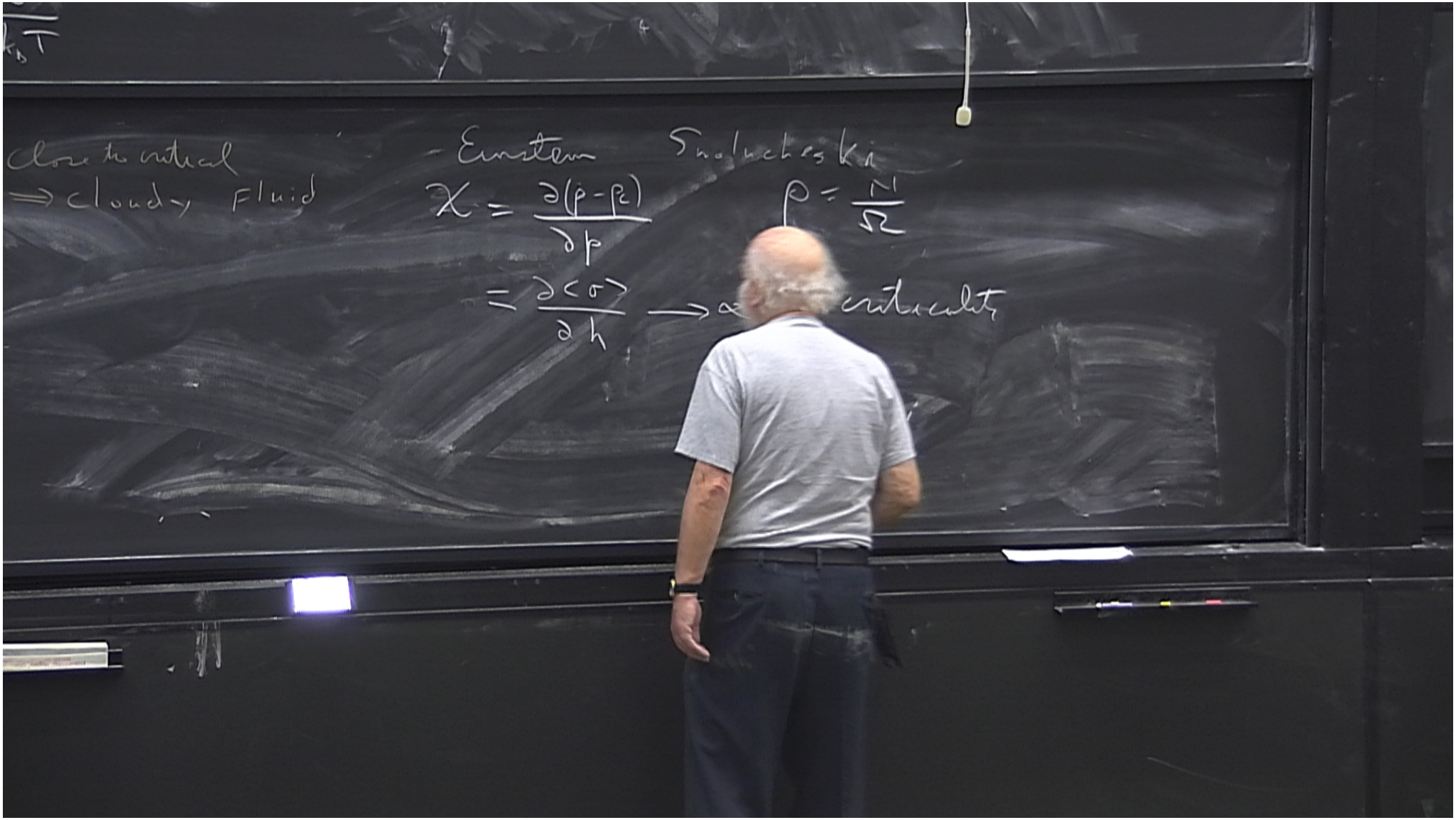
big drops of the "wrong" phase are formed

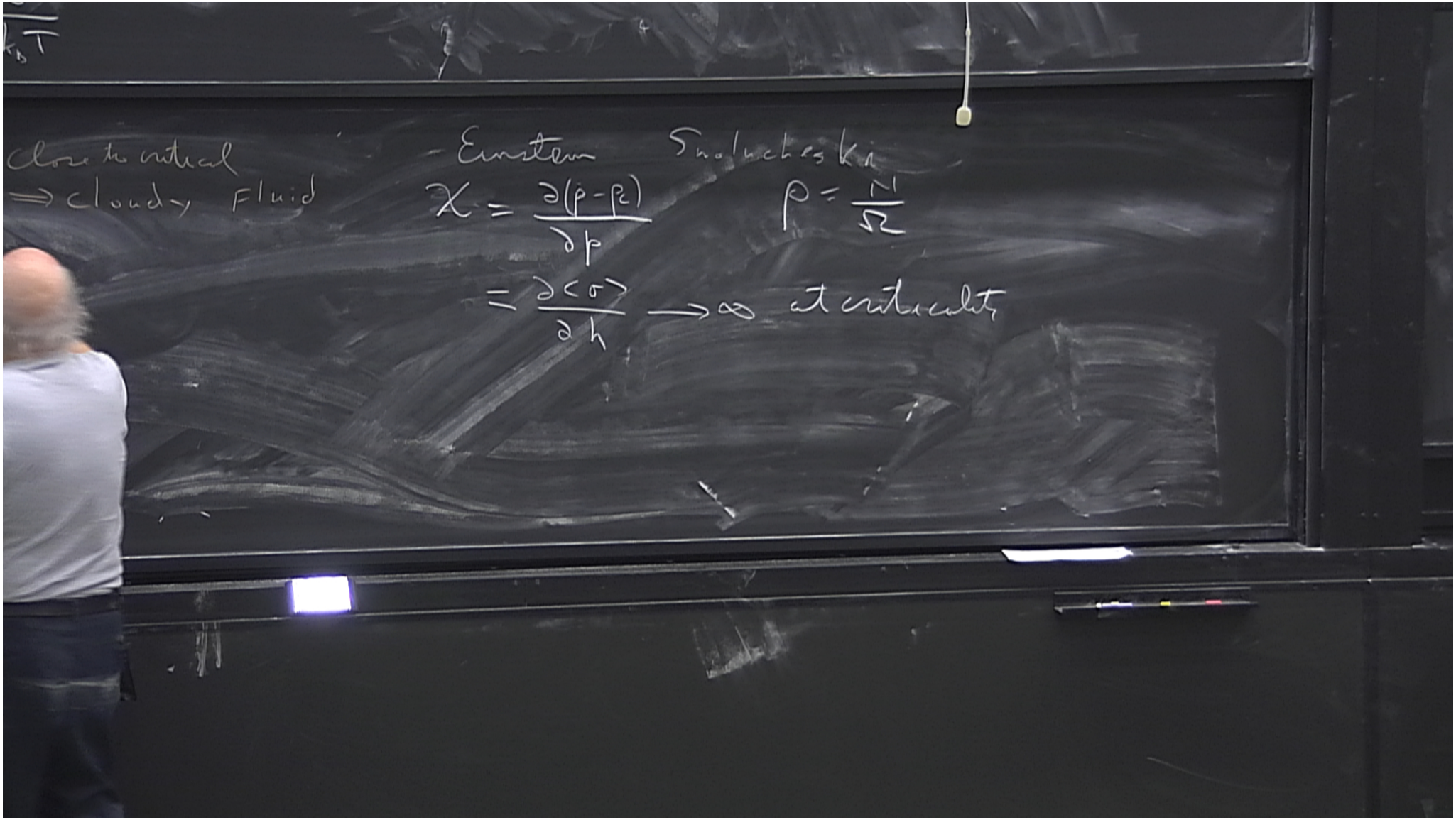
close to critical
$\Rightarrow$ cloudy fluid

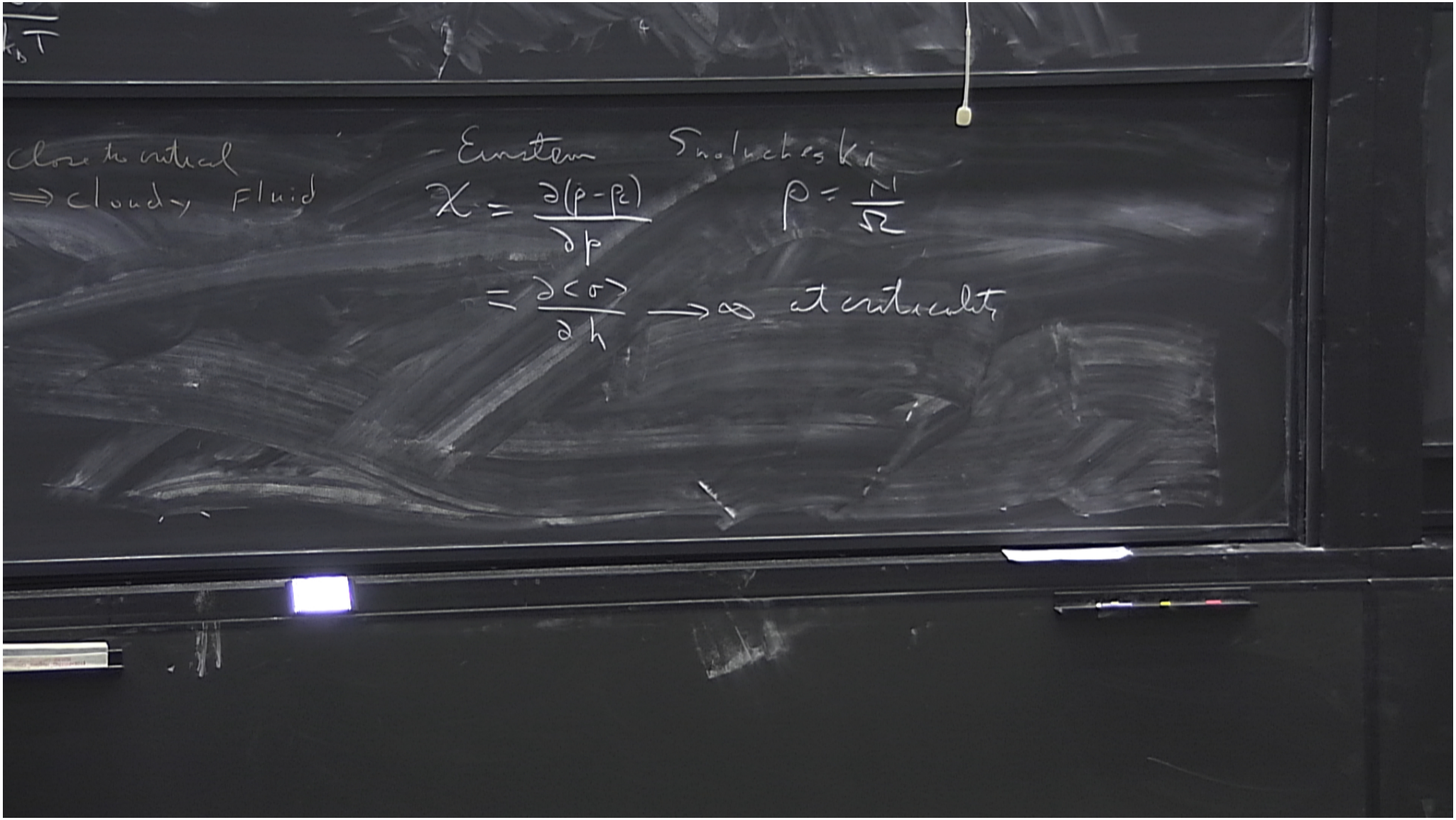

Einstein Smoluchowski
$\frac{1}{(E_i + E_{i'} - E_j - E_{j'}}$

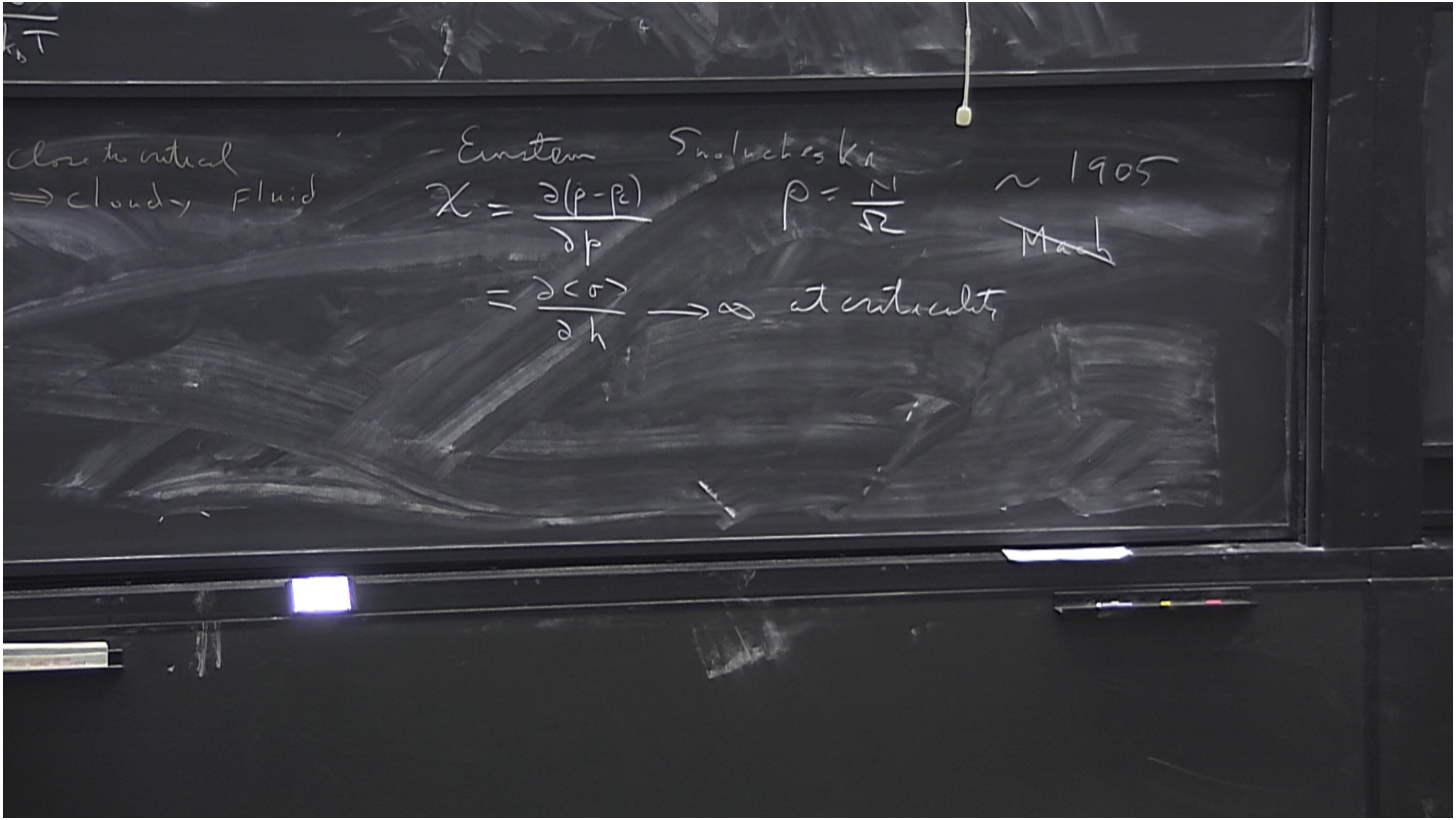

close to critical
⇒ cloudy Fluid
Einstein
Smoluchowski

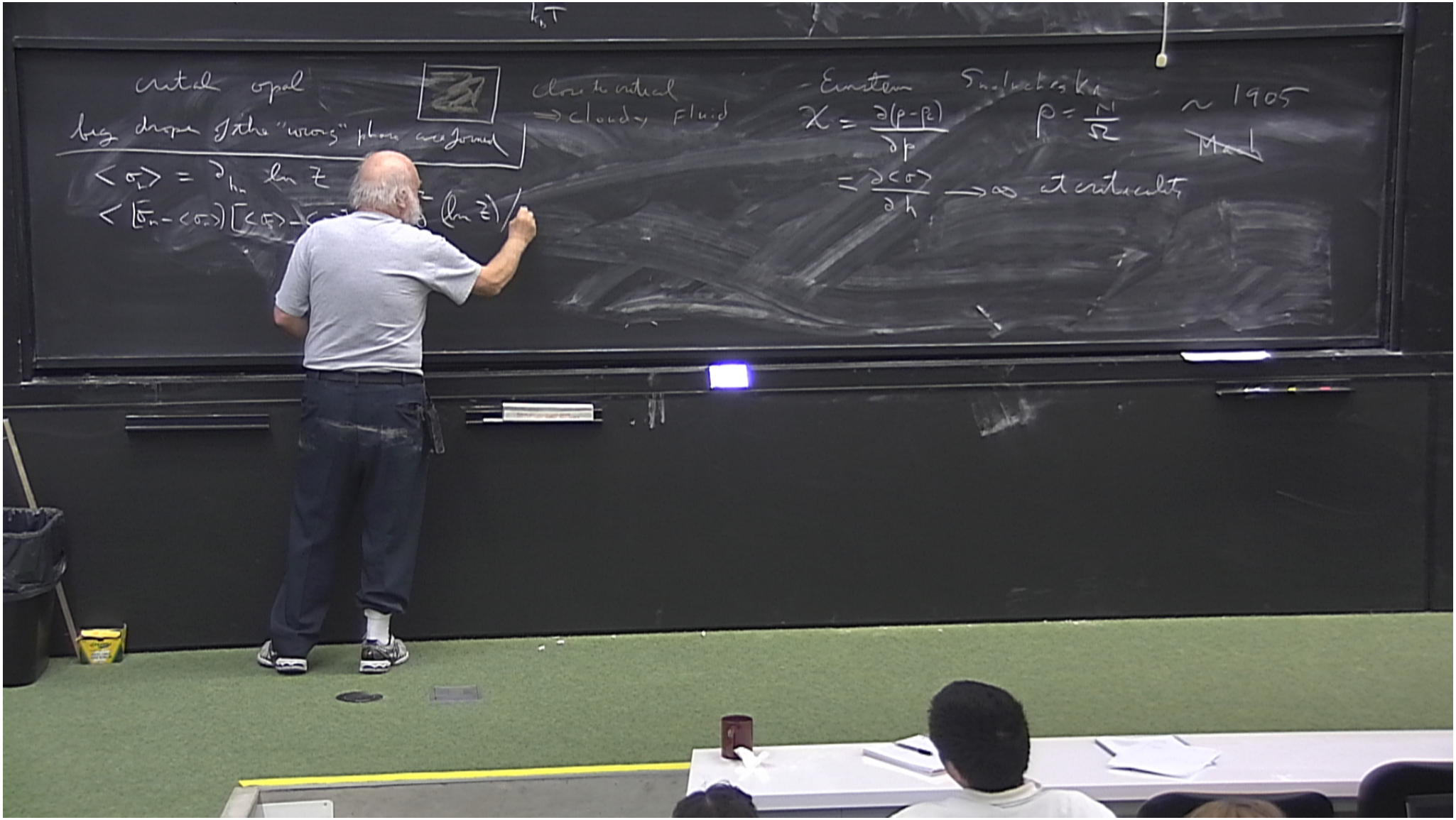

close to critical
⇒ cloudy Fluid
- Einstein
$\chi = \frac{\partial(\rho - \rho_2)}{\partial p}$
$= \frac{\partial \langle \sigma \rangle}{\partial h}$
Smoluchowski
$\rho = \frac{n}{\Omega}$

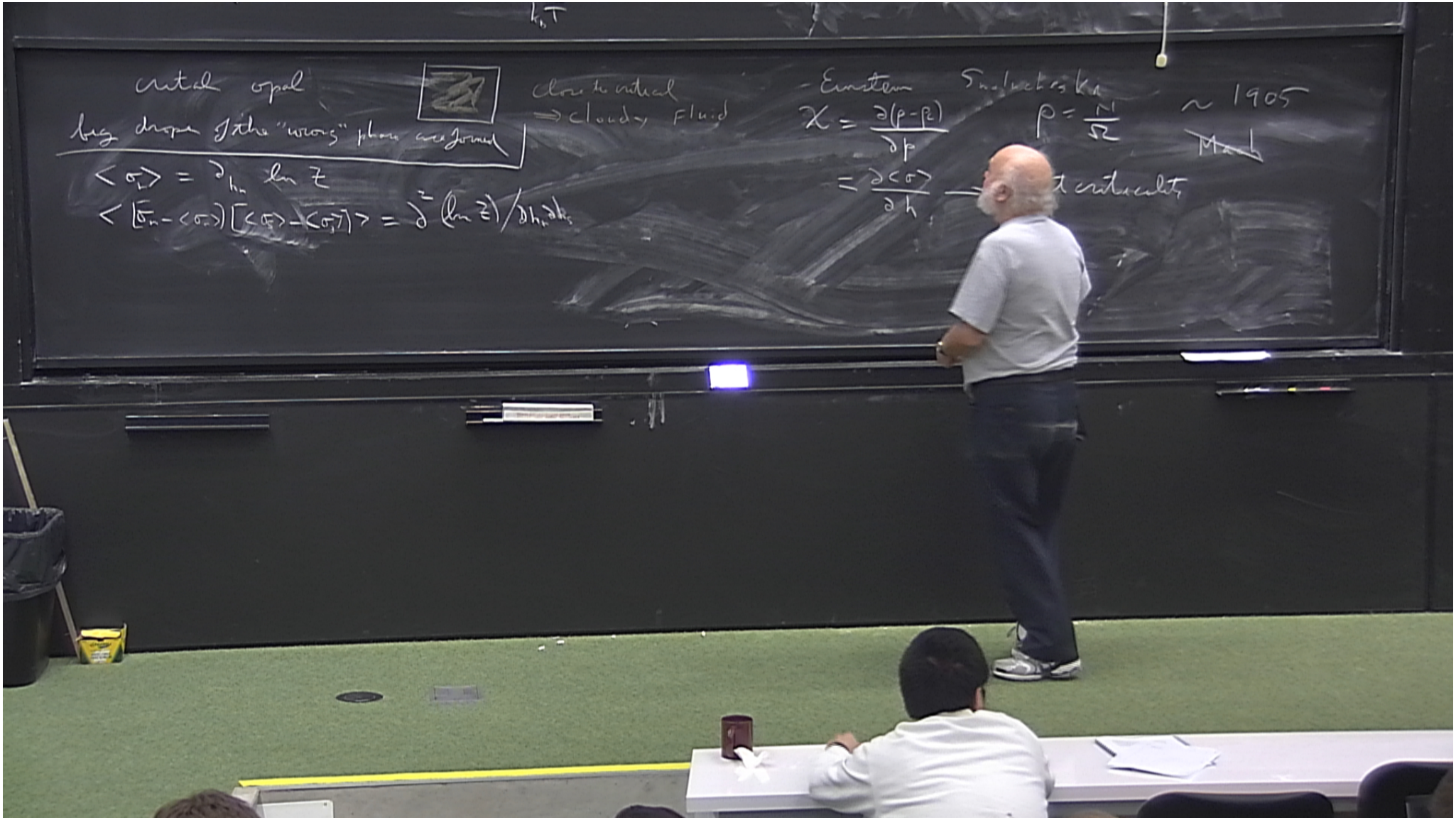

close to critical
⇒ cloudy Fluid
Einstein
Smoluchowski
$\chi = \frac{\partial(\rho - \rho_c)}{\partial p}$
$= \frac{\partial \langle \sigma \rangle}{\partial h}$
$\rho = \frac{n}{V}$

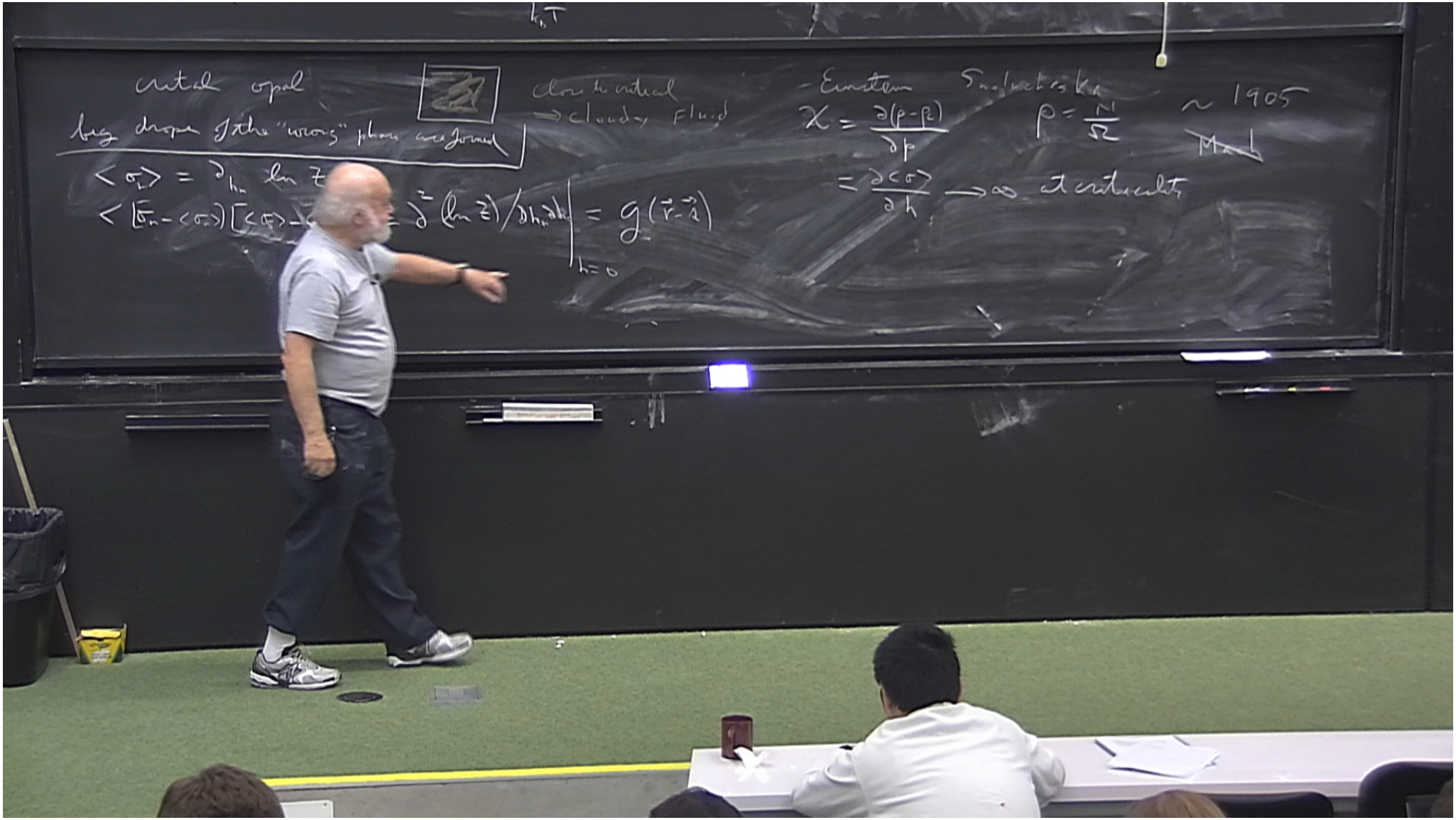

close to critical
⟹ cloudy Fluid
Einstein
Smoluchowski
$\chi = \frac{\partial(\rho - \rho_c)}{\partial p}$
$= \frac{\partial \langle \sigma \rangle}{\partial h} \to \infty$ at critical
$\rho = \frac{n}{\Omega}$

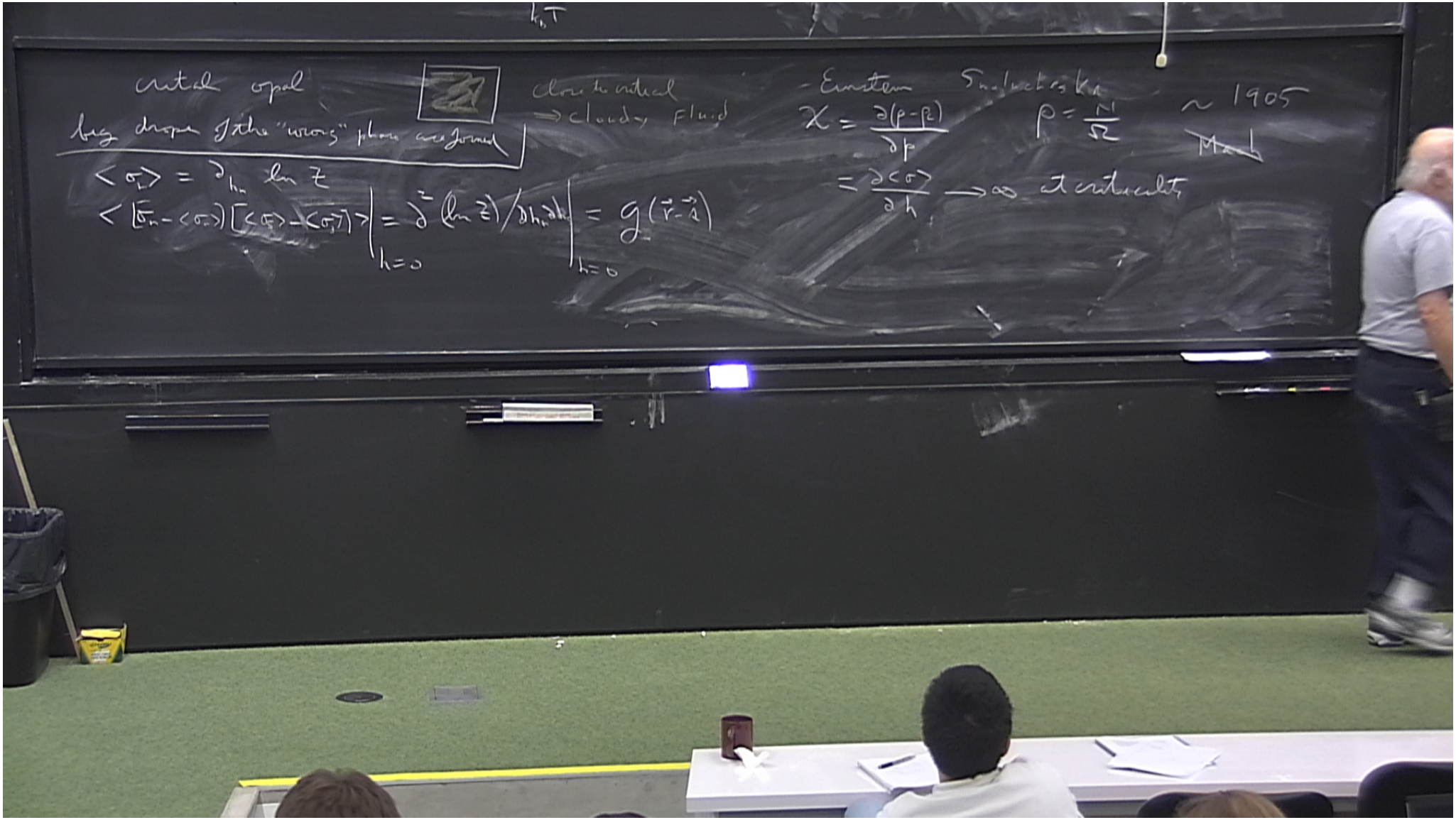

close to critical
⇒ cloudy Fluid
Einstein
Smoluchowski
$\chi = \frac{\partial(\rho - \rho_2)}{\partial p}$
$= \frac{\partial \langle \sigma \rangle}{\partial h}$
$\rho = \frac{n}{V}$
$\to \infty$ at critical

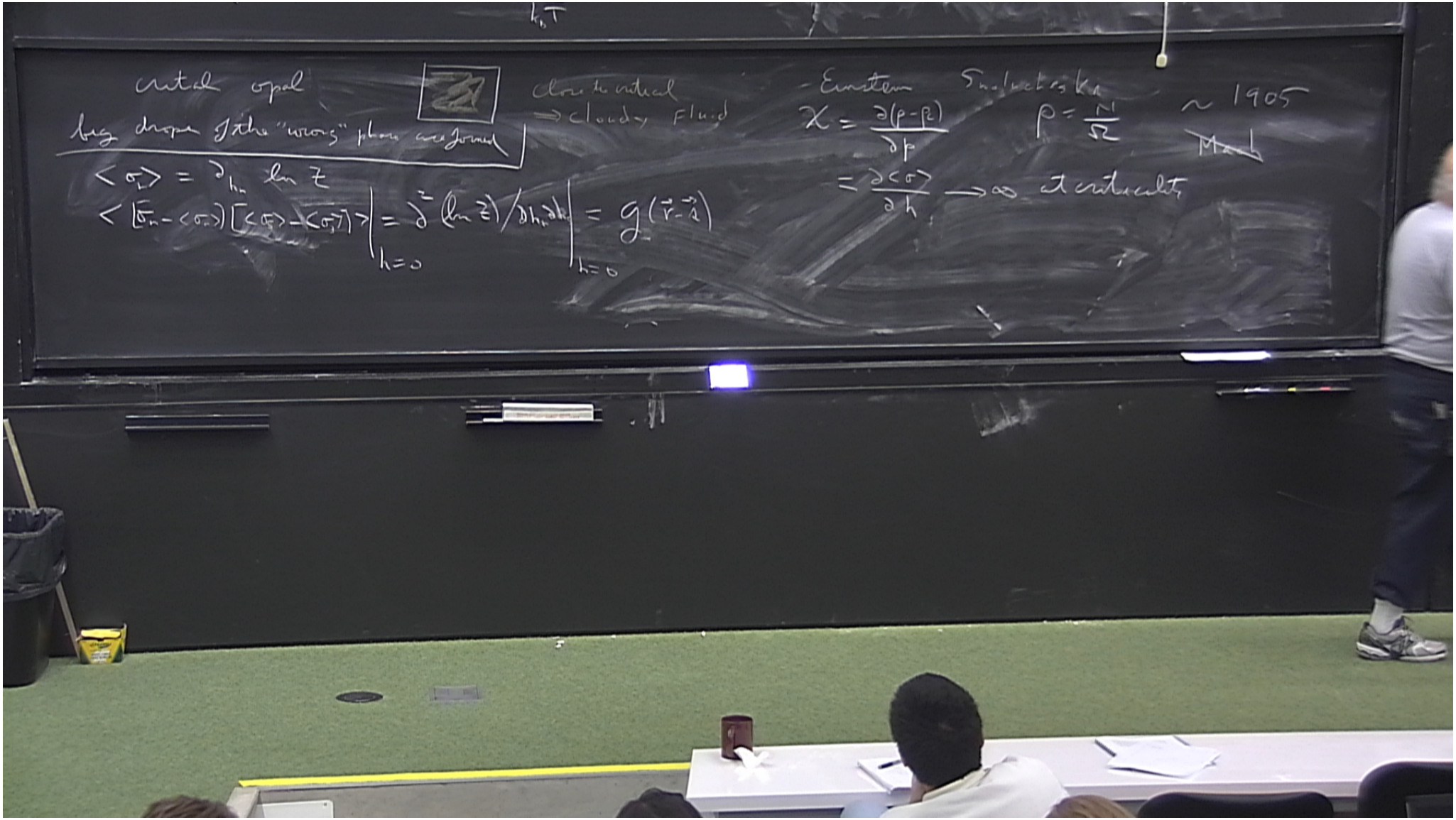

close to critical
⇒ cloudy Fluid
- Einstein Smoluchowski
$\chi = \frac{\partial(\rho - \rho_2)}{\partial p}$
$= \frac{\partial \langle \sigma \rangle}{\partial h} \to \infty$ at critical
$\rho = \frac{n}{V}$
$\sim$ 1905
Mach

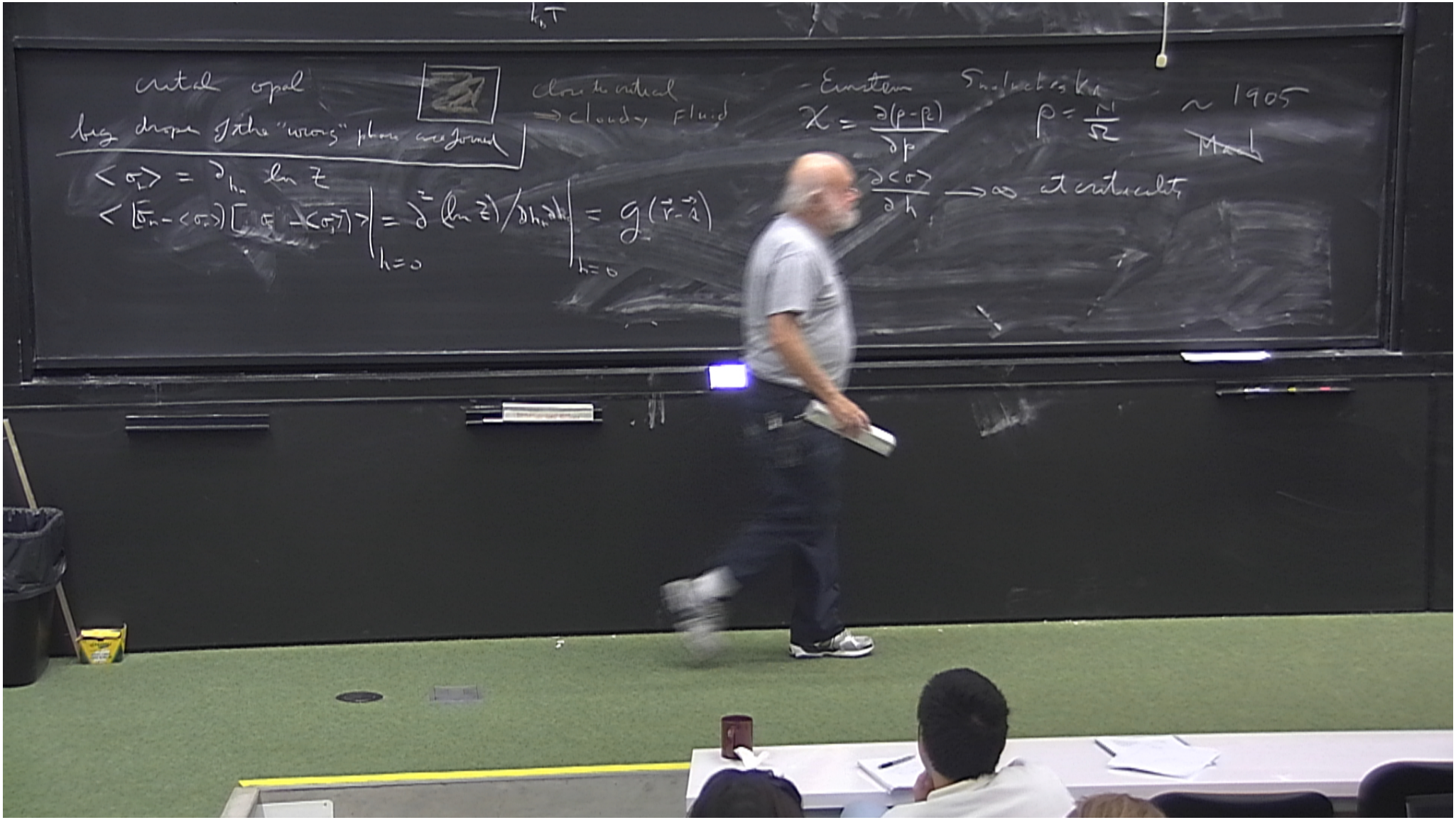

opal
close to critical
⇒ cloudy Fluid
Einstein
Smoluchowski
~ 1905
$\chi = \frac{\partial(\rho - \bar{\rho})}{\partial p}$
$\rho = \frac{n}{V}$
$= \frac{\partial \langle \sigma \rangle}{\partial h} \longrightarrow \infty$ at critical

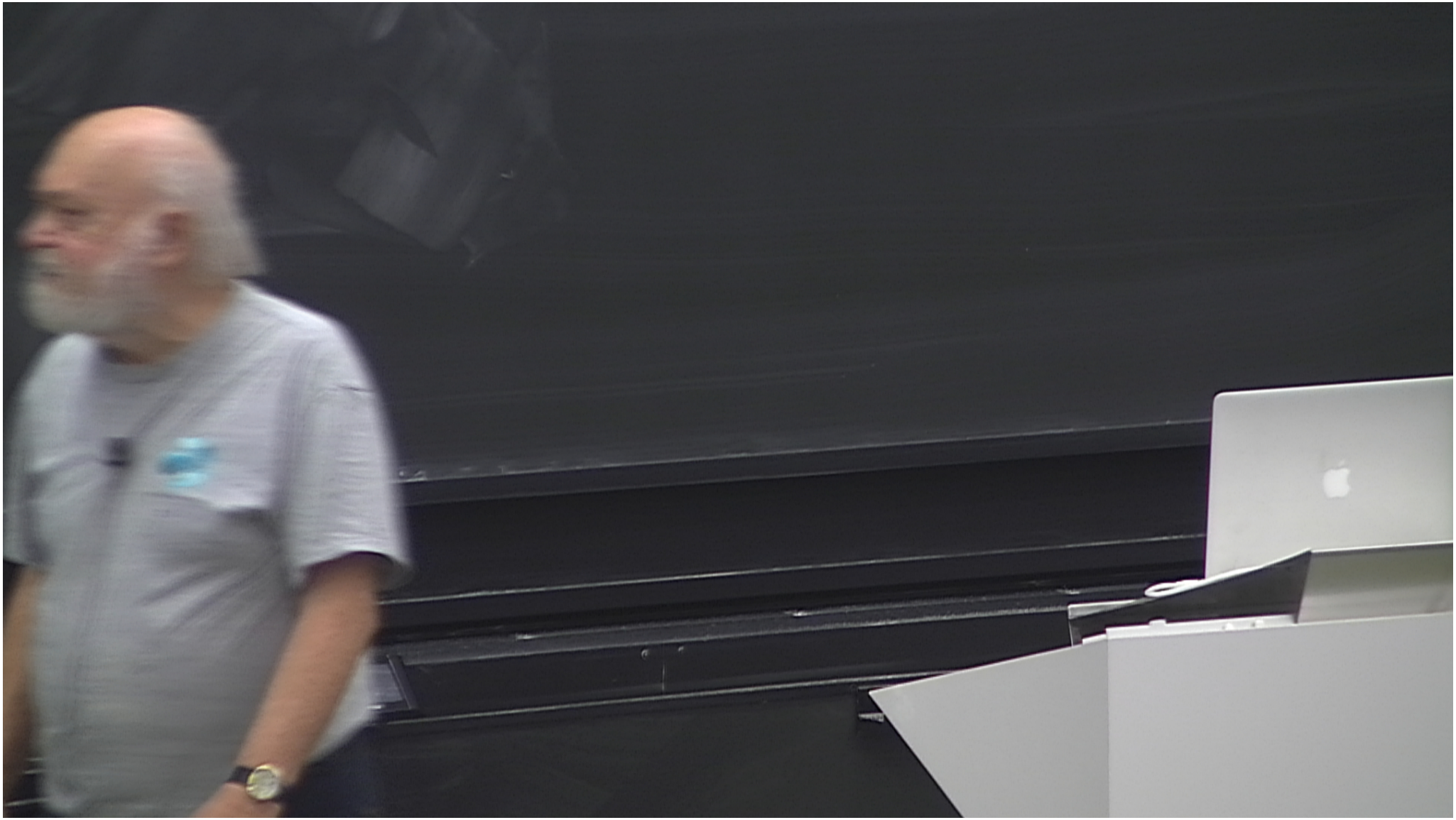

opal
close to critical
⇒ cloudy Fluid
Einstein
Smoluchowski
~ 1905

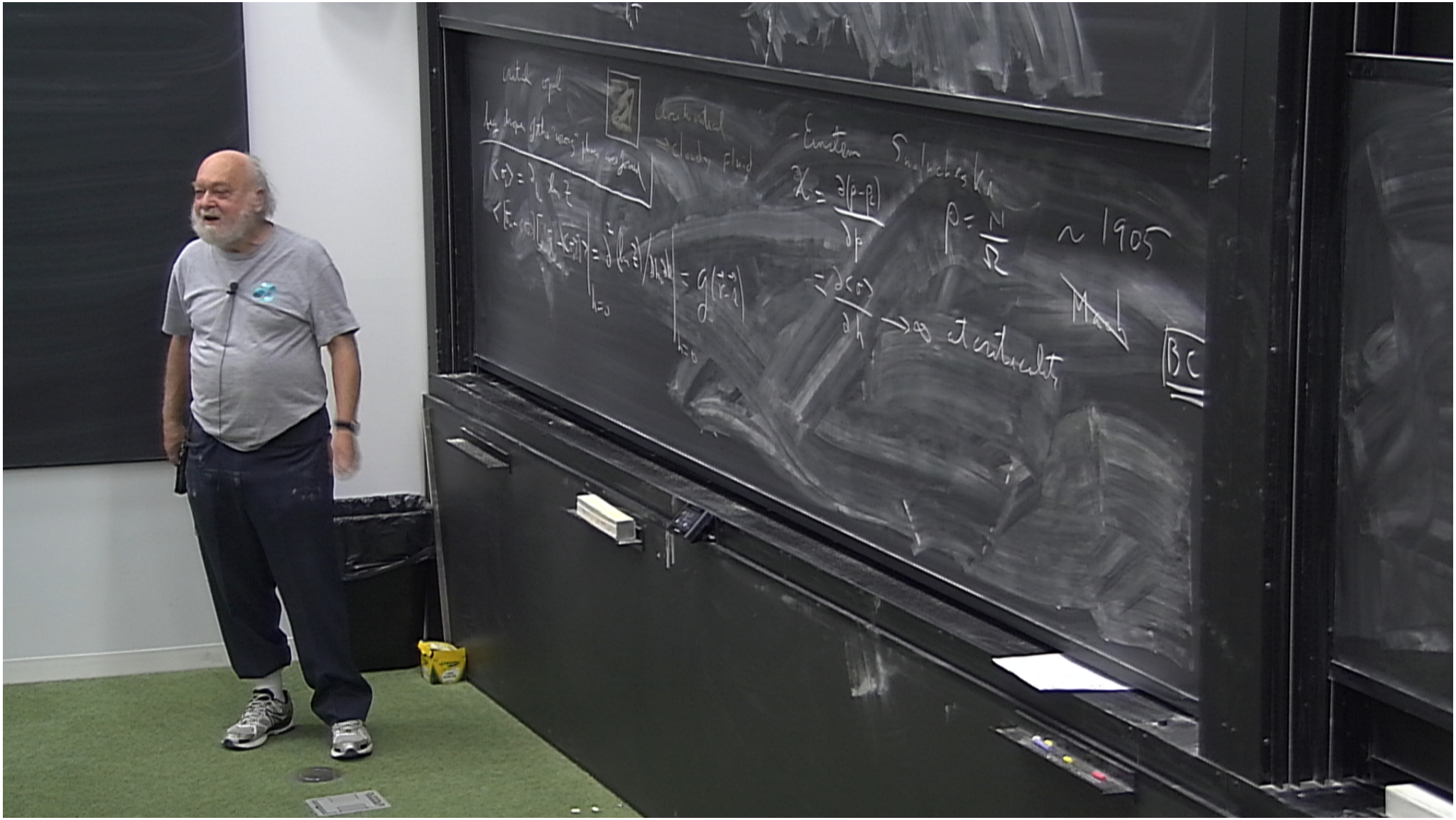

critical opal
long droplets of the "wrong" phase are formed
close to critical
⇒ cloudy Fluid
Einstein Smoluchowski
~ 1905
$\chi = \frac{\partial(\rho - \bar{\rho})}{\partial p}$
$\rho = \frac{n}{V}$
$= \frac{\partial \langle \sigma \rangle}{\partial h} \longrightarrow \infty$ at criticality
$\langle \sigma_n \rangle = \partial_{h_n} \ln Z$
$= g(\vec{r} - \vec{r}')$
$h = 0$

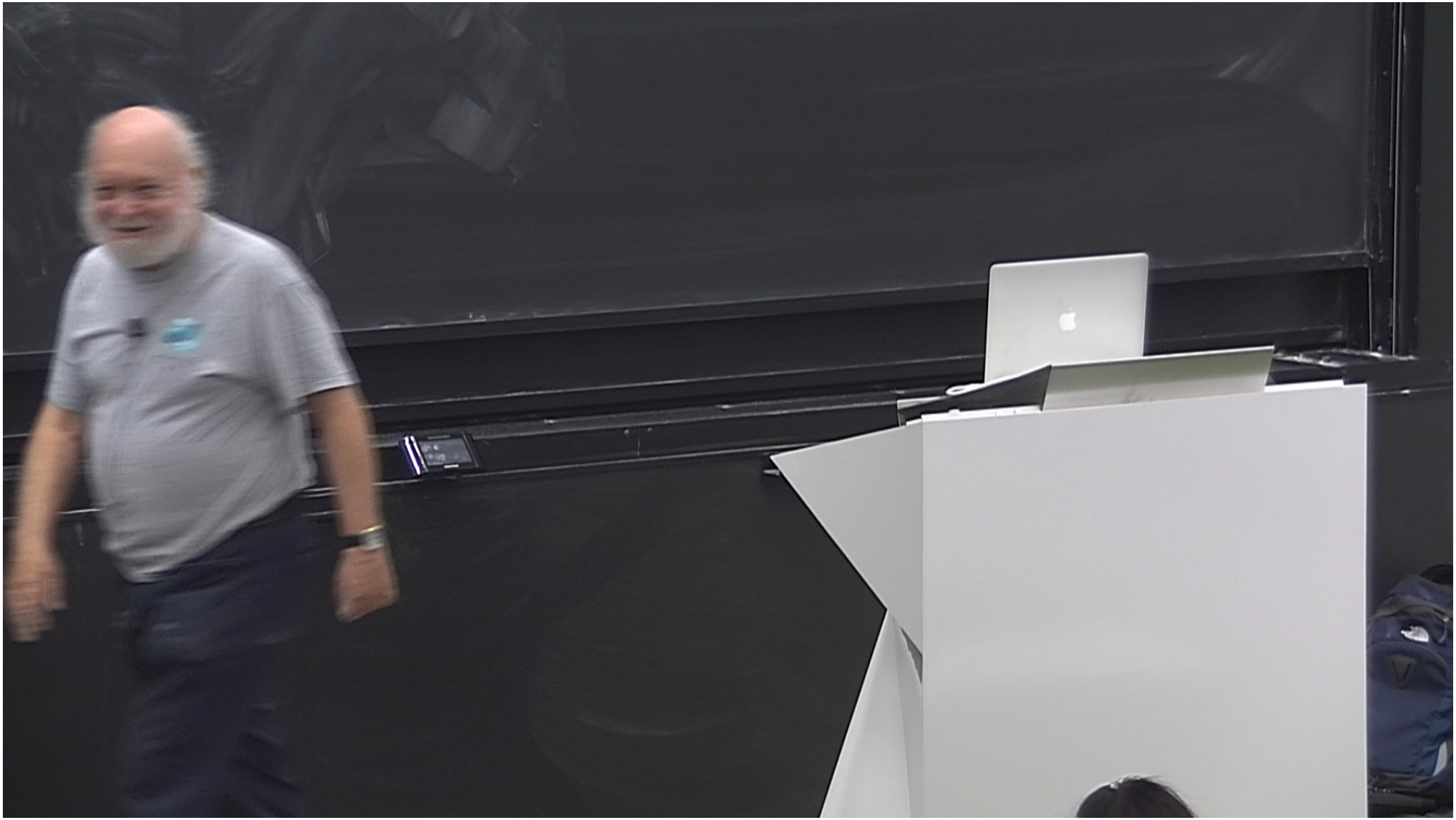

critical opal
long droplets of the "wrong" phase are formed
close to critical
⇒ cloudy Fluid
Einstein Smoluchowski
~ 1905
$\chi = \frac{\partial(\rho - \bar{\rho})}{\partial p}$
$\rho = \frac{n}{\Omega}$
$= \frac{\partial \langle \sigma \rangle}{\partial h} \longrightarrow \infty$ at criticality
$\langle \sigma_i \rangle = \partial_{h_i} \ln Z$
$\langle [\sigma_i - \langle \sigma_i \rangle][\langle \sigma_j \rangle - \langle \sigma_j \rangle] \rangle \Big|_{h=0} = \partial^2 (\ln Z) / \partial h_i \partial h_j \Big|_{h=0} = g(\vec{r} - \vec{s})$

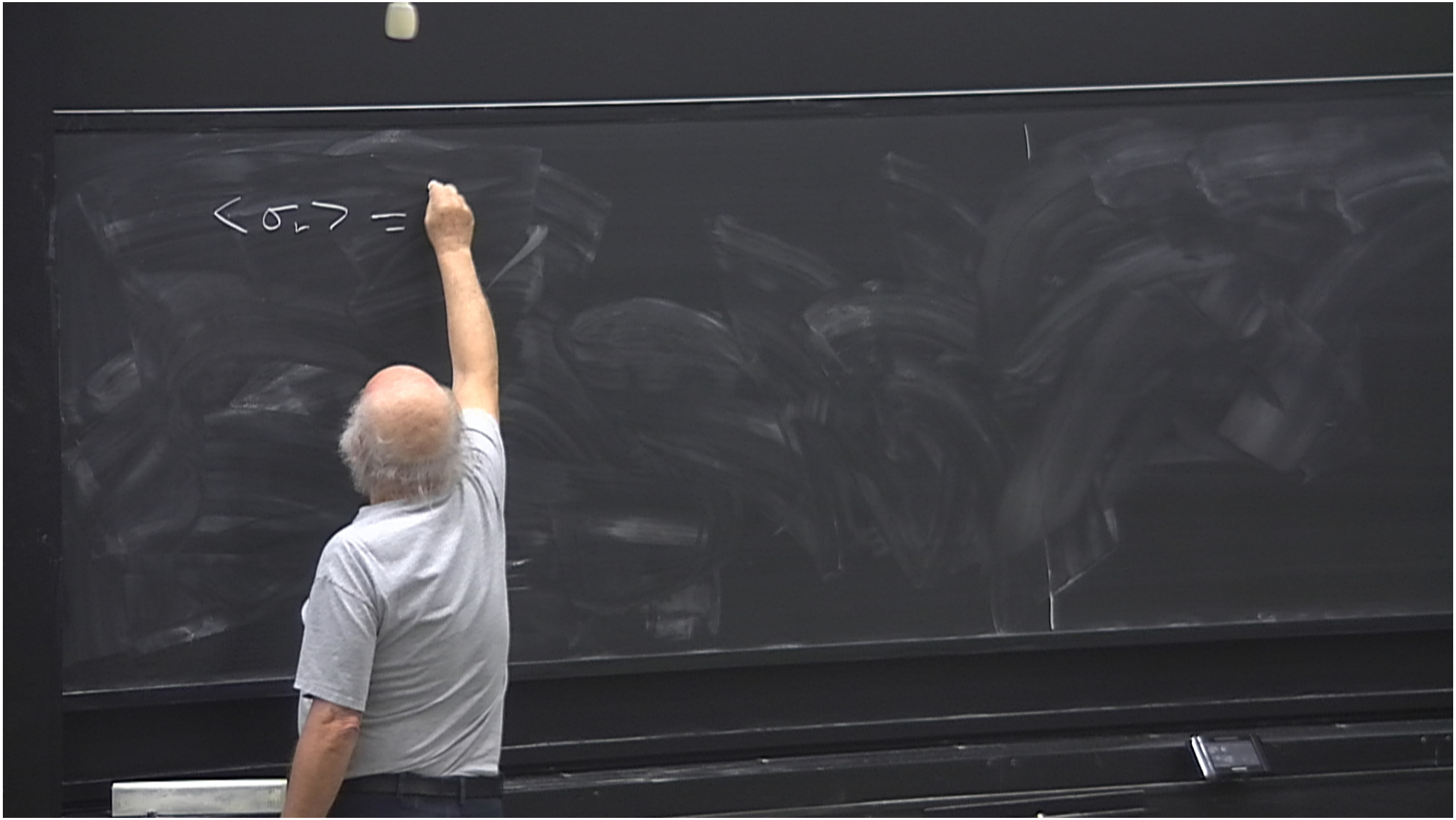

$k_B T$
critical opal
long droplets of the "wrong" phase are formed
close to critical
⇒ cloudy Fluid
- Einstein Smoluchowski
~ 1905
$\chi = \frac{\partial(\rho - \bar{\rho})}{\partial p}$
$\rho = \frac{n}{\Omega}$
$= \frac{\partial \langle \sigma \rangle}{\partial h} \longrightarrow \infty$ at criticality
$\langle \sigma_i \rangle = \partial_{h_i} \ln Z$
$\langle [\sigma_i - \langle \sigma_i \rangle][\langle \sigma_j \rangle - \langle \sigma_j \rangle] \rangle \Big|_{h=0} = \partial^2 (\ln Z) / \partial h_i \partial h_j \Big|_{h=0} = g(\vec{r} - \vec{r}')$

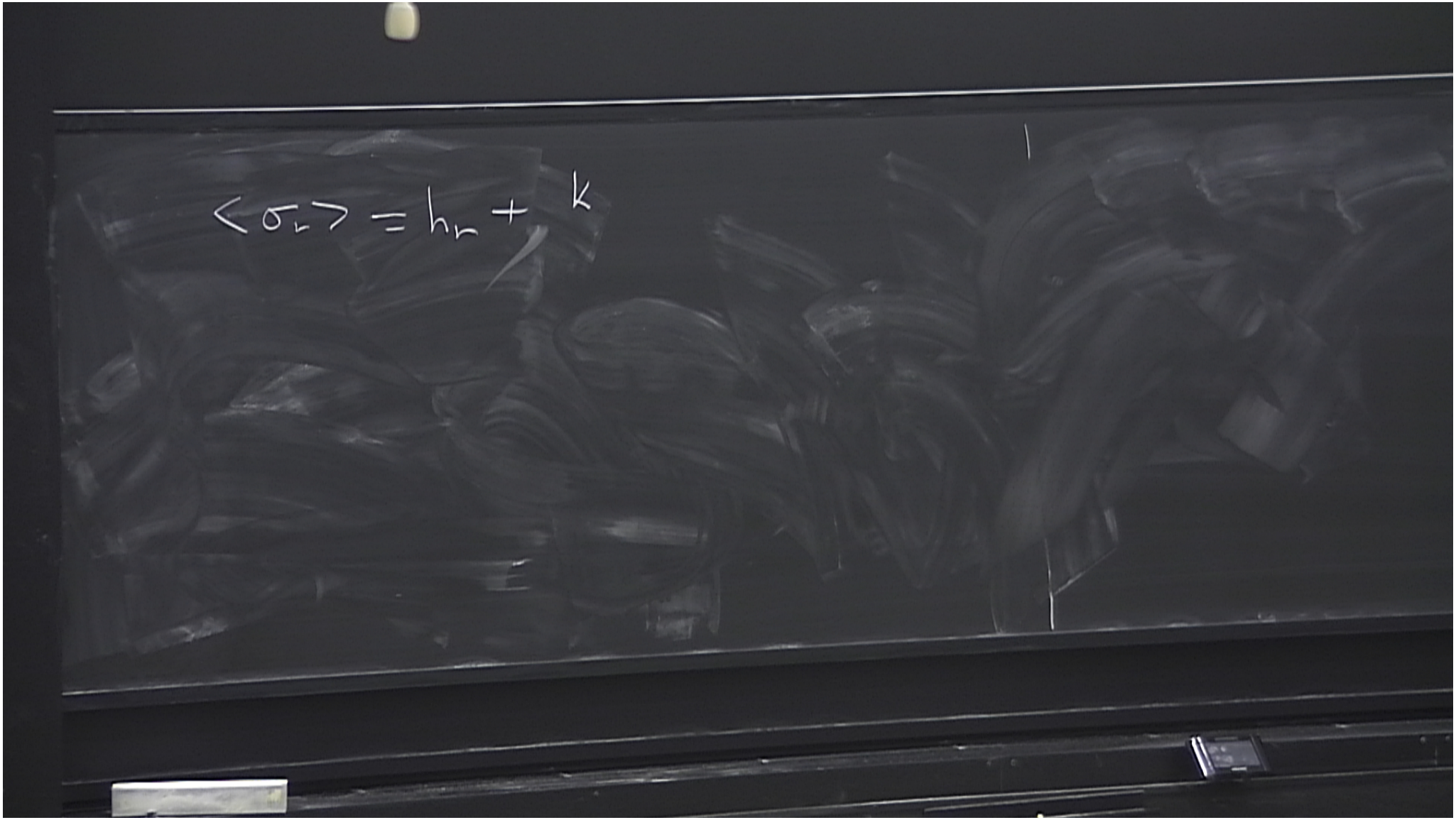

critical opal
long droplets of the "wrong" phase are formed
close to critical
⇒ cloudy Fluid
Einstein
Smoluchowski
~ 1905
Max
$\chi = \frac{\partial(\rho - \bar{\rho})}{\partial p}$
$\rho = \frac{n}{\Omega}$
$\langle \sigma_i \rangle = \partial_{h_i} \ln Z$
$\frac{\partial \langle \sigma \rangle}{\partial h} \to \infty$ at criticality
$h = 0$
$= g(\vec{r} - \vec{s})$

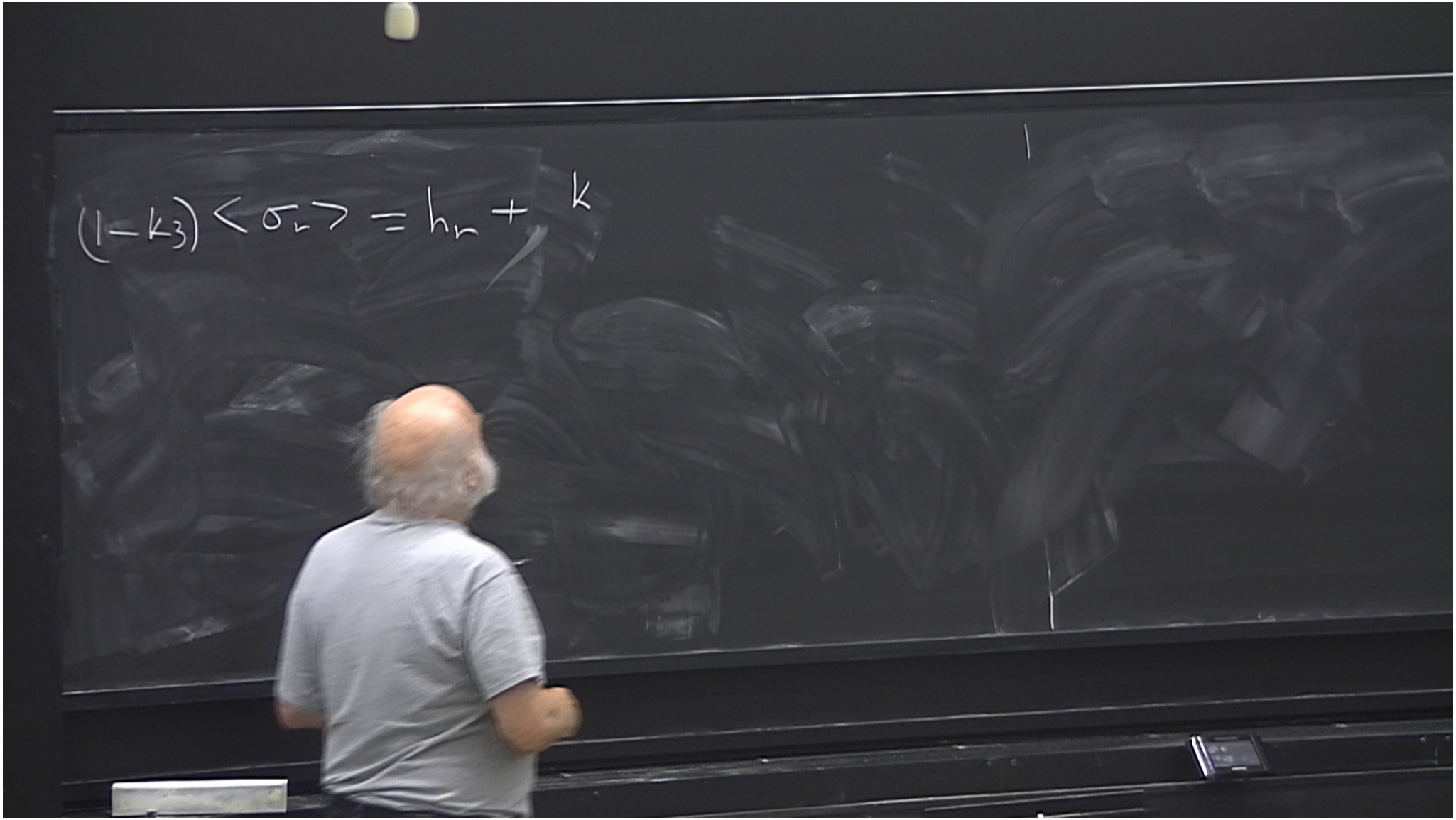


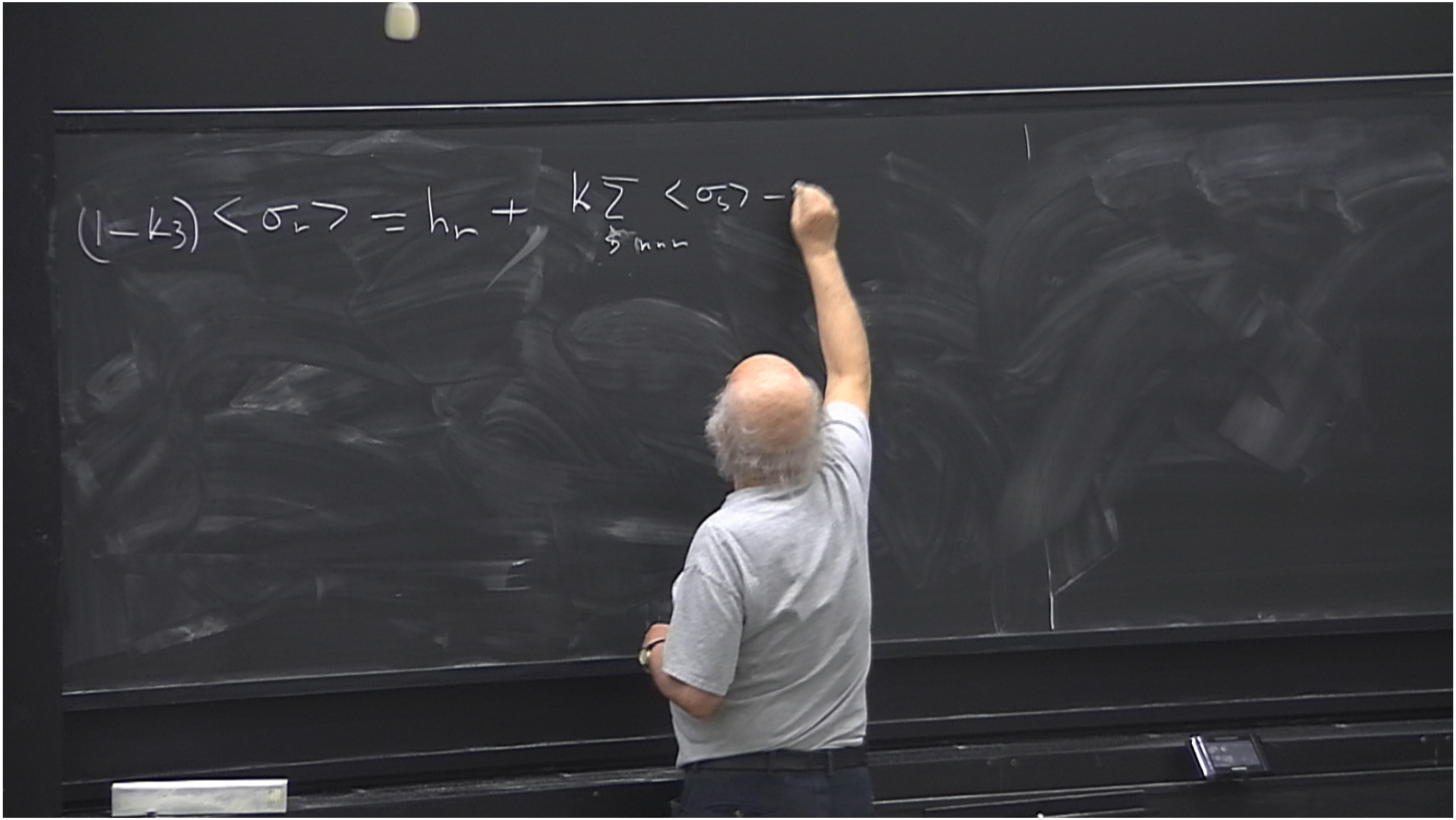

Einstein
~ 1905
BC

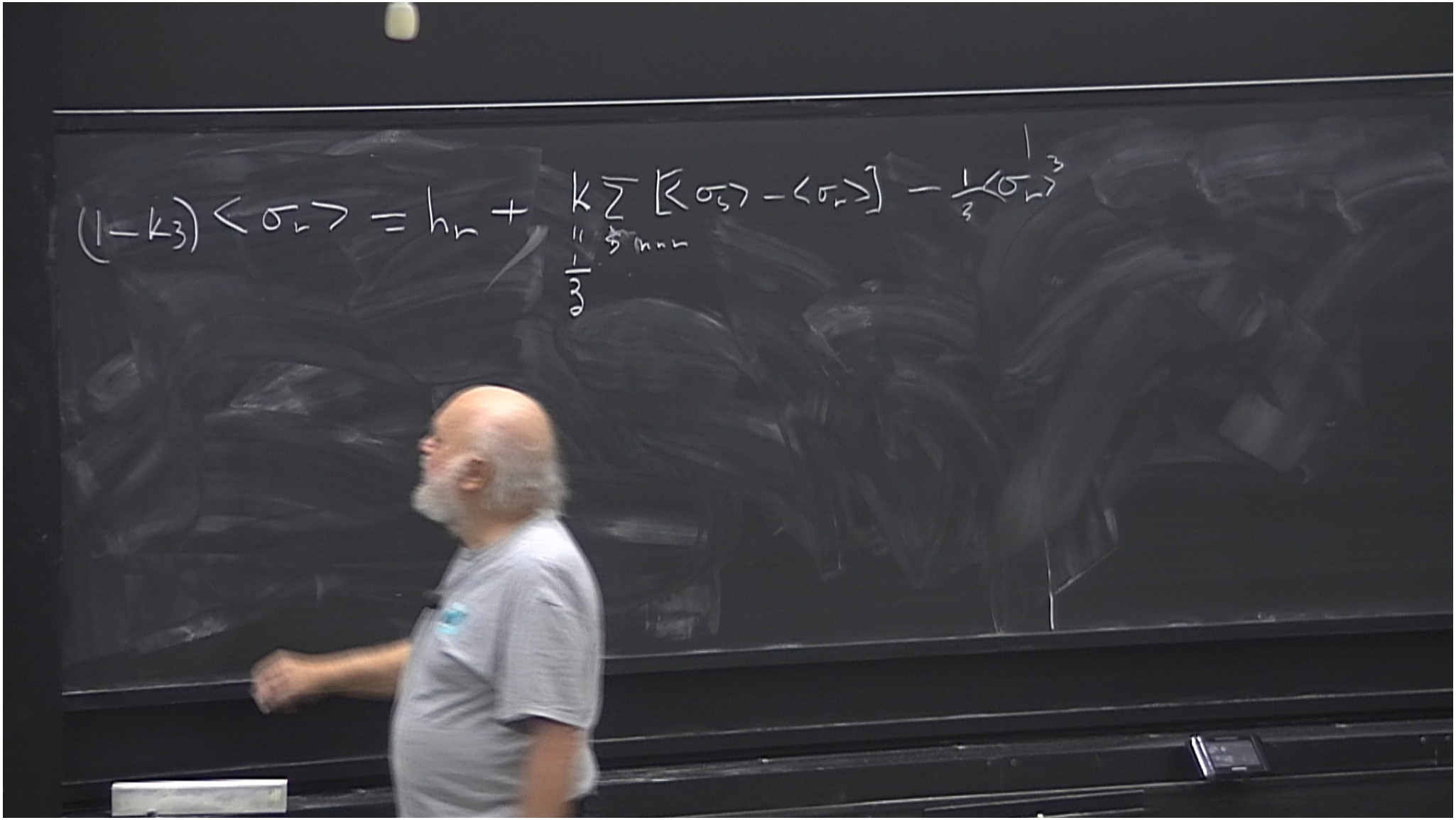


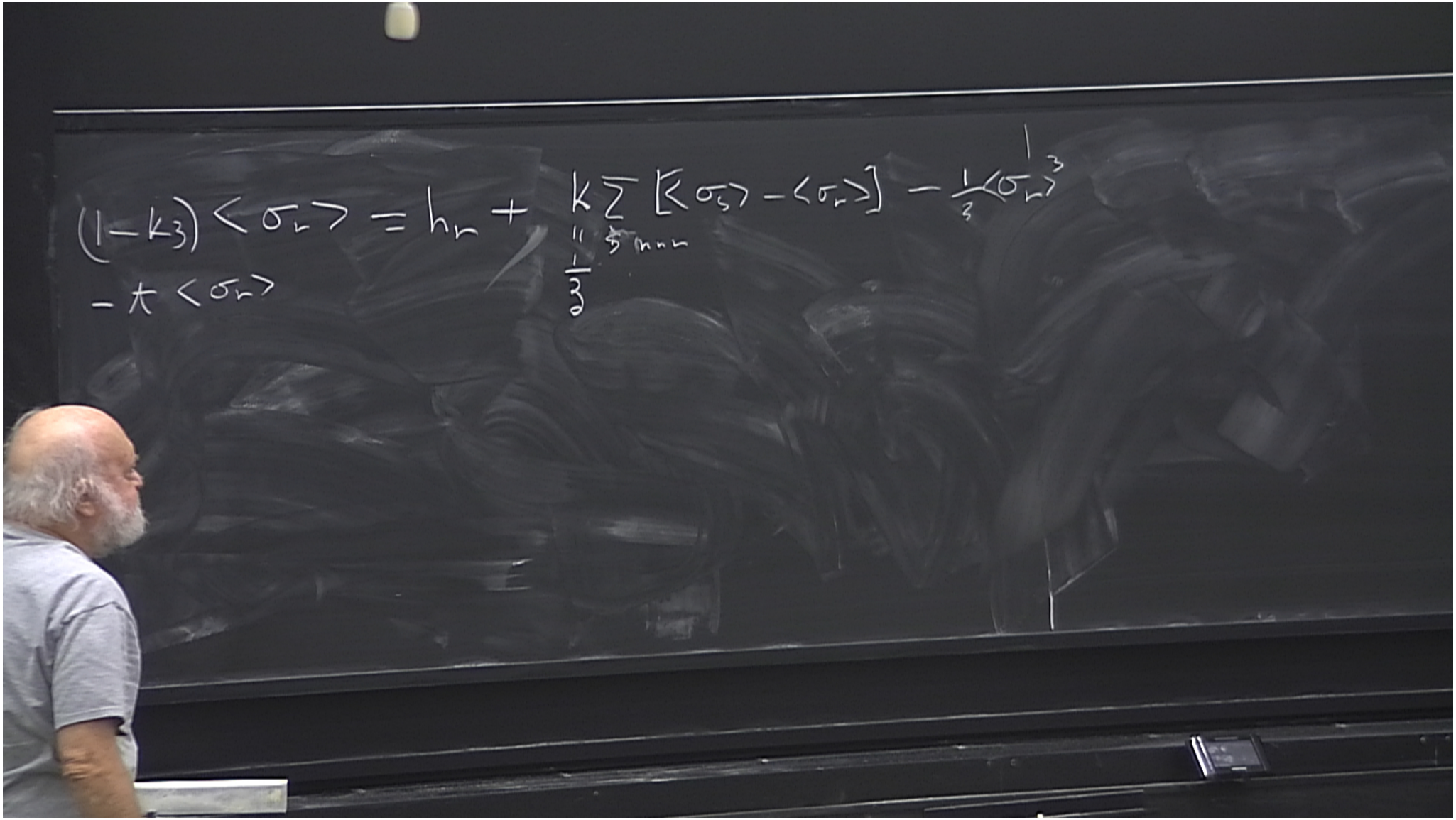

$\langle \sigma_z \rangle =$

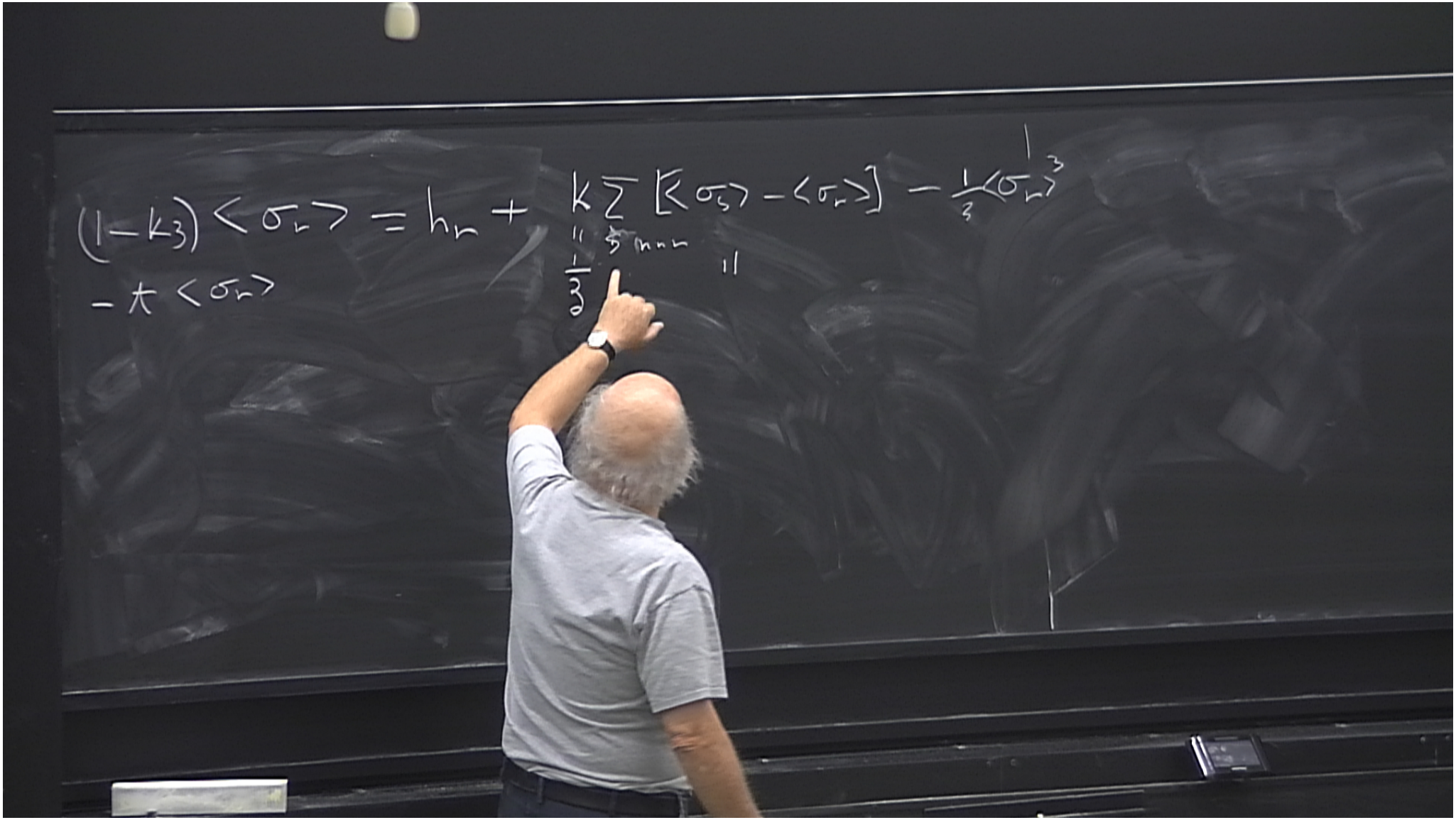

$\langle \sigma_r \rangle = h_r + k$

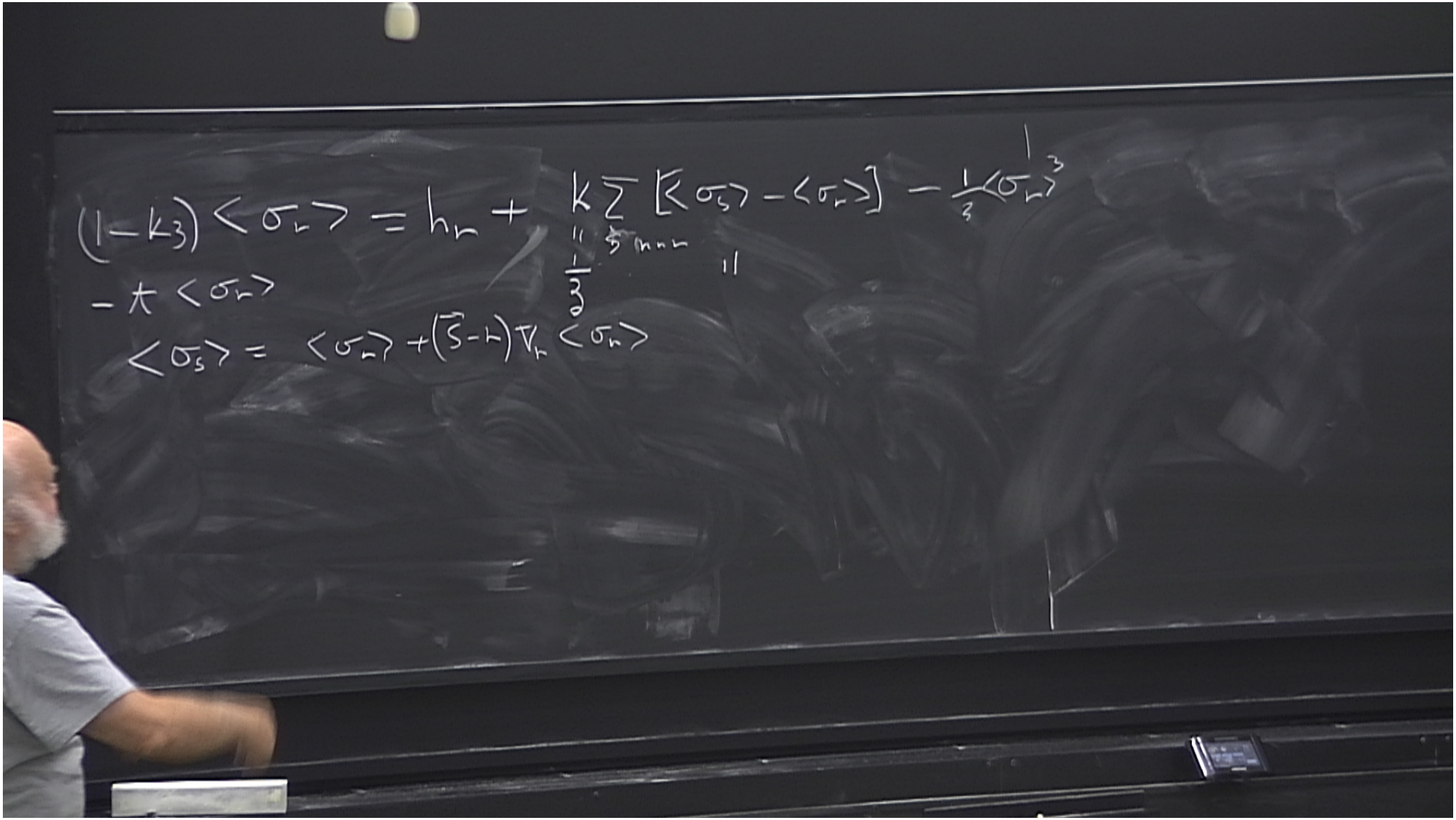

$(1-k_3)\langle\sigma_r\rangle = h_r + k$

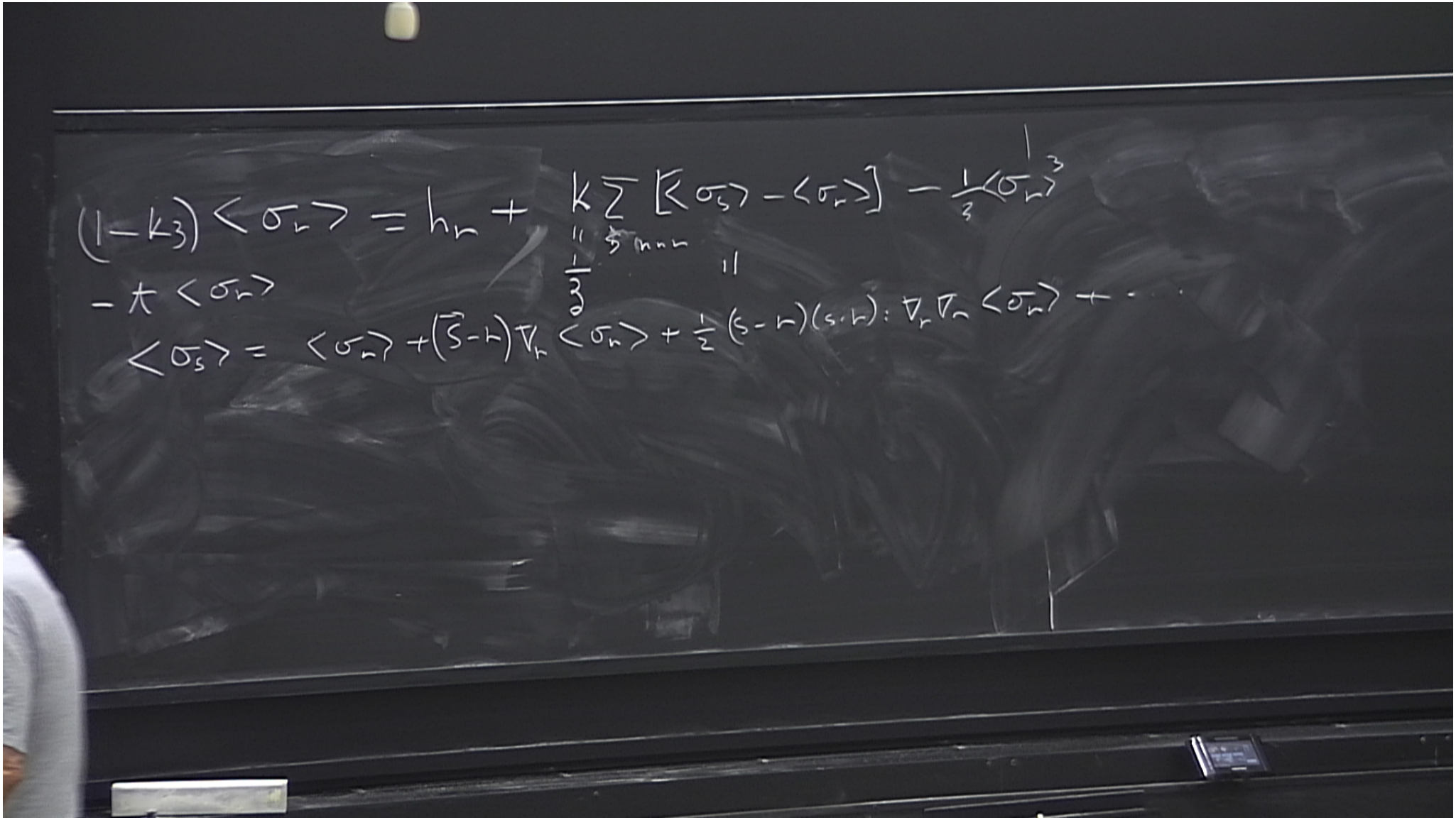

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum_{3\,nn\,n}\langle\sigma_3\rangle -$


$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{k}{3}\sum_{\langle n,m\rangle}[\langle\sigma_m\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$


$(1-k_3)\langle\sigma_r\rangle = h_r + k\sum_{s\,nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$k = \frac{1}{3}$


$(1-k3)\langle\sigma_r\rangle = h_r + k\sum_{s\ nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\frac{1}{3}$

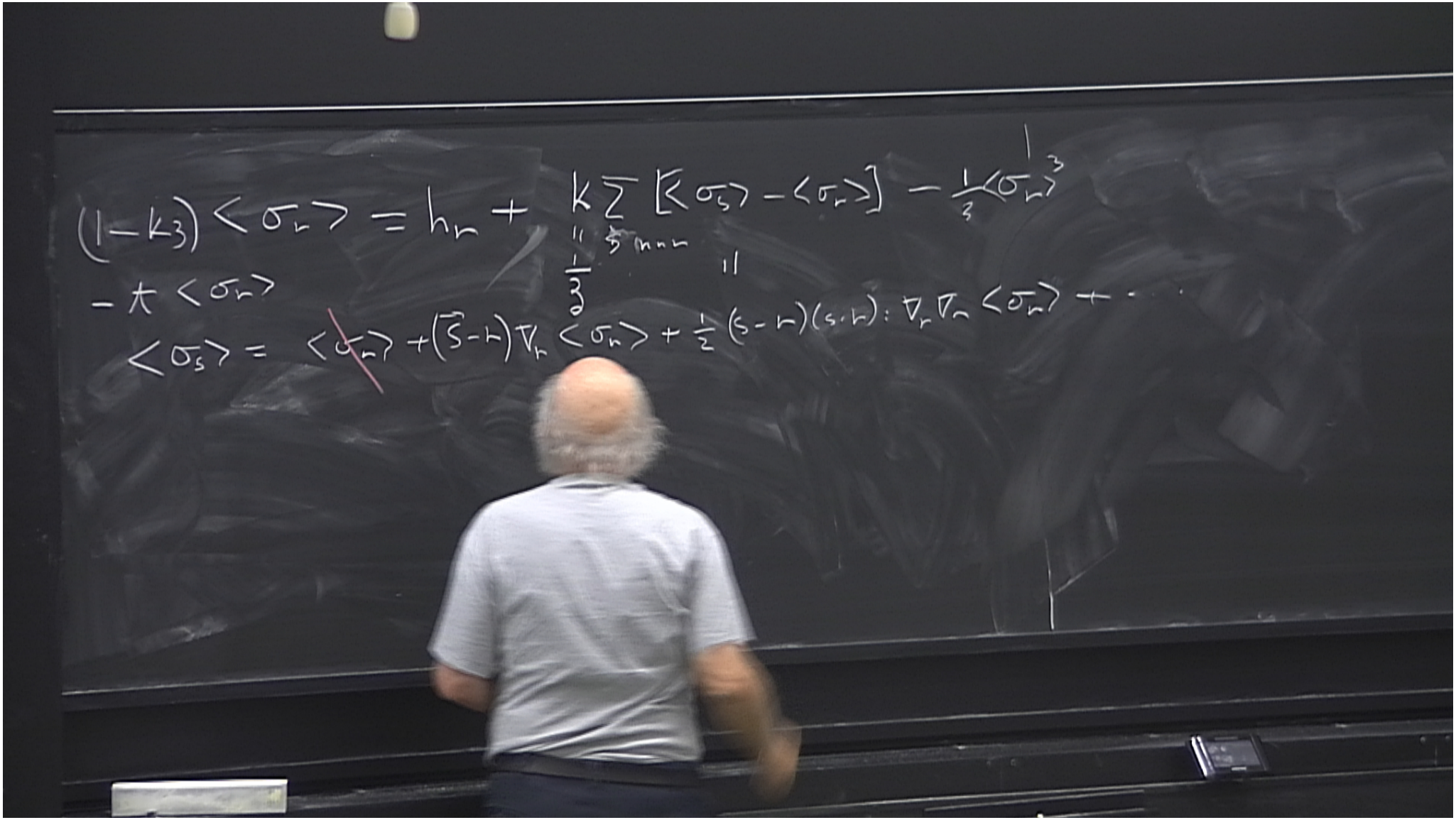

$(1-kz)\langle\sigma_r\rangle = h_r + k\sum_{s\,nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle$

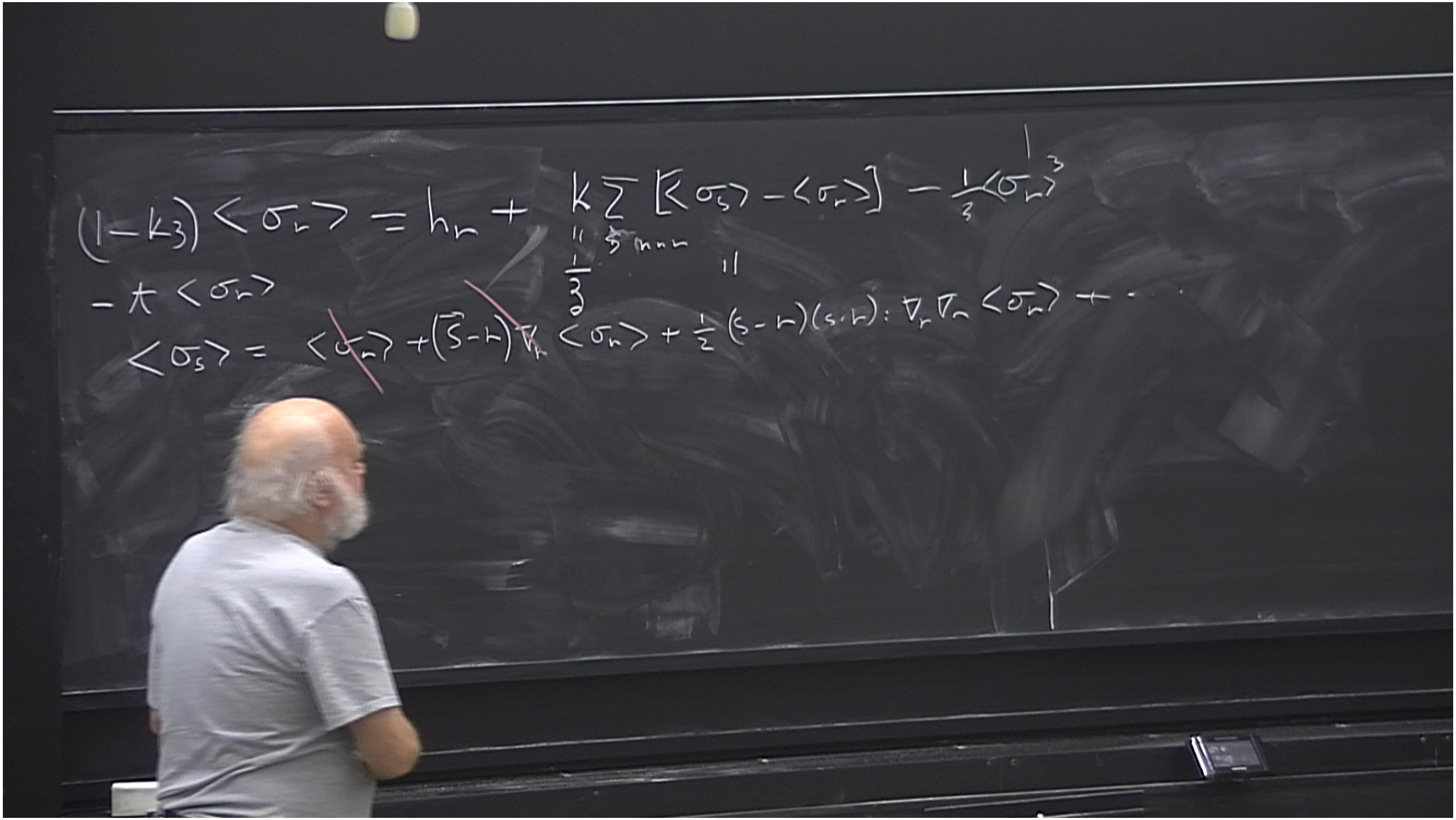


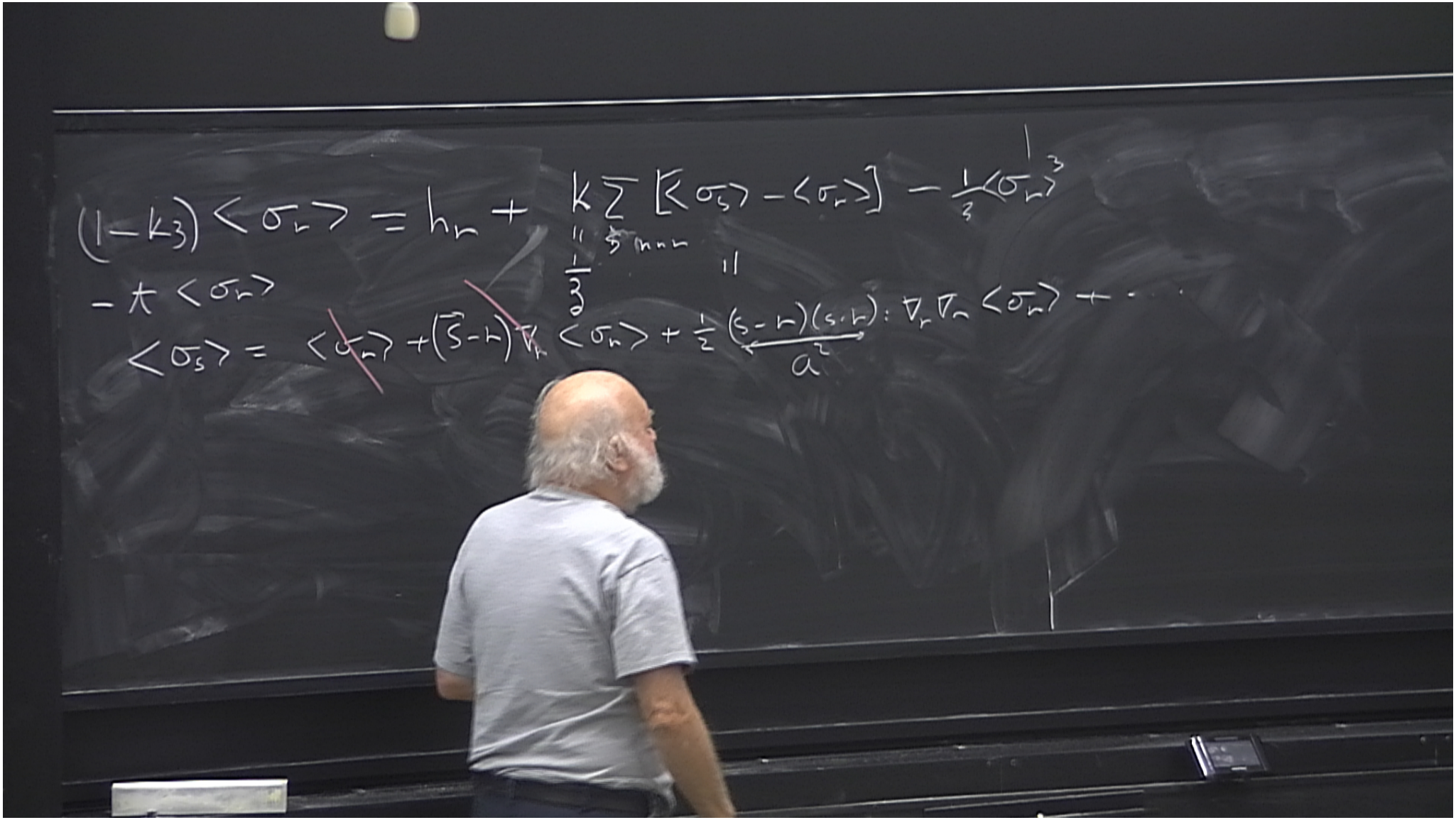
$$(1-k\zeta)\langle\sigma_r\rangle = h_r + \underset{\substack{\| \\ \frac{1}{\zeta}}}{k}\sum_{s\ nnr}\left[\langle\sigma_s\rangle - \langle\sigma_r\rangle\right] - \frac{1}{\zeta}\langle\sigma_r\rangle^3$$

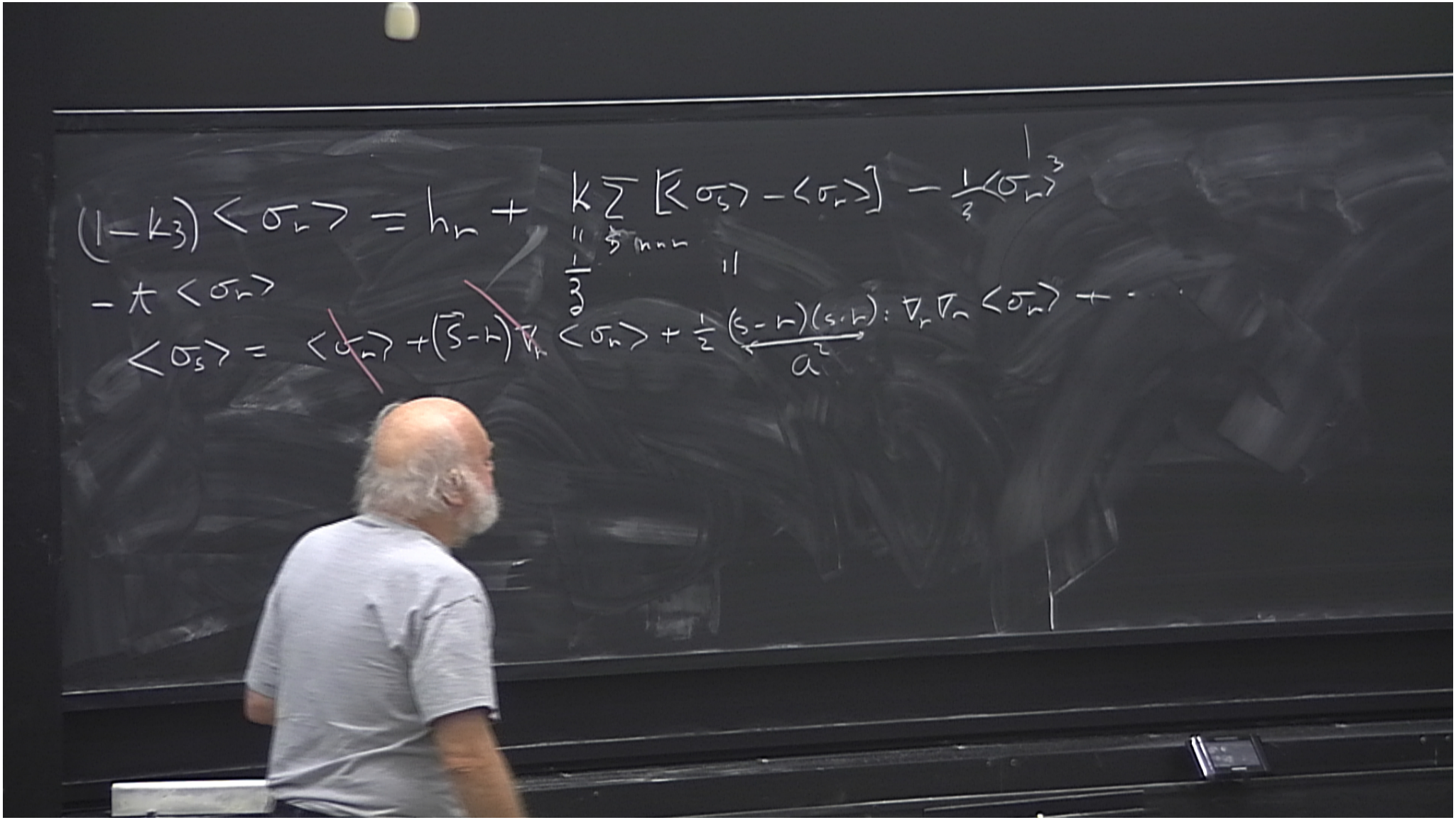
$$-t\langle\sigma_r\rangle$$

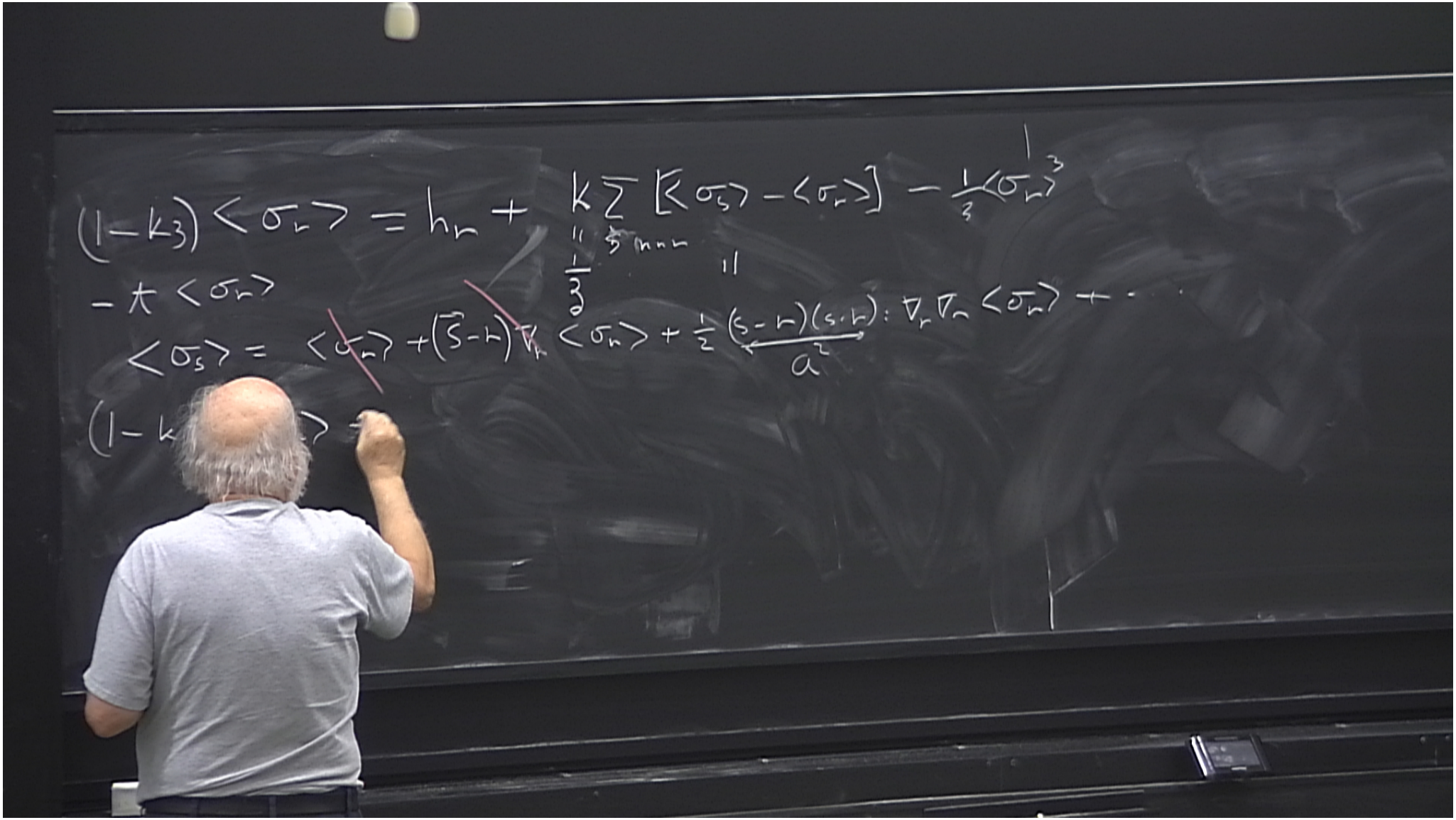
$$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$$

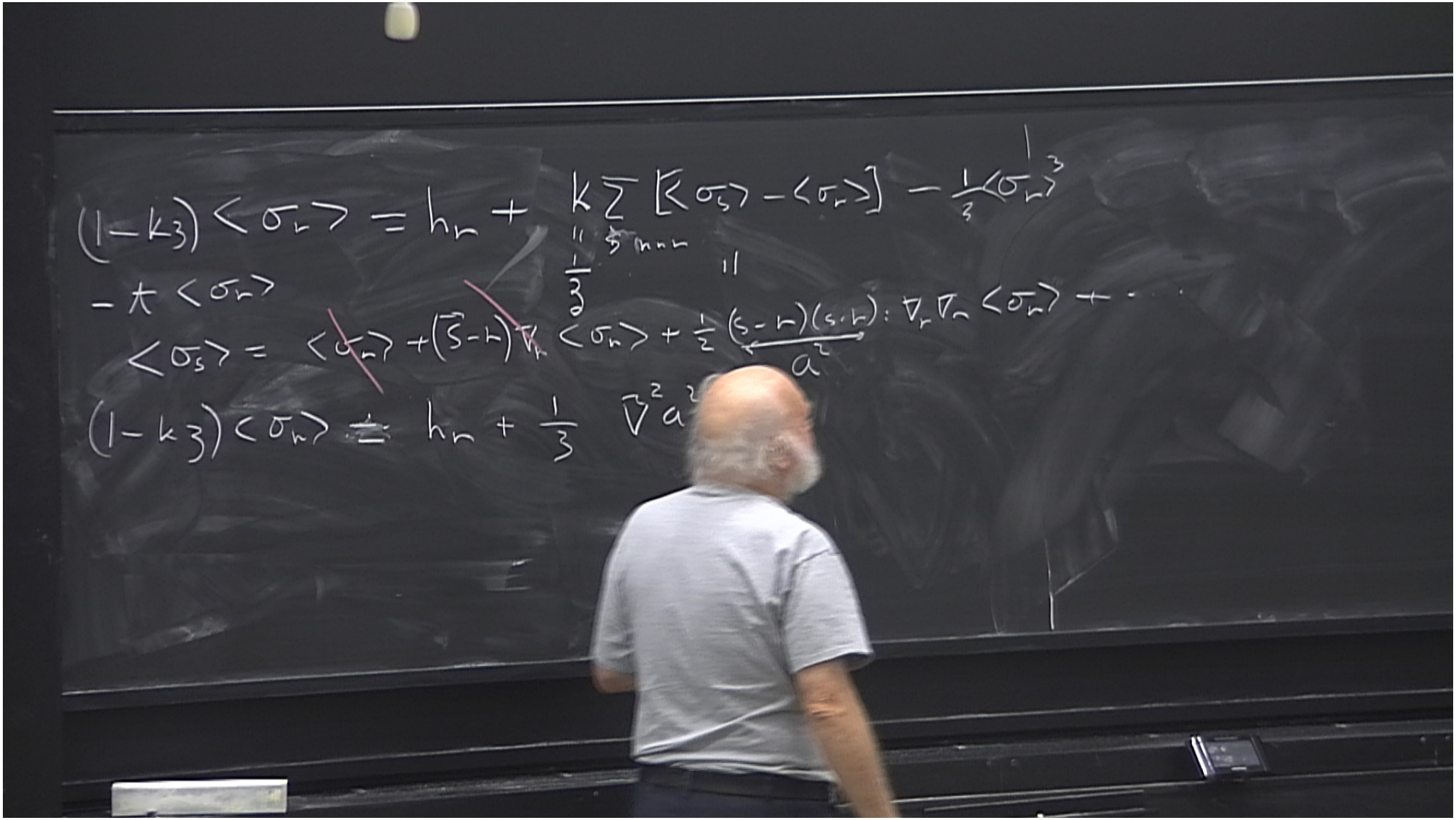

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum_{s\neq n}[\langle\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$-k\langle\sigma_n\rangle$
$\frac{1}{3}$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\nabla_n\langle\sigma_n\rangle + \frac{1}{2}(s-n)(s-n):\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$

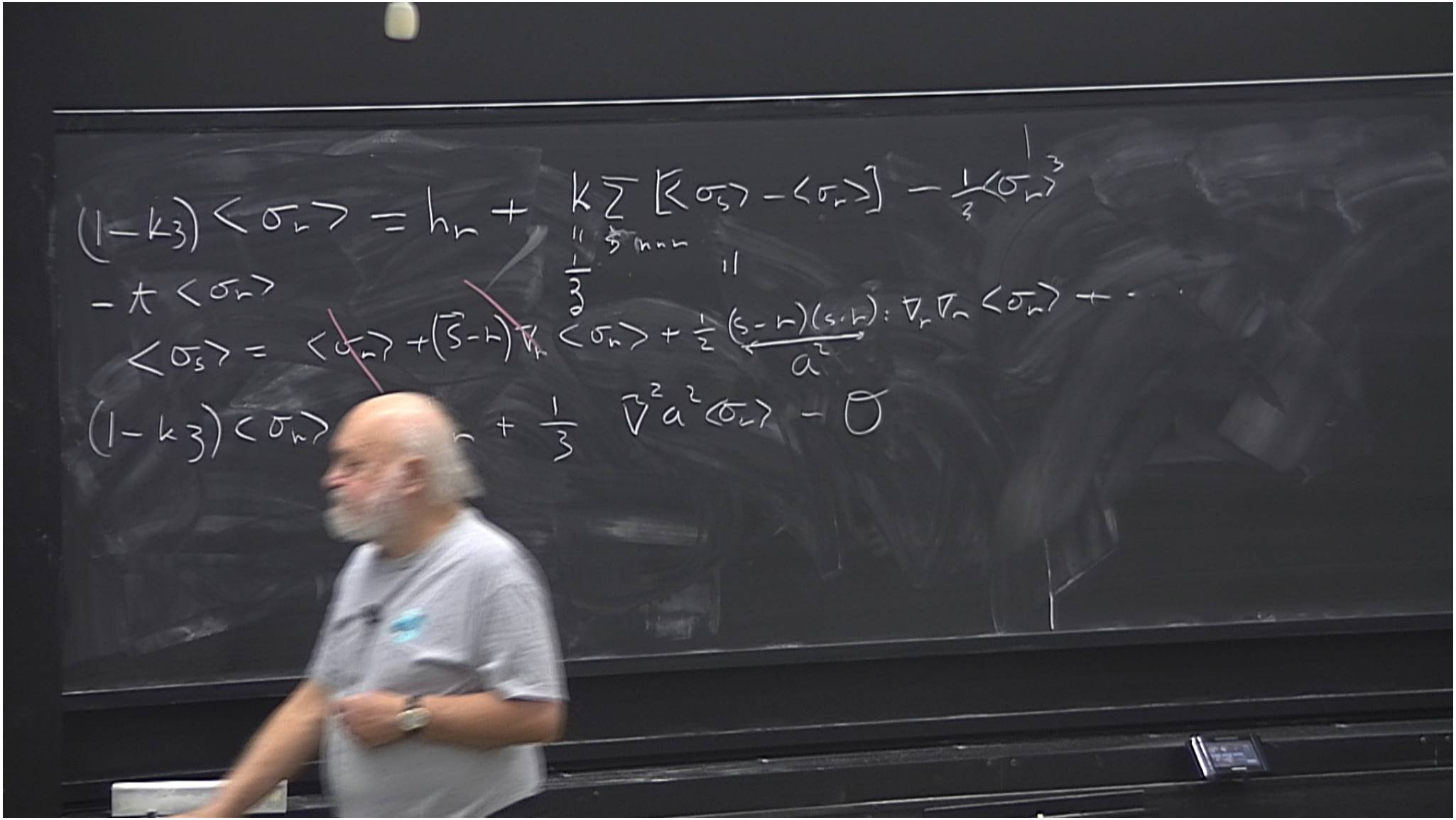

$(1-k\zeta)\langle\sigma_r\rangle = h_r + k\sum_{s\,nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$

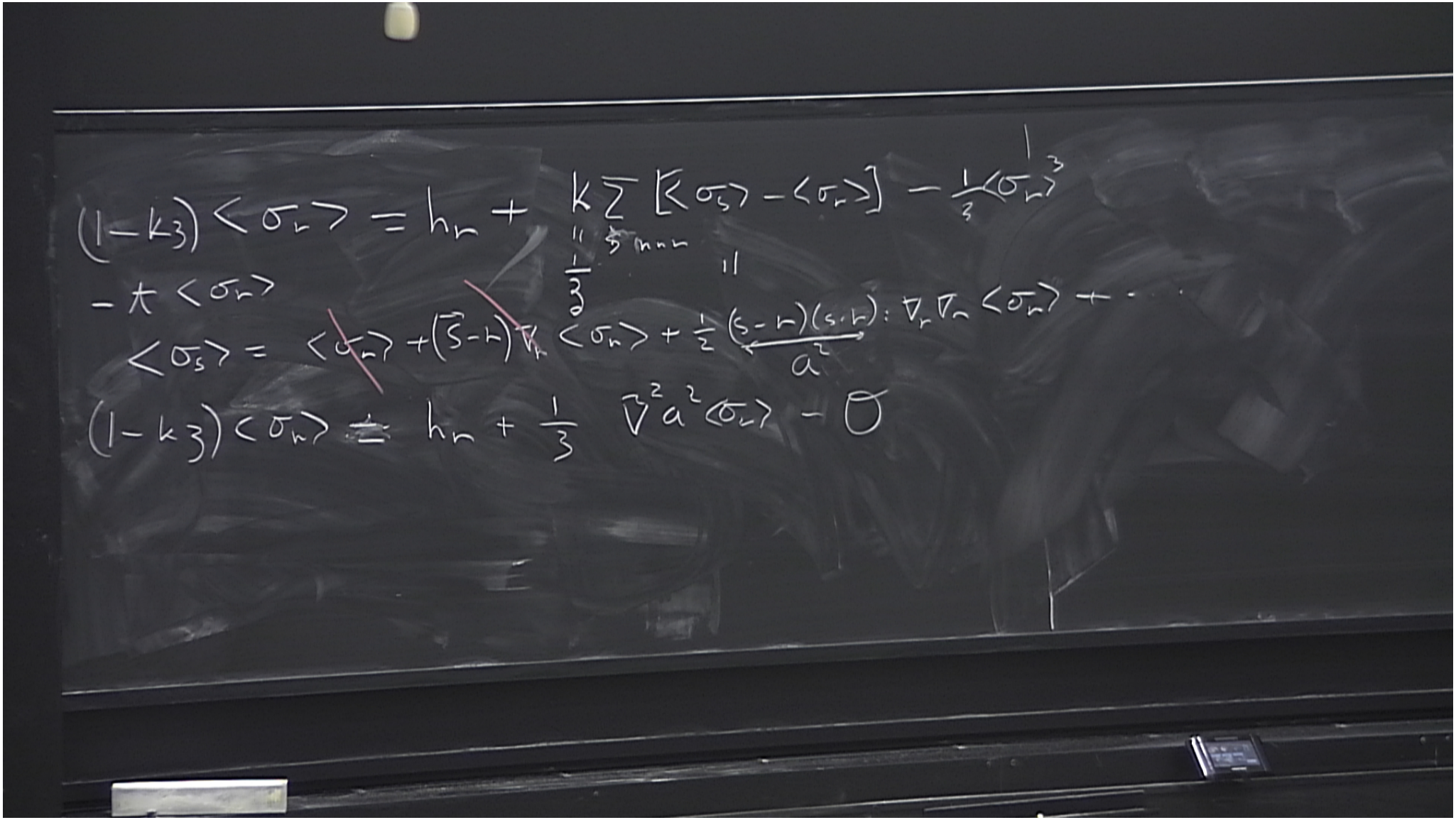

$(1-kz)\langle\sigma_r\rangle = h_r + k\sum_{s\,nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
a^2

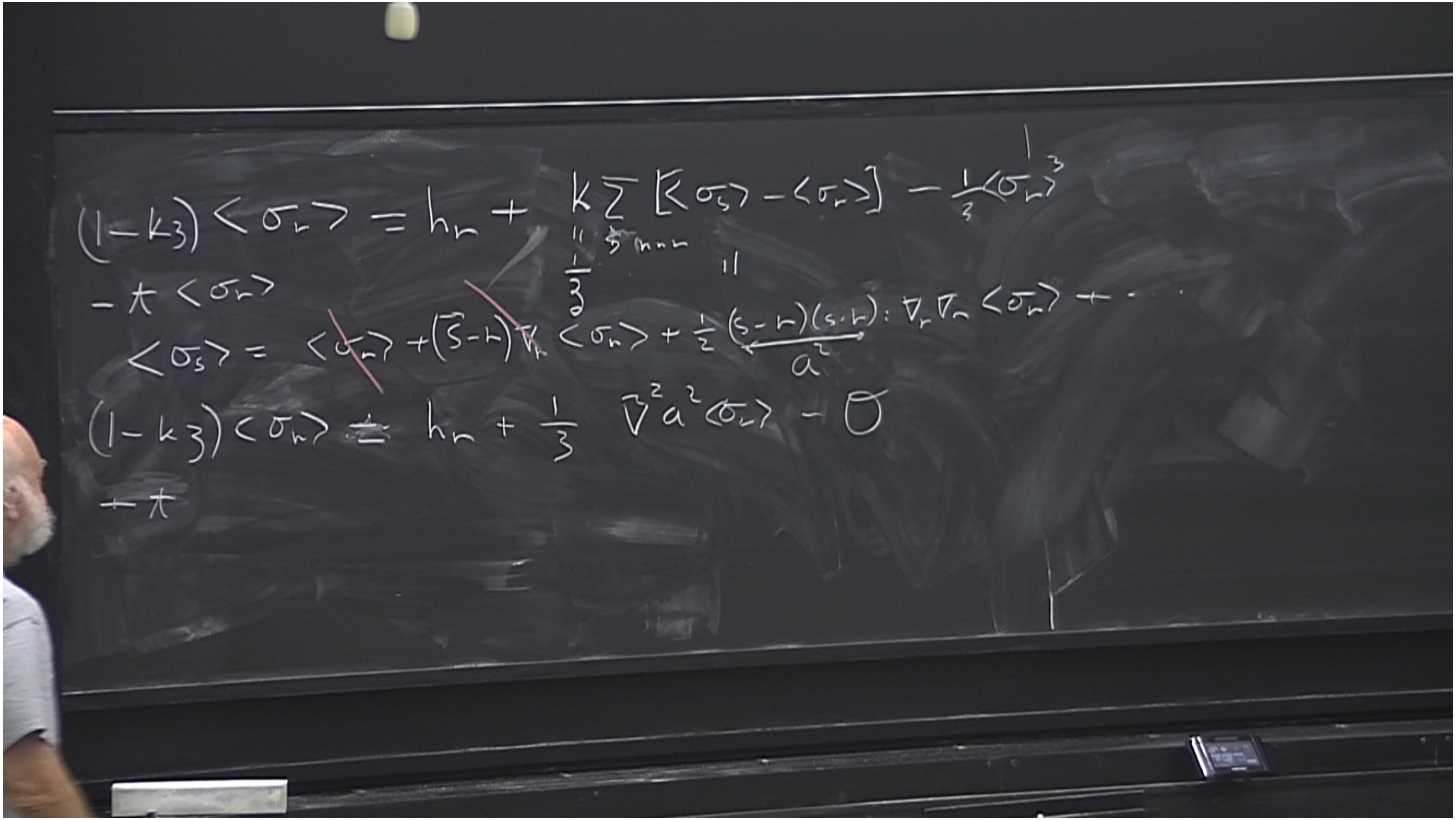

$(1-kz)\langle\sigma_r\rangle = h_r + k\sum_{s\,nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
a^2

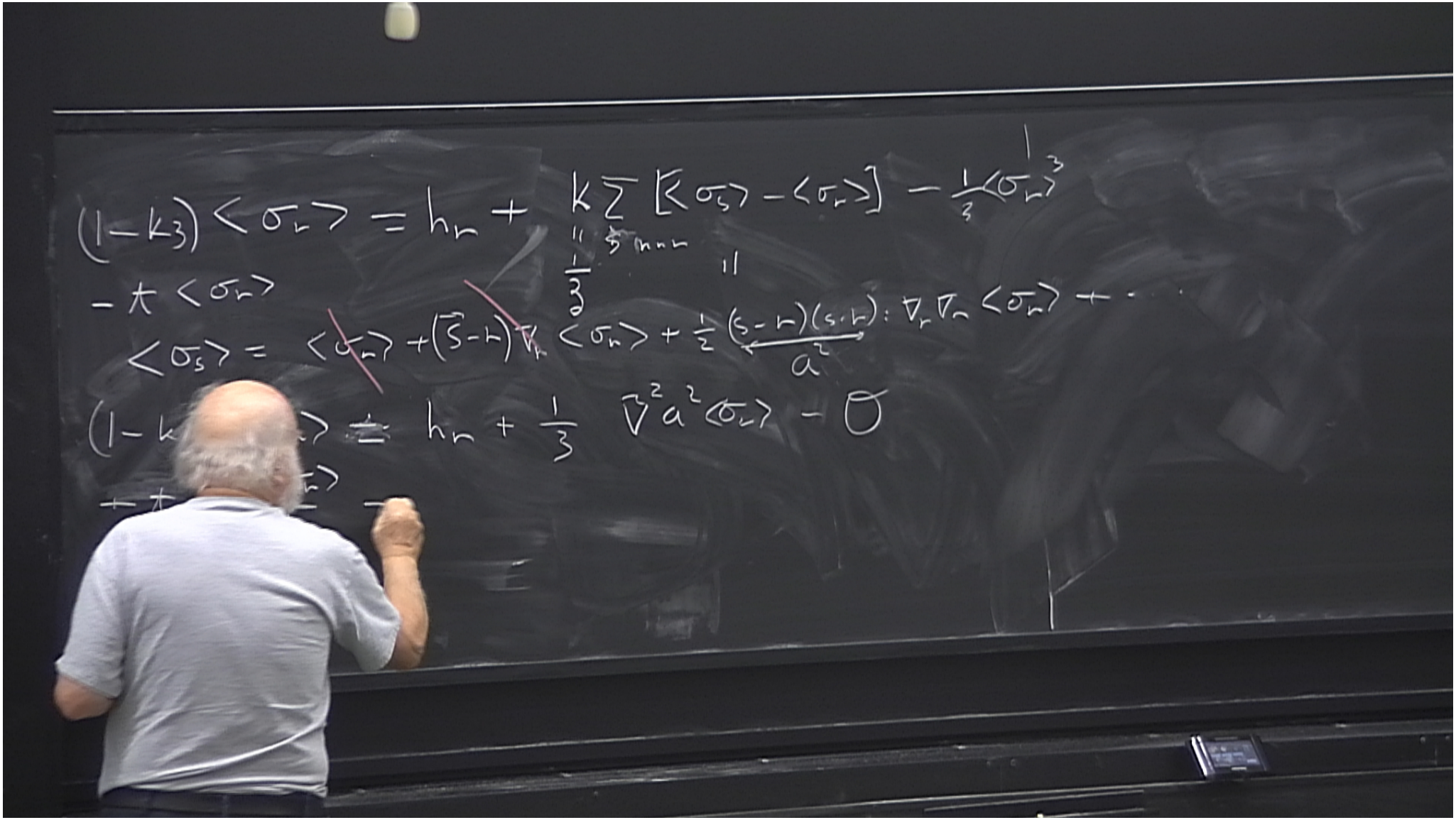

(1-kz) <σr> = hr + k Σ [<σs> - <σr>] - 1/3 <σr>^3
- t <σr>
<σs> = <σr> + (s-r) ∇r <σr> + 1/2 (s-r)(s-r) : ∇r ∇r <σr> + ...
a^2

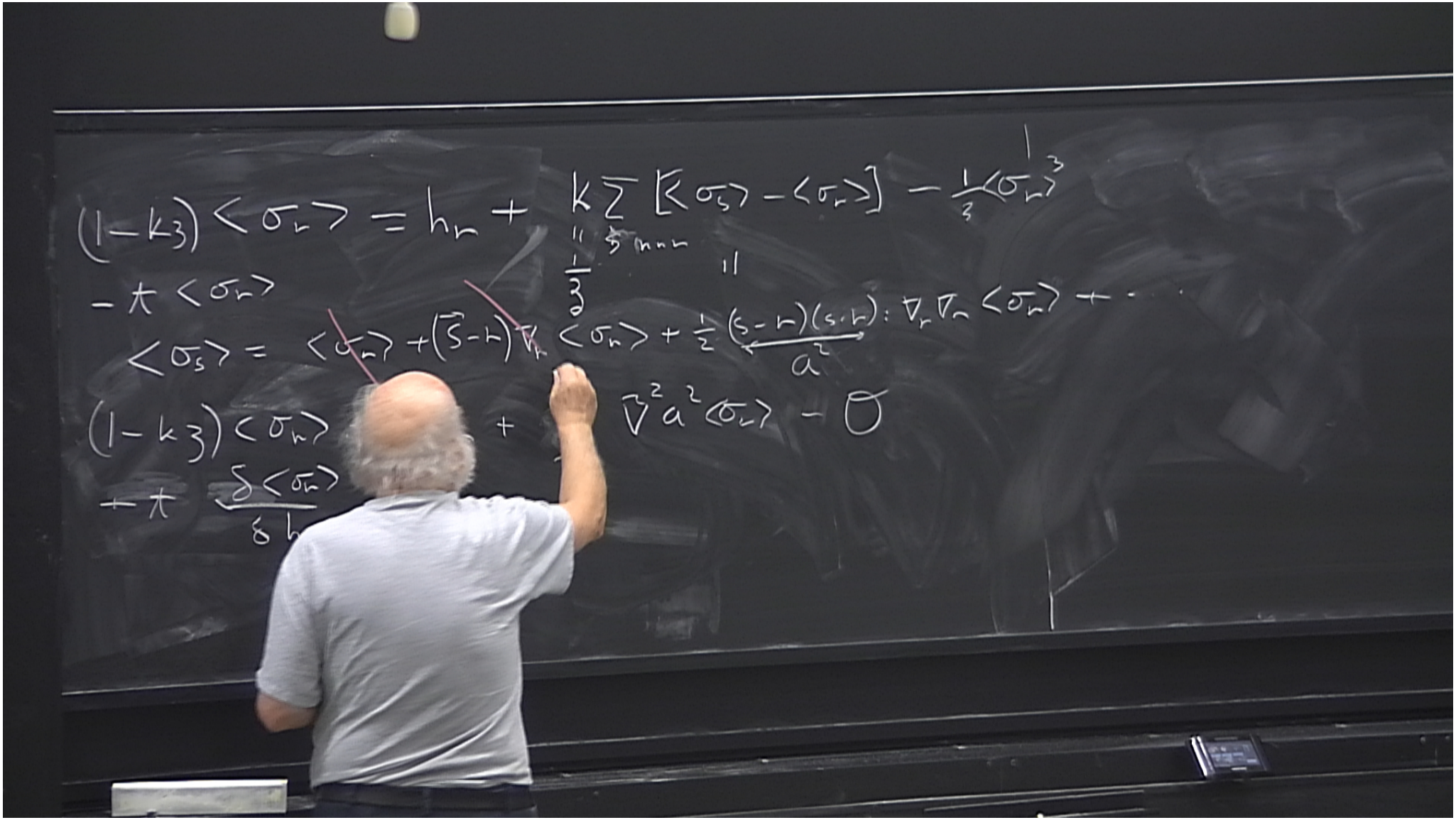

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum[\langle\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$\frac{1}{3}\delta_{mn}$
$-\star\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\nabla_n\langle\sigma_n\rangle + \frac{1}{2}\frac{(s-n)(s-n)}{a^2}:\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$(1-k_3)\langle\sigma_n\rangle \doteq h_n + \frac{1}{3}\nabla^2 a^2$

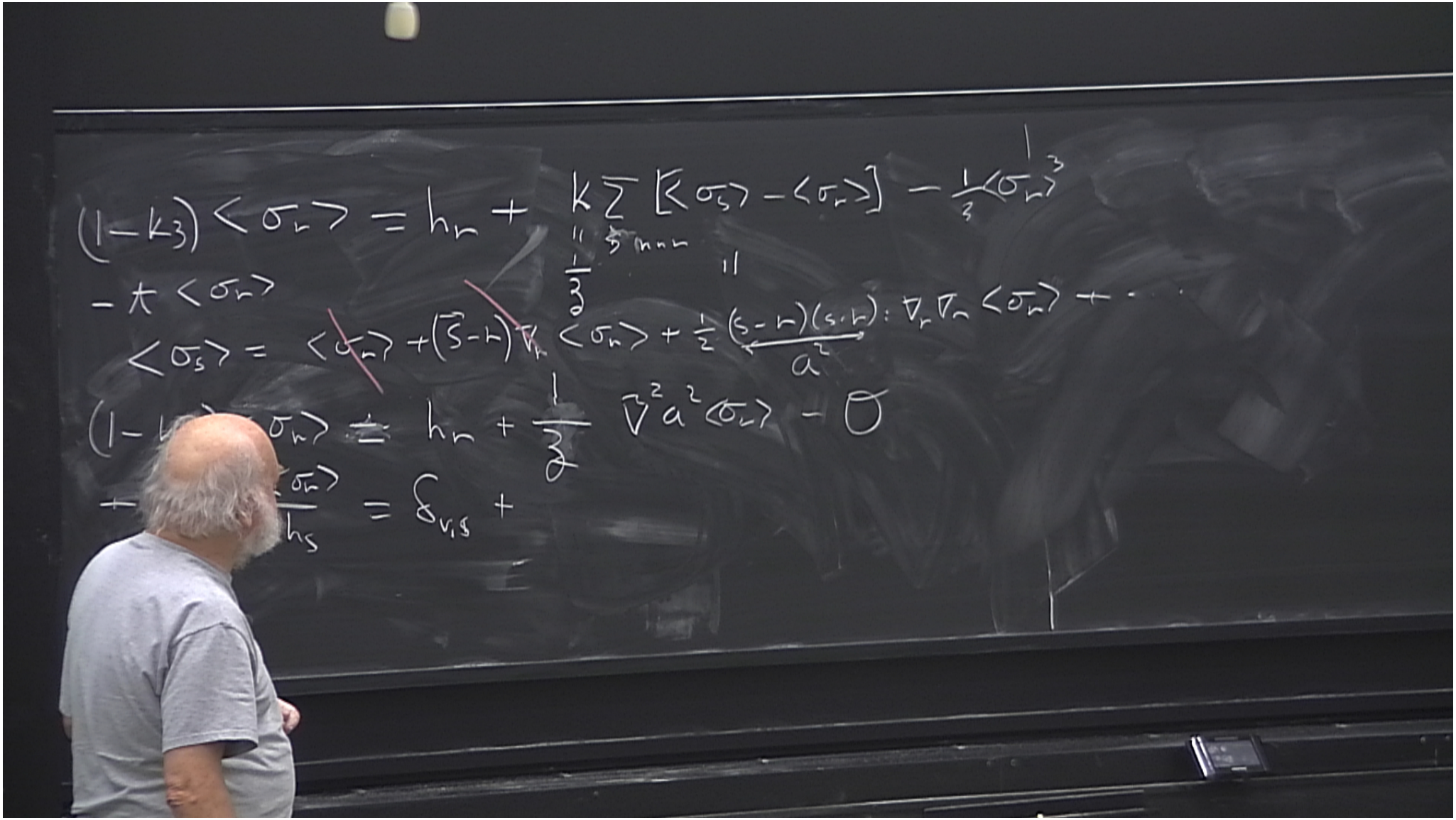

(1-kz) <σr> = hr + k Σ [<σs> - <σr>] - 1/3 <σr>^3
- t <σr>
<σs> = <σr> + (s-r) ∇r <σr> + 1/2 (s-r)(s-r) : ∇r ∇r <σr> + ...
a^2
(1-kz) <σr> + 1/3 ∇^2 a^2 <σr> - O

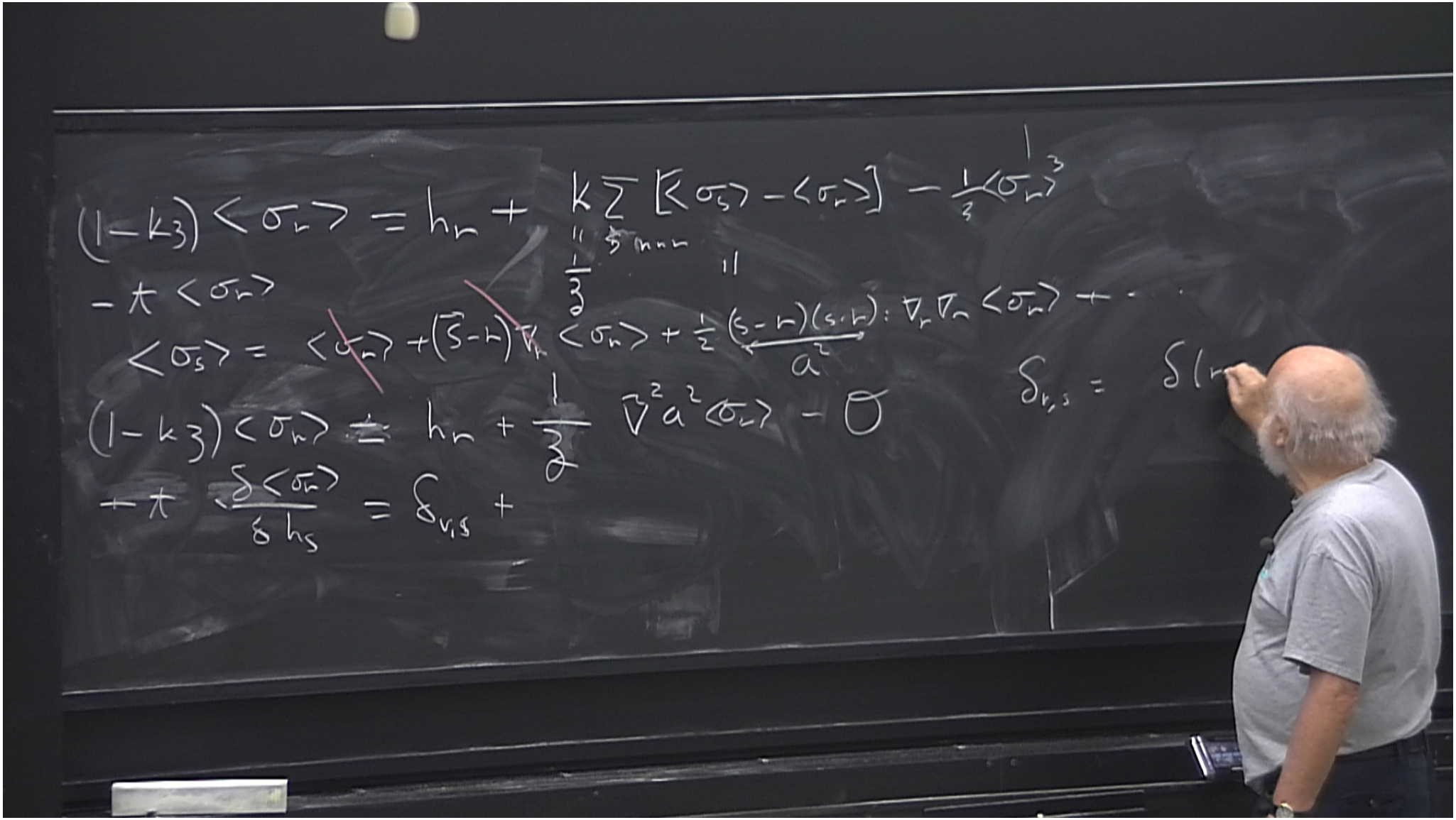

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum[K\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$\frac{1}{3}\delta_{mnn}$
$-k\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\nabla_n\langle\sigma_n\rangle + \frac{1}{2}\frac{(s-n)(s-n)}{a^2}:\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{1}{3}\nabla^2 a^2\langle\sigma_n\rangle - \sigma$

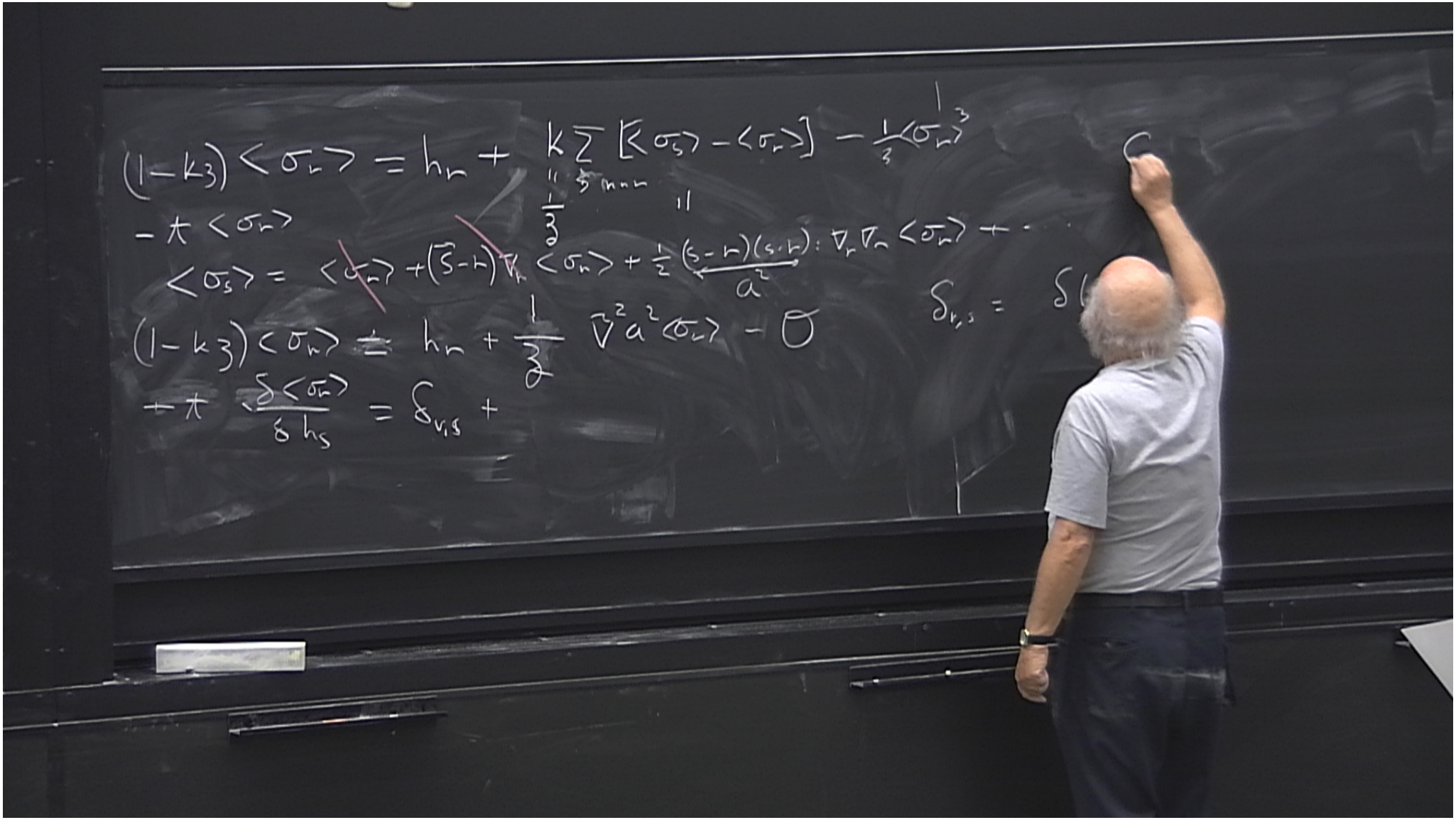

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum[K\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$\frac{1}{3}\delta_{nnn}$
$-\nabla\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\nabla_n\langle\sigma_n\rangle + \frac{1}{2}\frac{(s-n)(s-n)}{a^2}:\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{1}{3}\nabla^2 a^2\langle\sigma_n\rangle - \sigma$
$-\nabla$

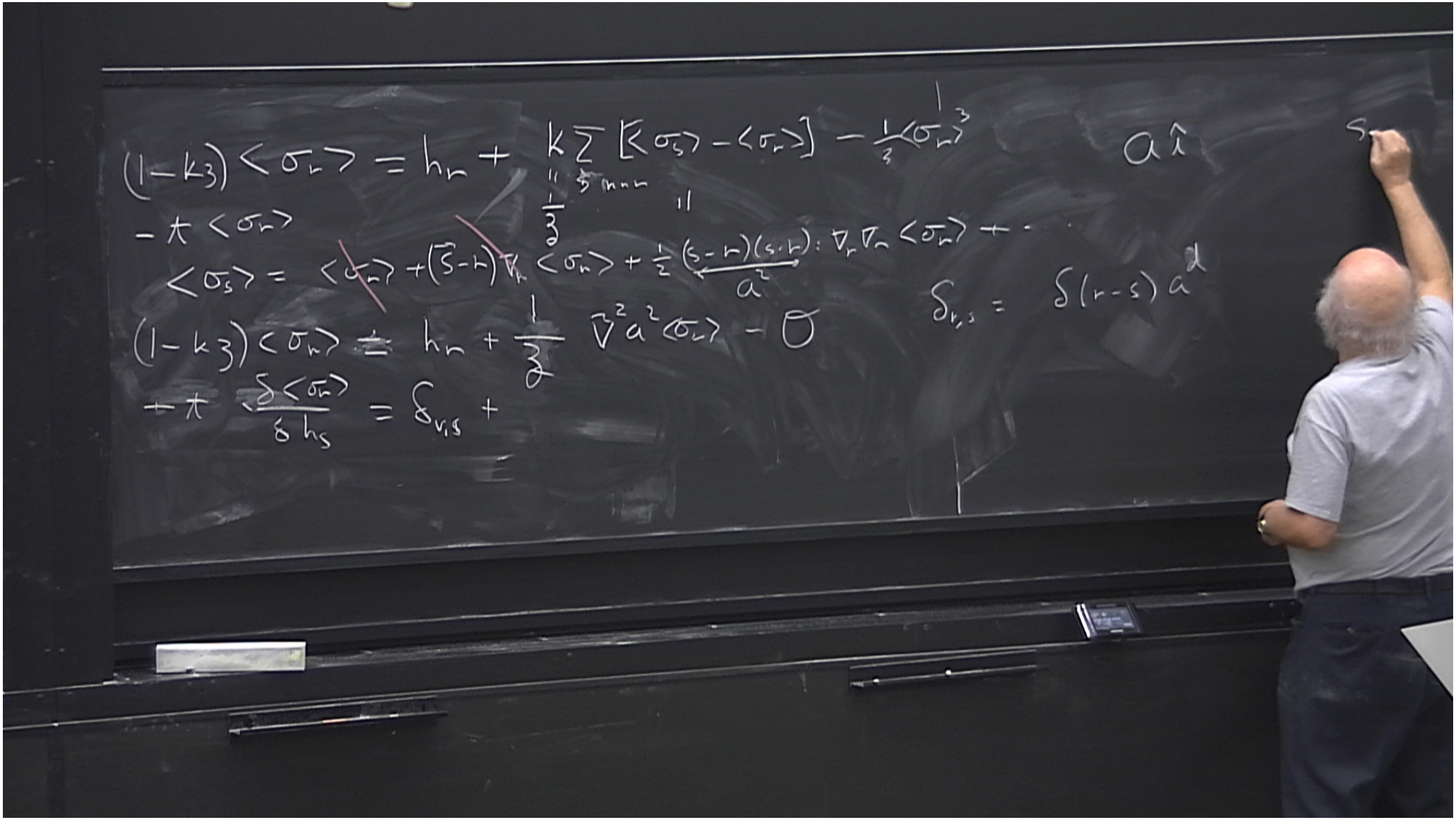

(1-kz) <σr> = hr + k Σ [<σs> - <σr>] - 1/3 <σr>^3
- t <σr>
<σs> = <σr> + (s-r) ∇r <σr> + 1/2 (s-r)(s-r) : ∇r ∇r <σr> + ...
a^2
hr + 1/3 ∇^2 a^2 <σr> - O

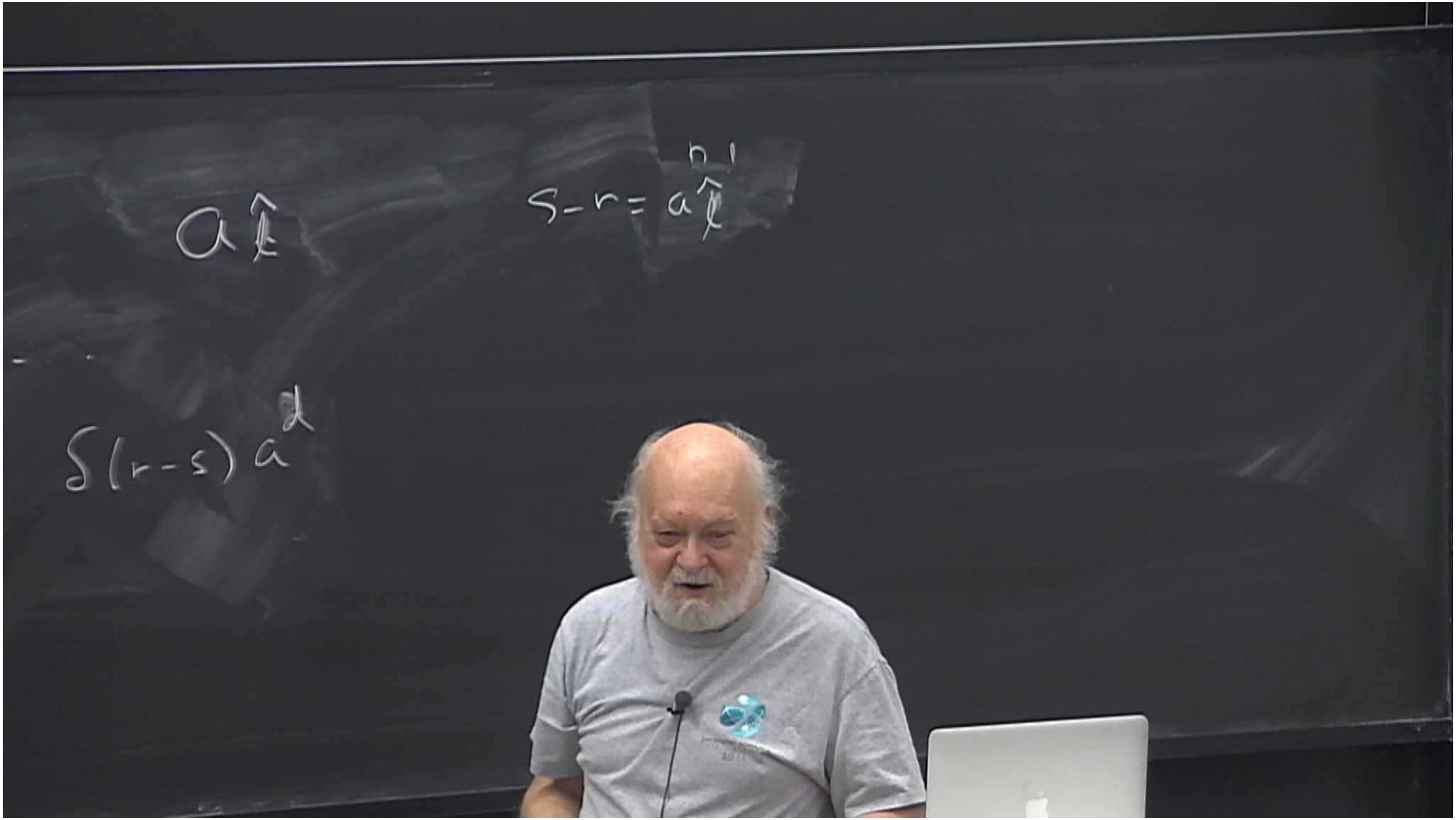

(1-kz) <σr> = hr + k Σ [<σs> - <σr>] - 1/3 <σr>^3
- t <σr>
<σs> = <σr> + (s-r) ∇r <σr> + 1/2 (s-r)(s-r) : ∇r ∇r <σr> + ...
a^2
(1-kz) <σr> + ∇^2 a^2 <σr> - O
+ t δ<σr>/δh

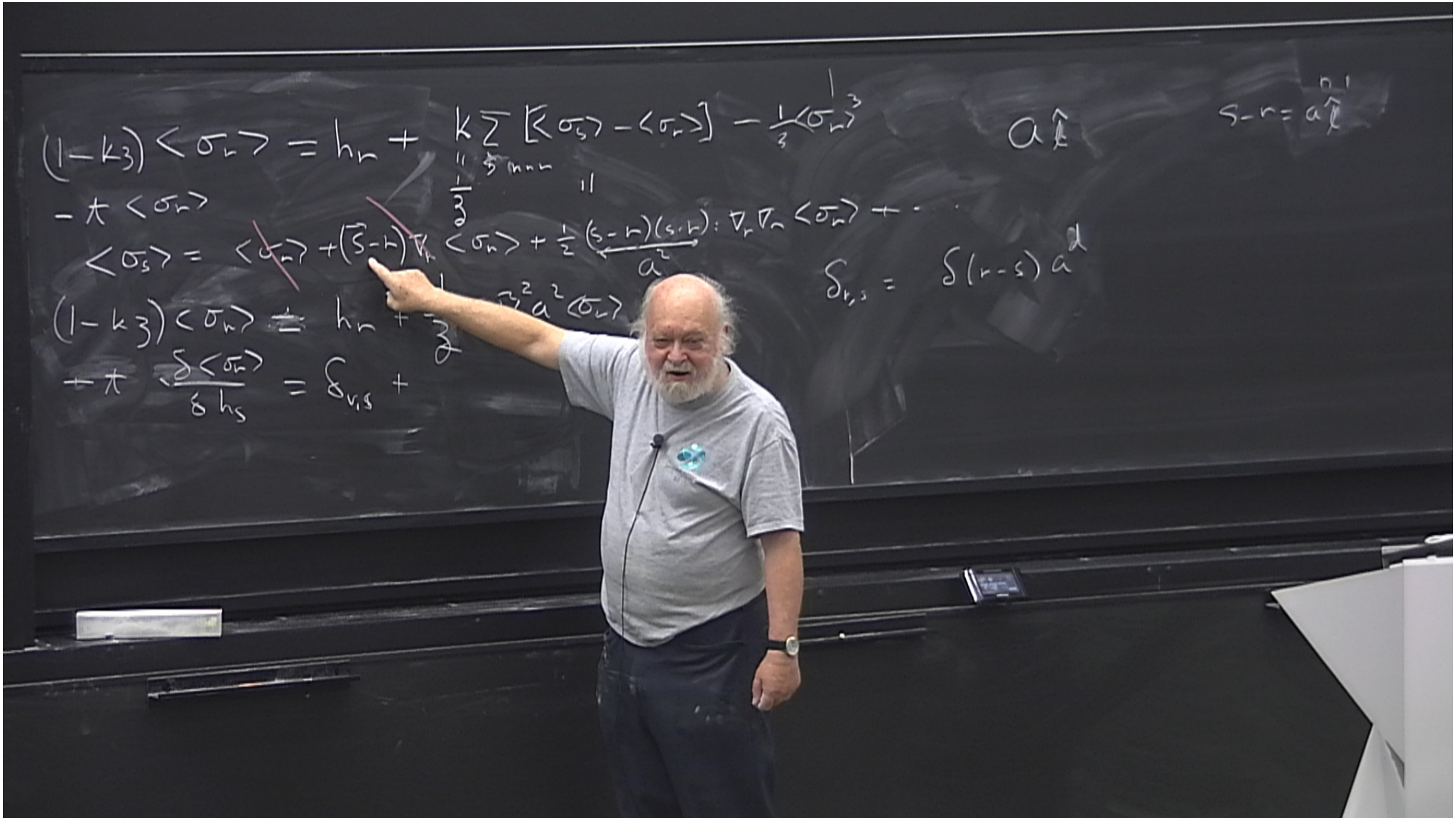

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum[\langle\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$\frac{1}{3}\delta_{mnn}$
$-\dagger\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\nabla_n\langle\sigma_n\rangle + \frac{1}{2}\frac{(s-n)(s-n)}{a^2}:\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{1}{3}\nabla^2 a^2\langle\sigma_n\rangle - \Theta$
$+ \frac{\langle\sigma_n\rangle}{h_s} = \xi_{vis} +$

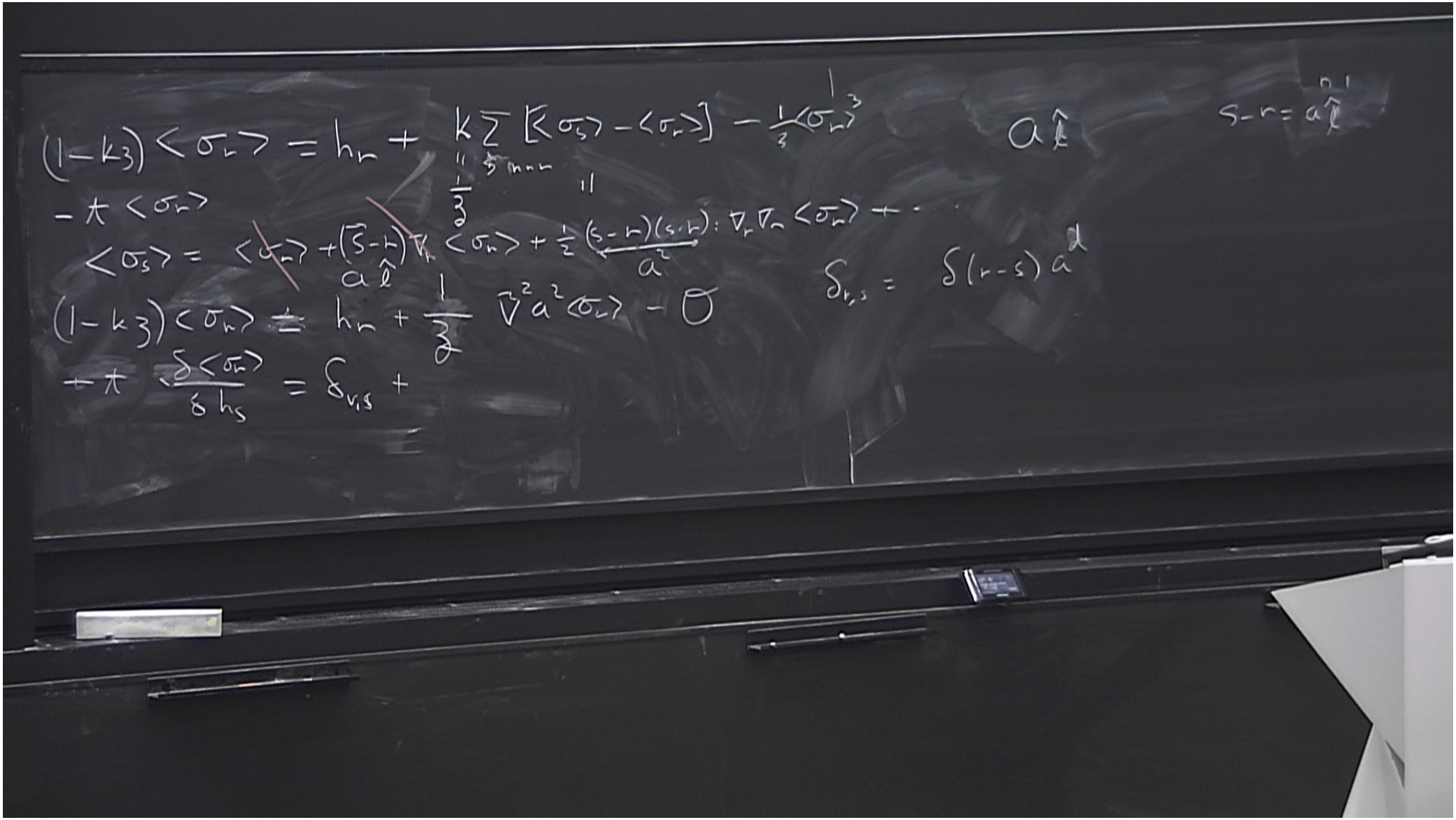

$(1-kz)\langle\sigma_r\rangle = h_r + k\sum_{s\ nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
a^2
$(1-kz)\langle\sigma_r\rangle = h_r + \frac{1}{z}\nabla^2 a^2\langle\sigma_r\rangle - \mathcal{O}$
$+t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} +$
$\delta_{r,s} = \delta(r$

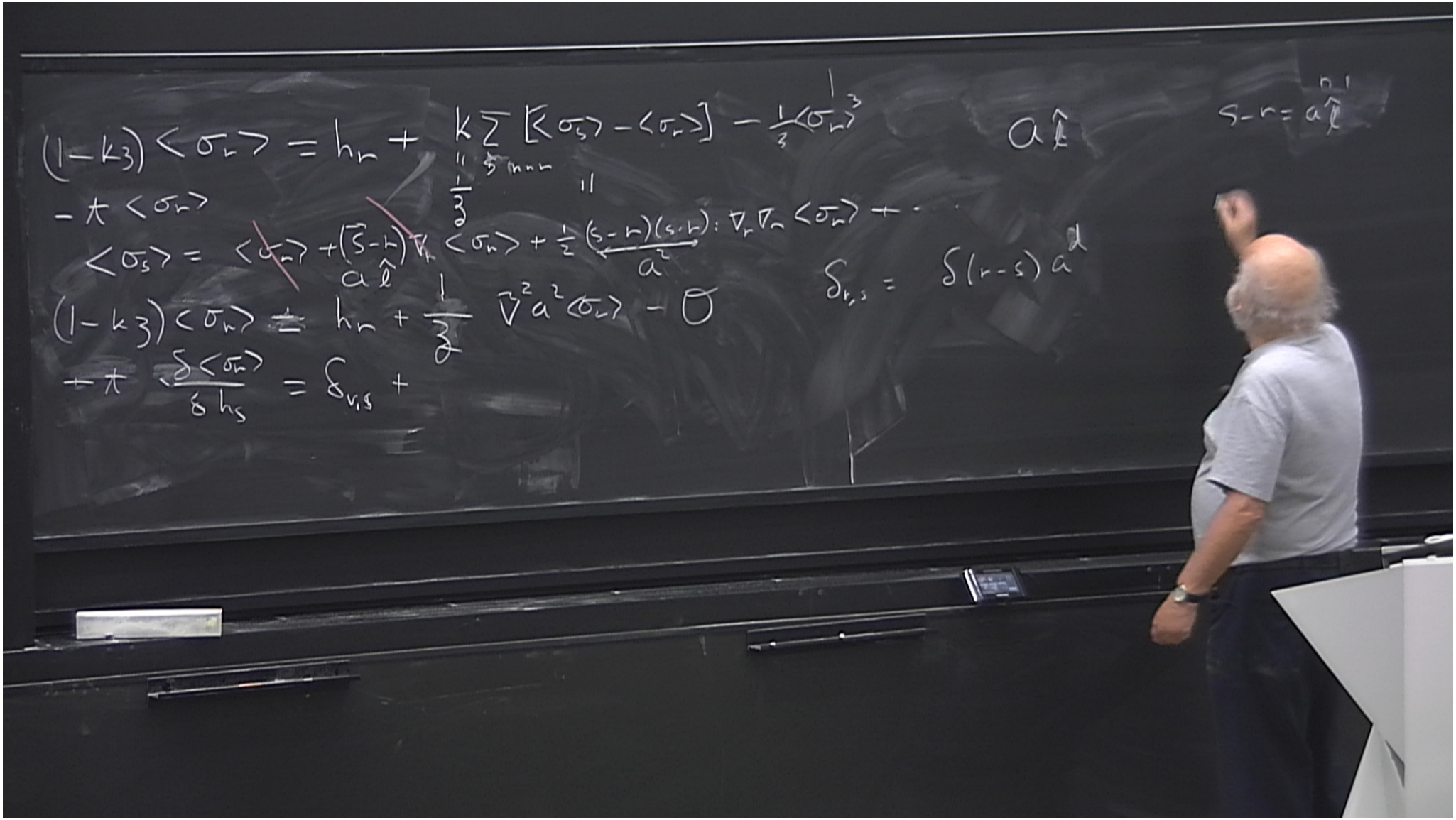

$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{k}{3}\sum_{mnn}[\langle\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$\frac{1}{3}$
$-+\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\nabla_n\langle\sigma_n\rangle + \frac{1}{2}\frac{(s-n)(s-n)}{a^2}:\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{1}{3}\nabla^2 a^2\langle\sigma_n\rangle - \Theta$
$+-\frac{\delta\langle\sigma_n\rangle}{\delta h_s} = \delta_{n,s} +$
$\delta_{n,s} = \delta($

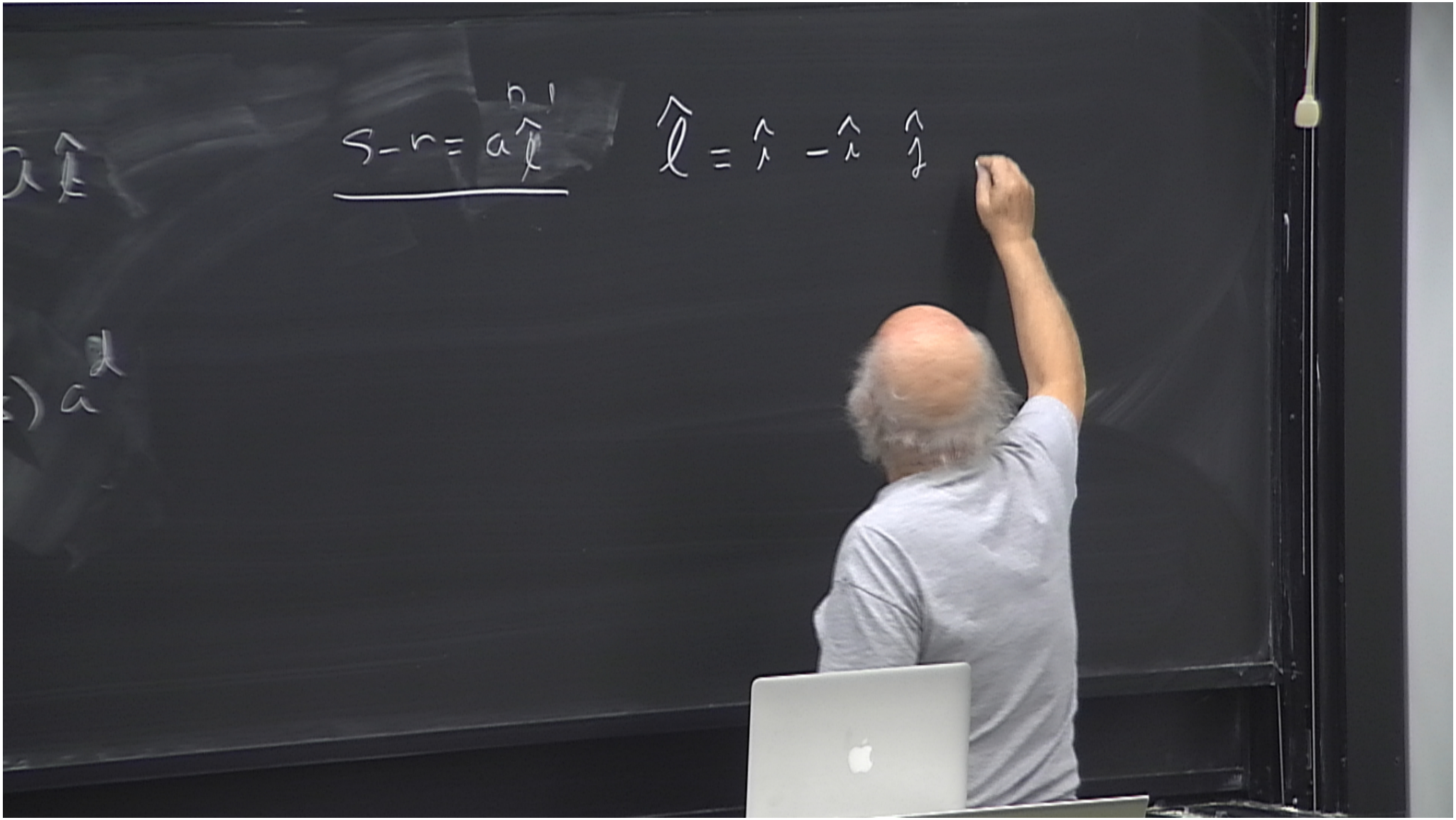

$(1-kz)\langle\sigma_r\rangle = h_r + k\sum_{s\,n\,n\,r}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$a\hat{i}$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}\frac{(s-r)(s-r)}{a^2}:\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$\delta_{r,s} = \delta(r-s)\,a^d$
$(1-kz)\langle\sigma_r\rangle = h_r + \frac{1}{z}\nabla^2 a^2\langle\sigma_r\rangle - \mathcal{O}$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} +$

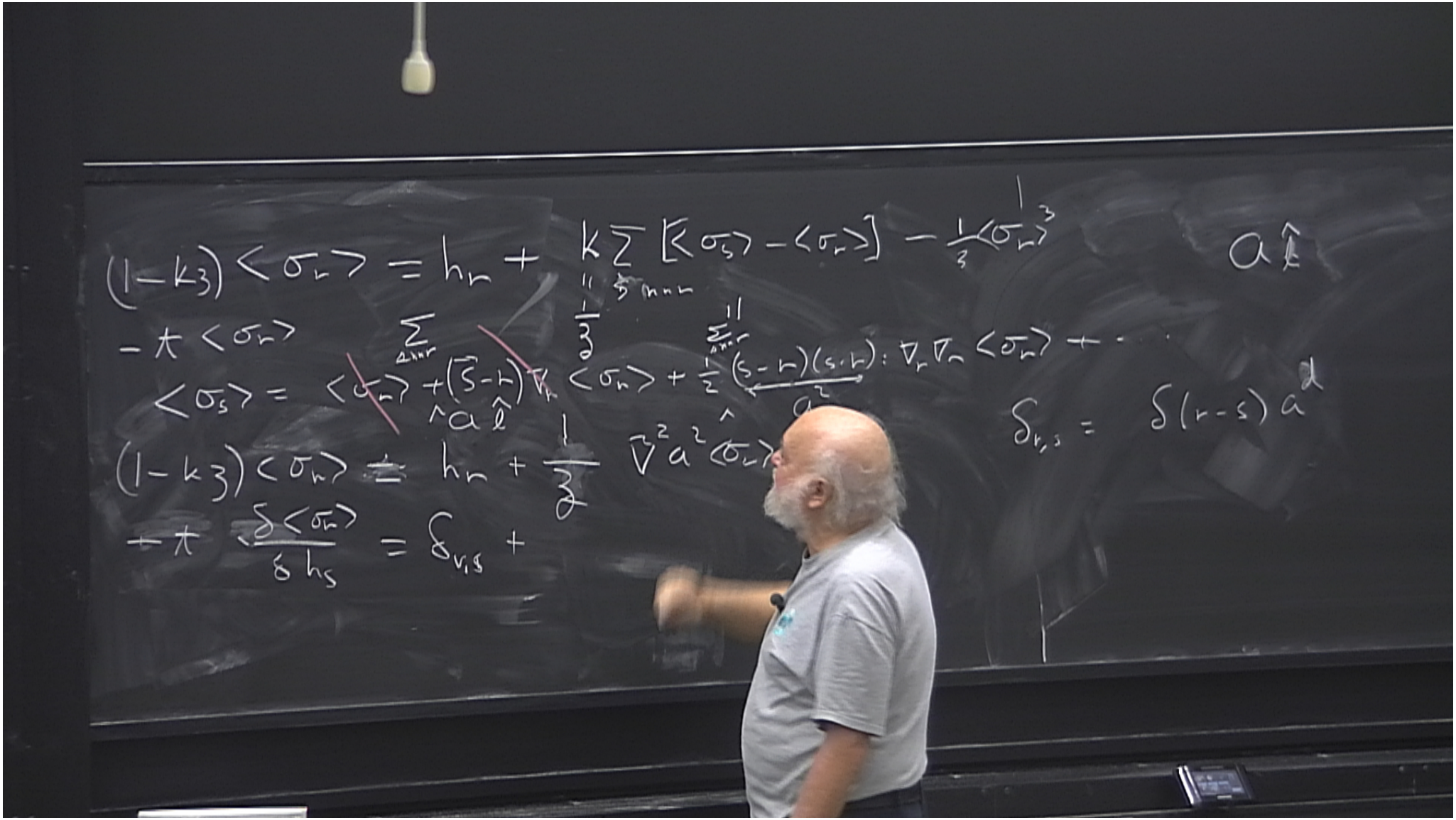

$a\hat{\ell}$
$s-r = a^n \hat{\ell}^1$
$\delta(r-s)\, a^d$

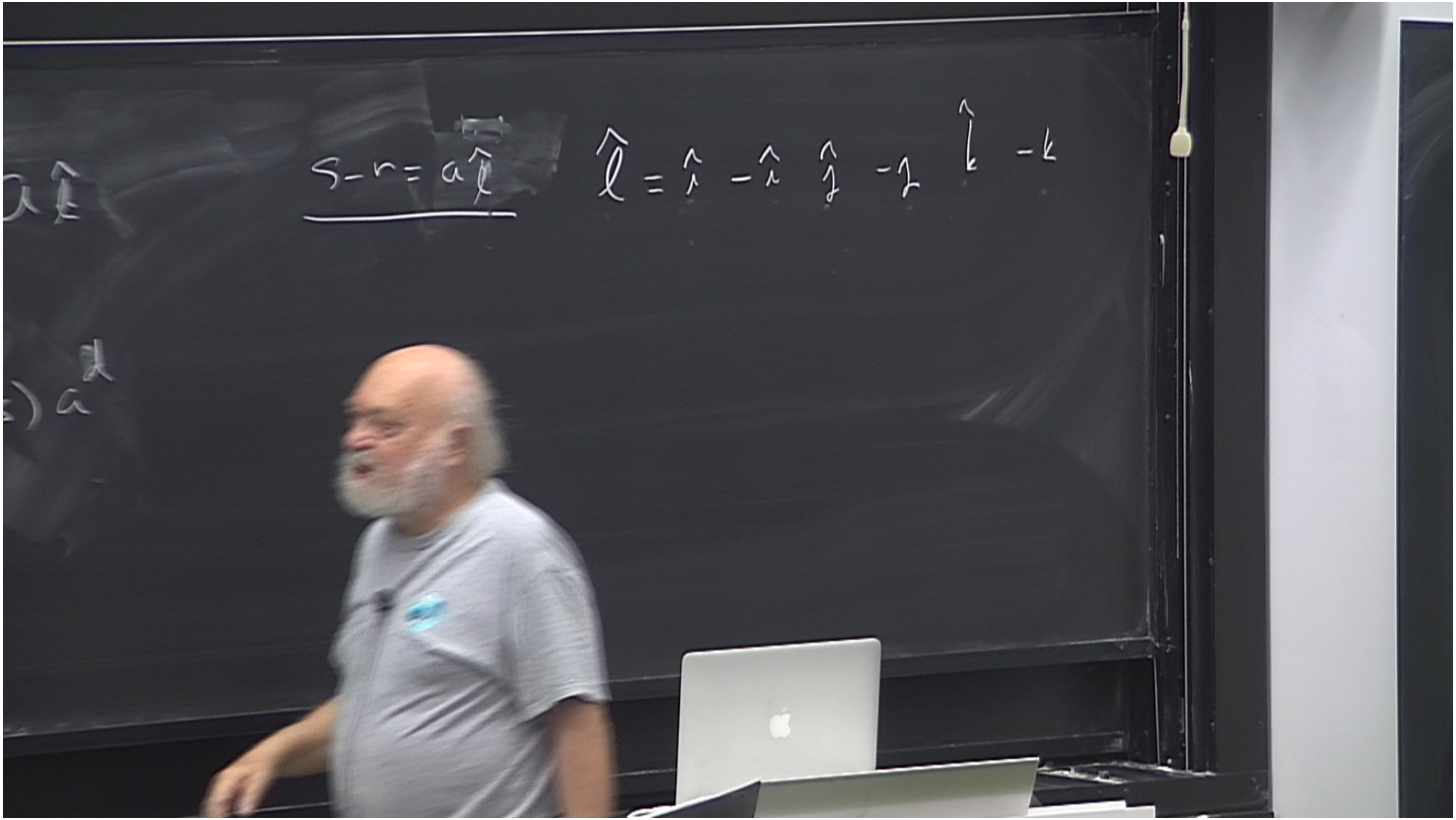

$(1-k\beta)\langle\sigma_r\rangle = h_r + k\sum_s [\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\nabla_r\langle\sigma_r\rangle + \frac{1}{2}\frac{(s-r)(s-r)}{a^2}:\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$(1-k\beta)\langle\sigma_r\rangle = h_r + \frac{1}{3}\sigma^2 a^2\langle\sigma_r\rangle$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} +$
$\delta_{r,s} = \delta(r-s)a^d$
$s-r = a\hat{\ell}$

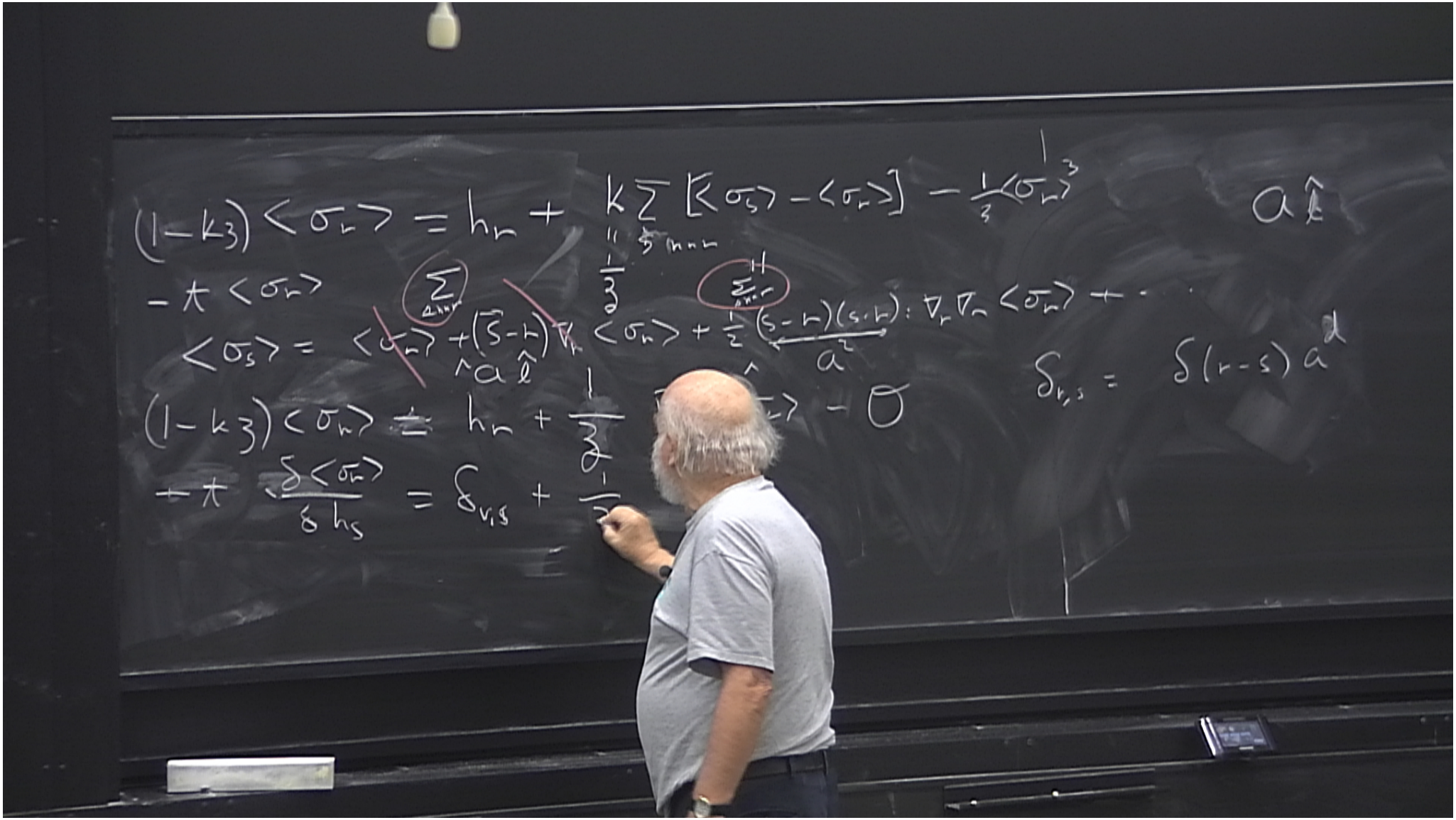

$(1-k_3)\langle\sigma_r\rangle = h_r + k\sum_{s\neq r}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$a\hat{\ell}$
$s-r = a\hat{\ell}$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$a\hat{\ell}$
$\delta_{r,s} = \delta(r-s)a^d$
$(1-k_3)\langle\sigma_r\rangle = h_r + \frac{1}{2}\nabla^2 a^2\langle\sigma_r\rangle - \sigma$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} +$

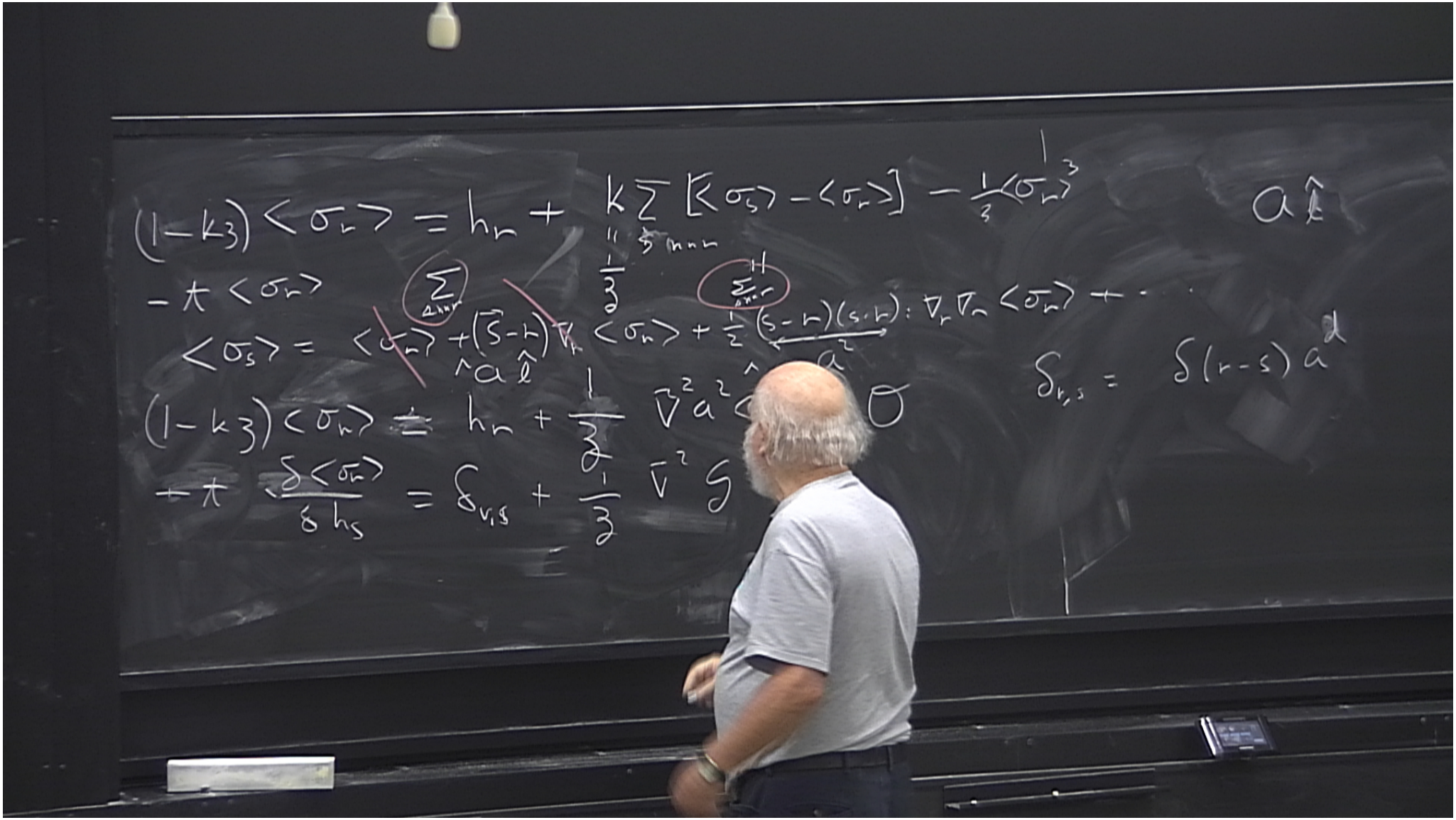

$(1-k\beta)\langle\sigma_r\rangle = h_r + k\sum_s [K_{rs}\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$a\hat{\ell}$
$(1-k\beta)\langle\sigma_r\rangle = h_r + \frac{1}{2}\nabla^2 a^2\langle\sigma_r\rangle - \sigma$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{rs} +$
$s-r = a\hat{\ell}$
$\delta_{rs} = \delta(r-s)a^d$

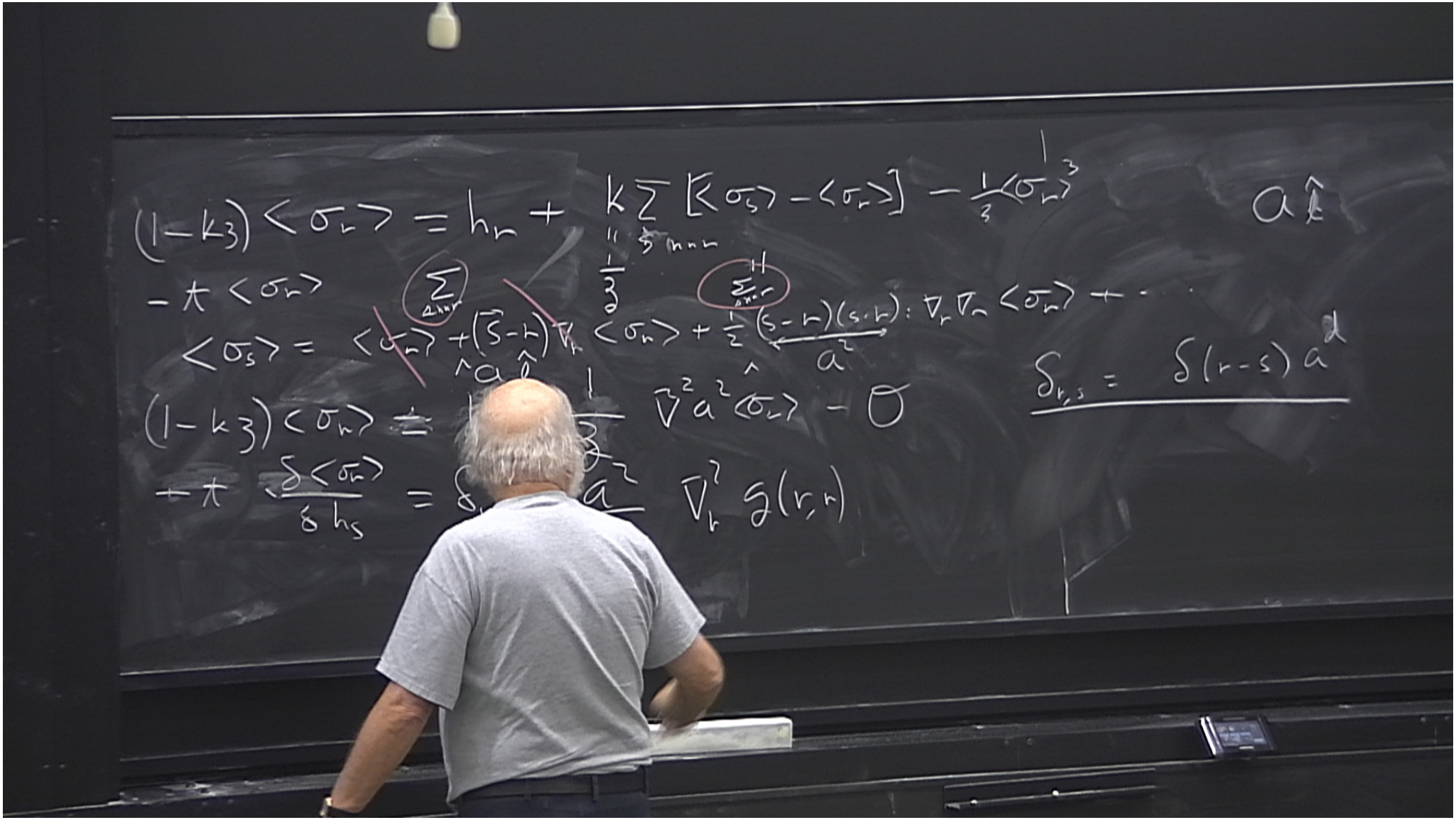

$s - r = a\hat{n}'$
$\hat{n} = \hat{x} - \hat{z}$

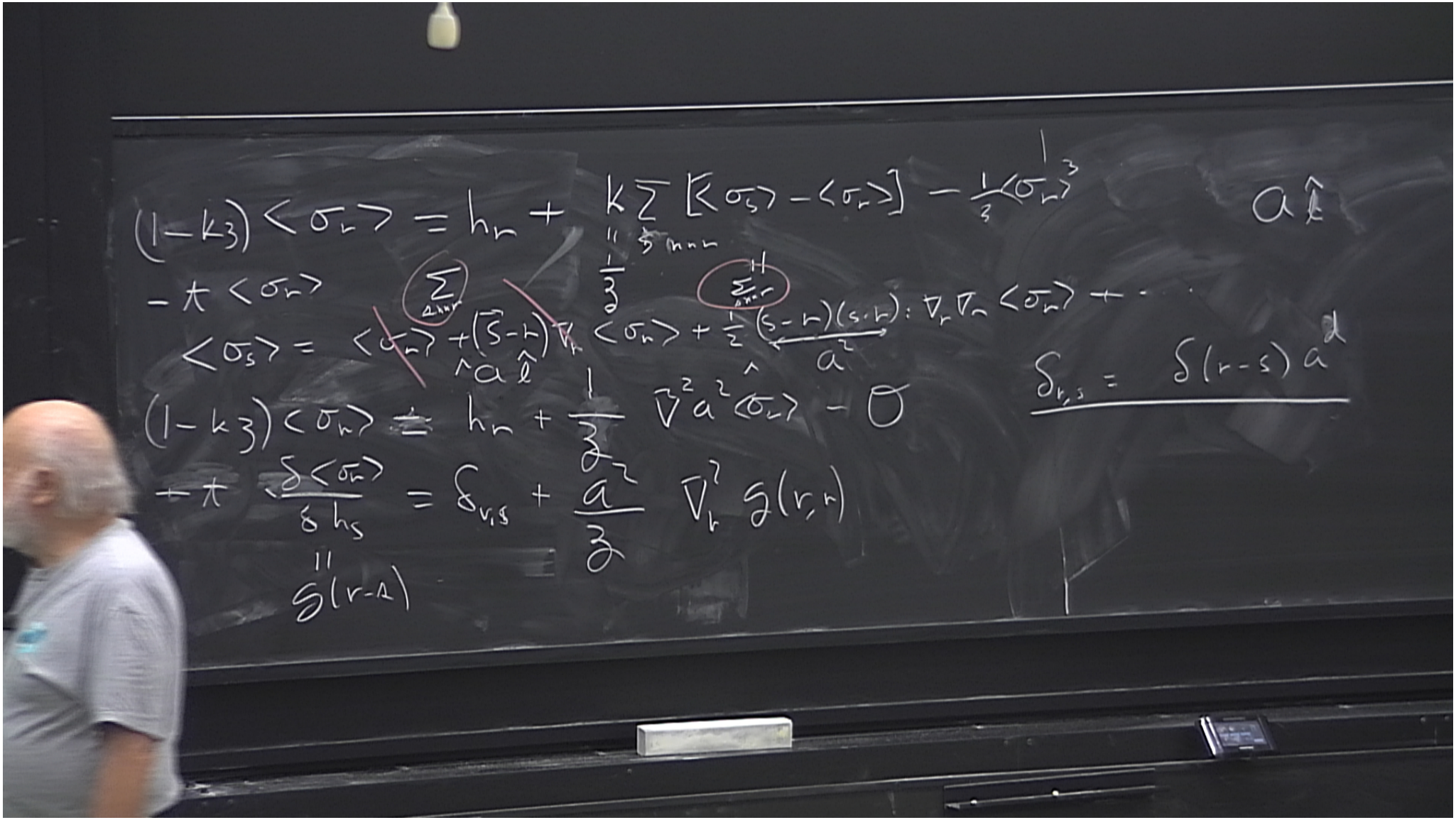

$(1-k\beta)\langle\sigma_r\rangle = h_r + k\sum_{s\neq r}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\nabla_r\langle\sigma_r\rangle + \frac{1}{2}\sum_{\alpha\beta=1}^{3}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$\delta_{r,s} = \delta(r-s)\,a^d$
$(1-k\beta)\langle\sigma_r\rangle = h_r + \frac{1}{3}\nabla^2 a^2\langle\sigma_r\rangle$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \chi_{r,s} +$

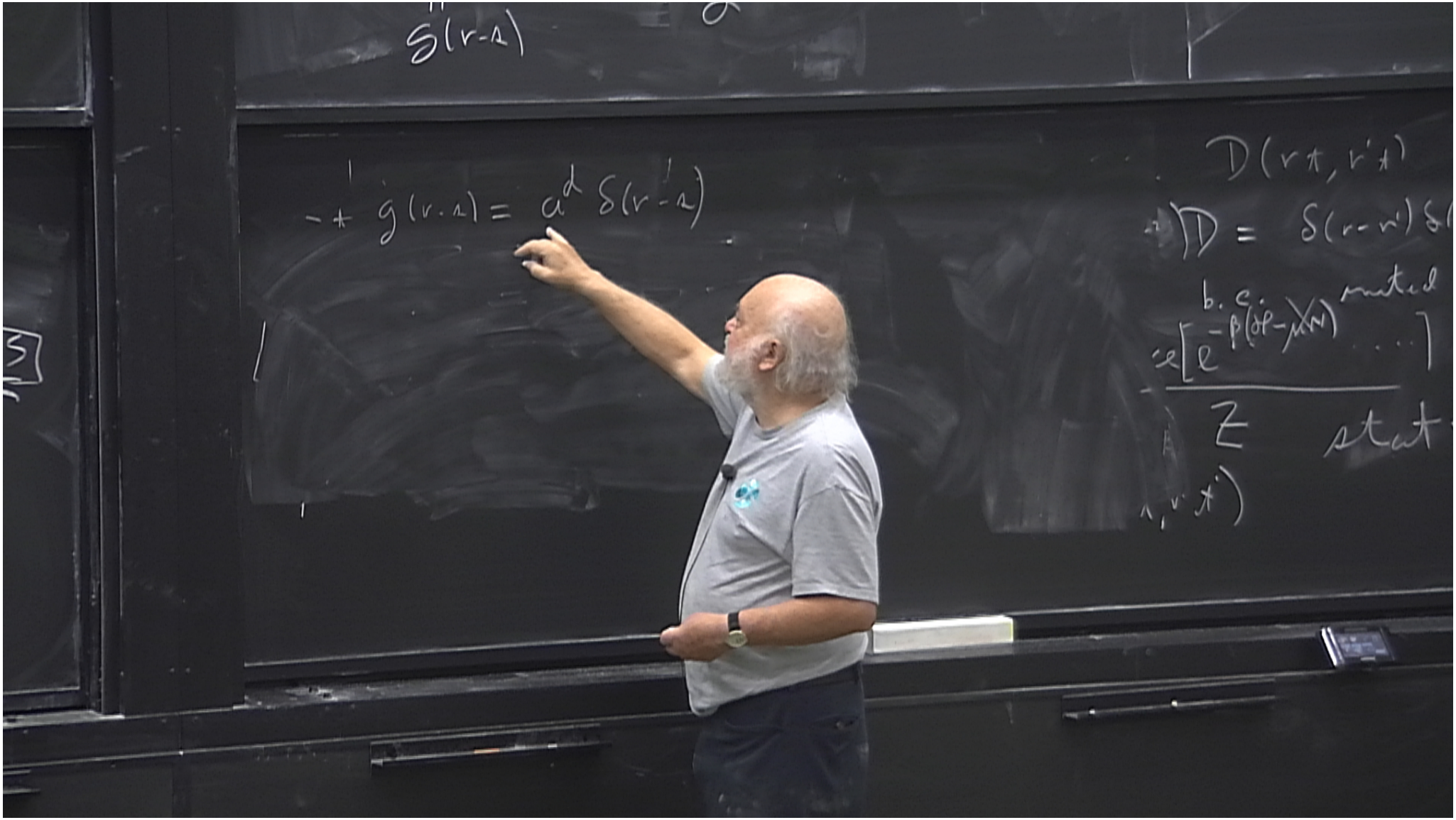

$\vec{s} - \vec{r} = a\hat{\ell}$
$\hat{\ell} = \hat{\imath} - \hat{\imath}\,\hat{\jmath} - \hat{\jmath}\,\hat{k} - \hat{k}$

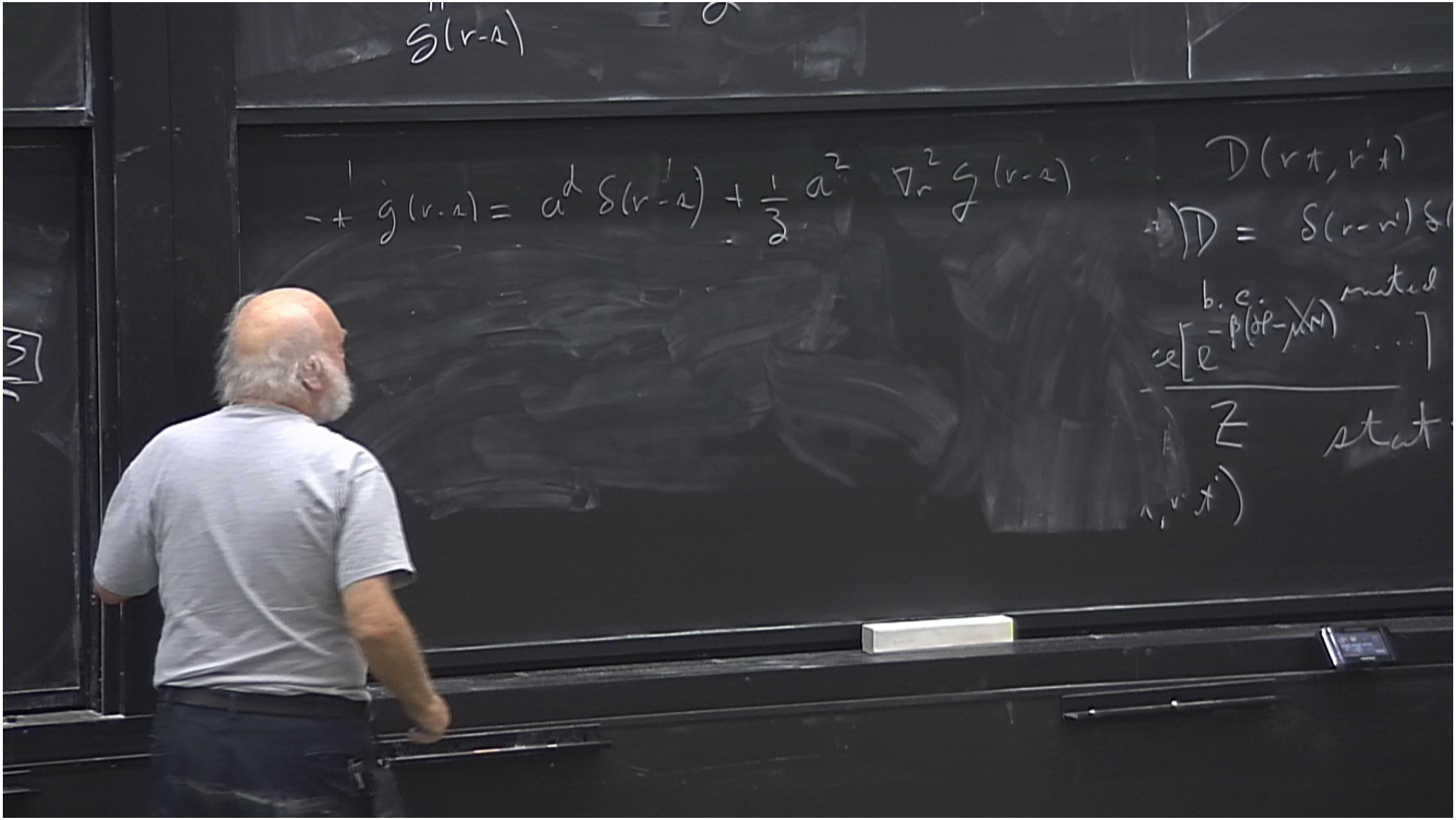

$(1-k_3)\langle\sigma_n\rangle = h_n + k\sum_{s\neq n}[\langle\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$-t\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\cdot\nabla_n\langle\sigma_n\rangle + \frac{1}{2}\frac{(s-n)(s-n)}{a^2}:\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$\delta_{n,s} = \delta(n-s)$
$(1-k_3)\langle\sigma_n\rangle = h_n + \frac{1}{3}$
$-t\frac{\delta\langle\sigma_n\rangle}{\delta h_s} = \delta_{n,s} + \frac{1}{3}$

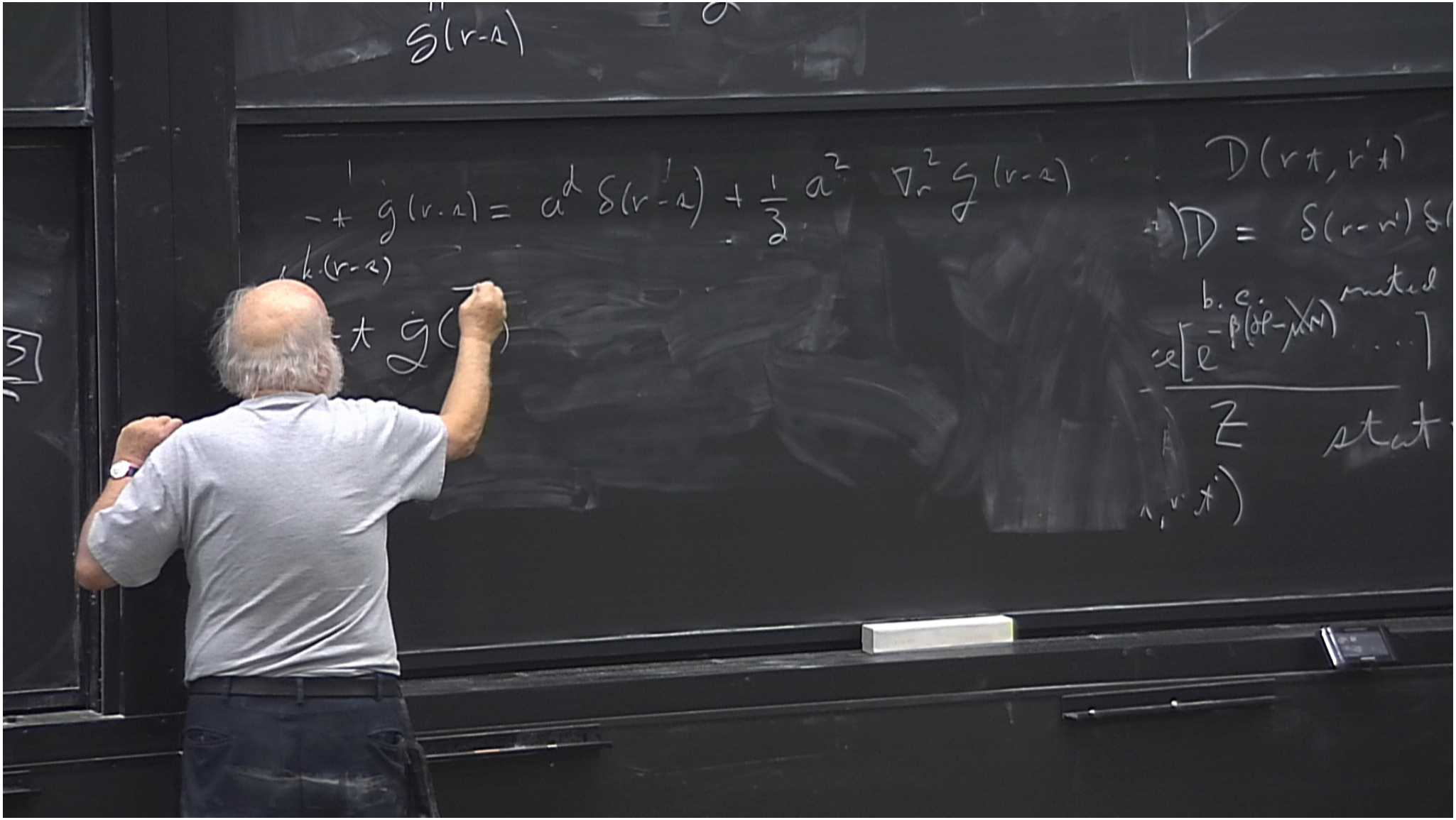

$(1-k3)\langle\sigma_n\rangle = h_n + \frac{k}{3}\sum_{s\neq n}[\langle\sigma_s\rangle - \langle\sigma_n\rangle] - \frac{1}{3}\langle\sigma_n\rangle^3$
$-t\langle\sigma_n\rangle$
$\langle\sigma_s\rangle = \langle\sigma_n\rangle + (\vec{s}-\vec{n})\cdot\nabla_n\langle\sigma_n\rangle + \frac{1}{2}(\vec{s}-\vec{n})(\vec{s}-\vec{n}):\nabla_n\nabla_n\langle\sigma_n\rangle + \cdots$
$(1-k3)\langle\sigma_n\rangle = h_n + \frac{1}{3}\nabla^2 a^2 \langle\sigma_n\rangle$
$-t\frac{\delta\langle\sigma_n\rangle}{\delta h_s} = \delta_{n,s} + \frac{1}{3}\nabla^2 G$
$\delta_{n,s} = \delta(n-s)$

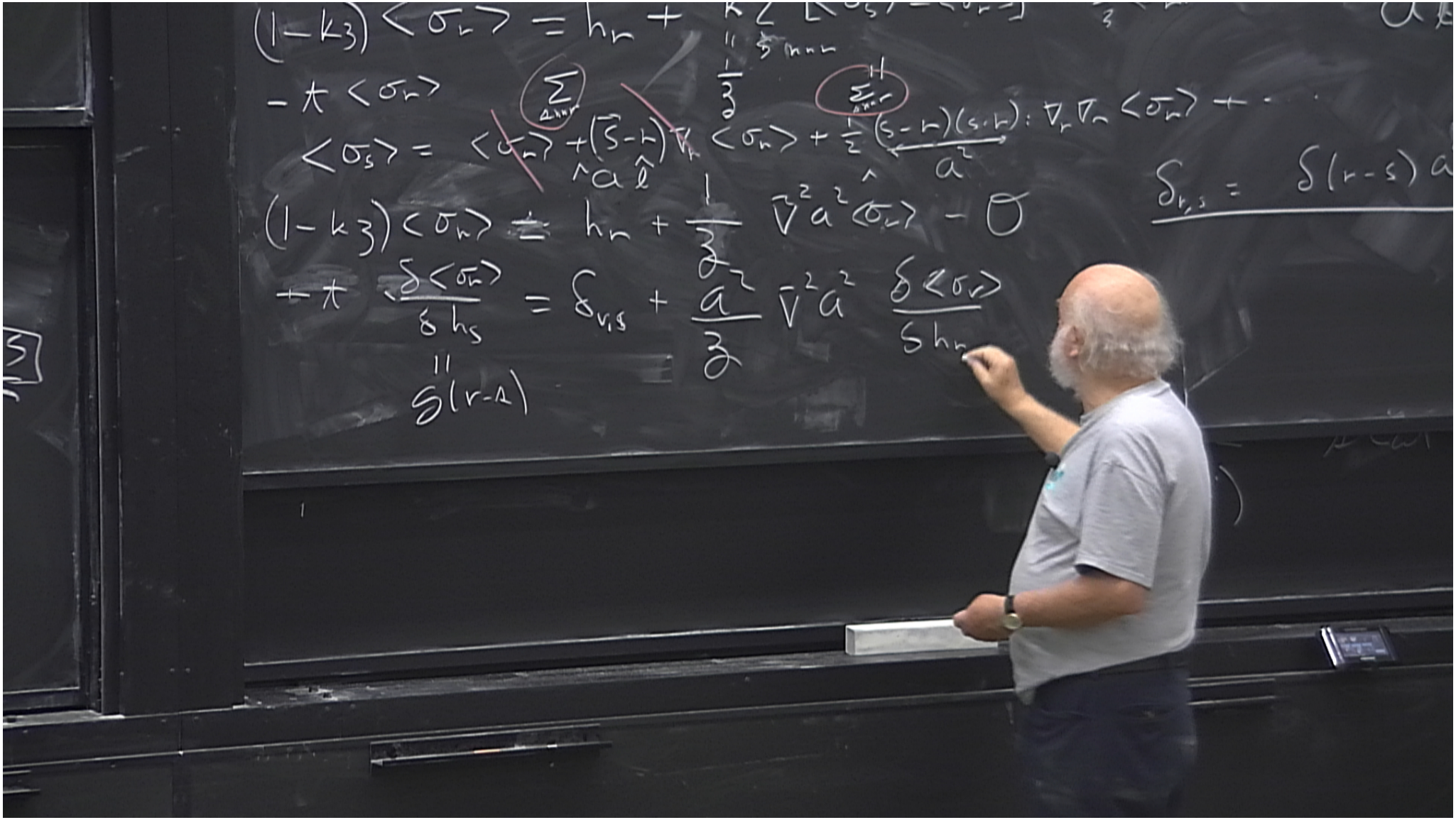

$(1-k\beta)\langle\sigma_r\rangle = h_r + k\sum_{s\neq r}[K_{rs}\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\cdot\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(\vec{s}-\vec{r})(\vec{s}-\vec{r}):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$\hat{a}$
$\frac{(\vec{s}-\vec{r})}{a^2}$
$\delta_{r,s} = \delta(r-s)\,a^d$
$(1-k\beta)\langle\sigma_r\rangle = \frac{1}{3}\nabla^2 a^2\langle\sigma_r\rangle - 0$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} - \frac{1}{a^2}\nabla_r^2 g(r,s)$

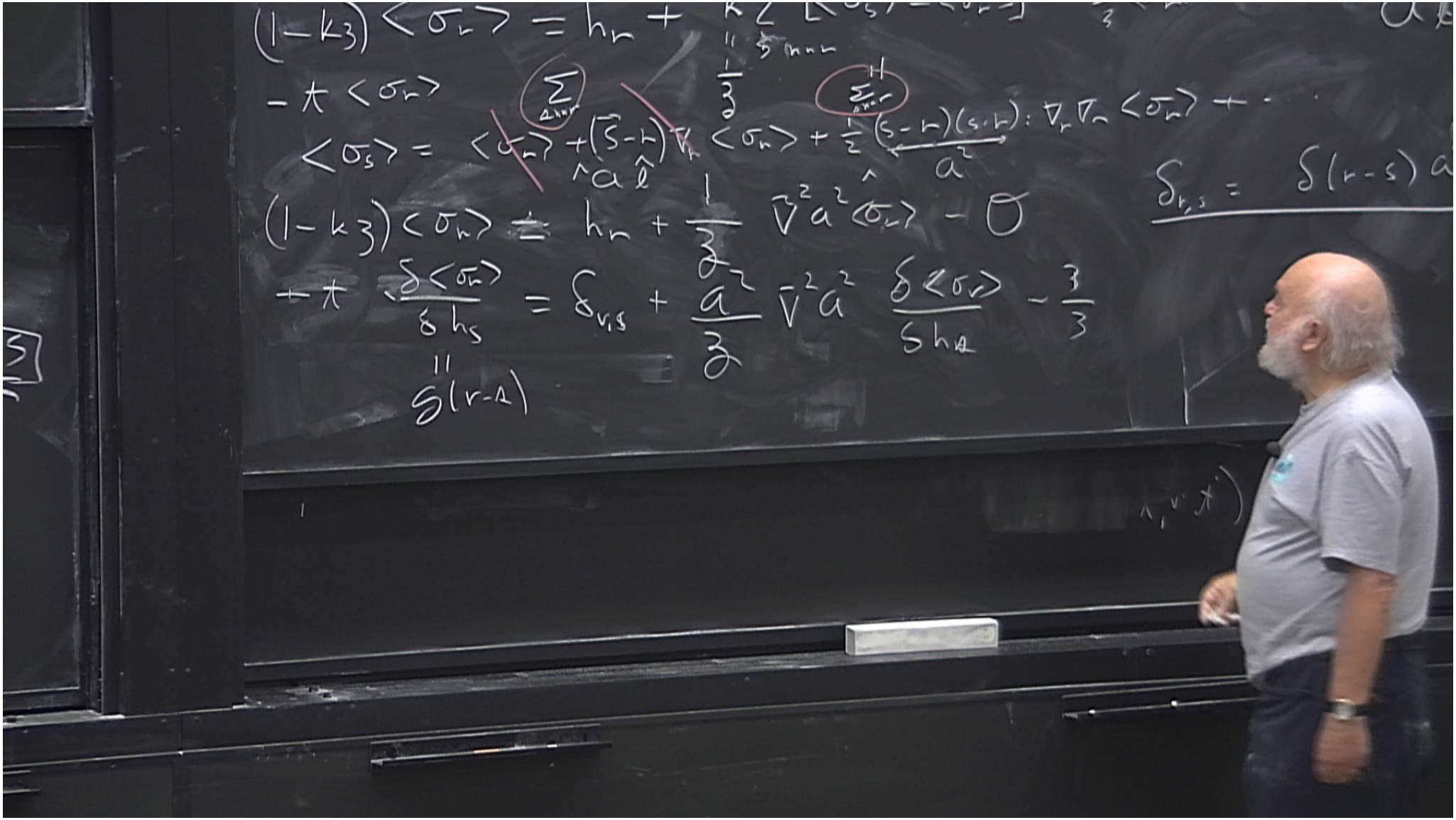

$(1-kz)\langle\sigma_r\rangle = h_r + k\sum_{s\,nnr}[\langle\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$a\hat{\ell}$
$-t\langle\sigma_r\rangle$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-r)\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
a^2
$\delta_{r,s} = \delta(r-s)\,a^d$
$(1-kz)\langle\sigma_r\rangle = h_r + \frac{1}{z}\nabla^2 a^2\langle\sigma_r\rangle - 0$
$-t\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} + \frac{a^2}{z}\nabla_r^2 g(r,r)$
$g(r-s)$

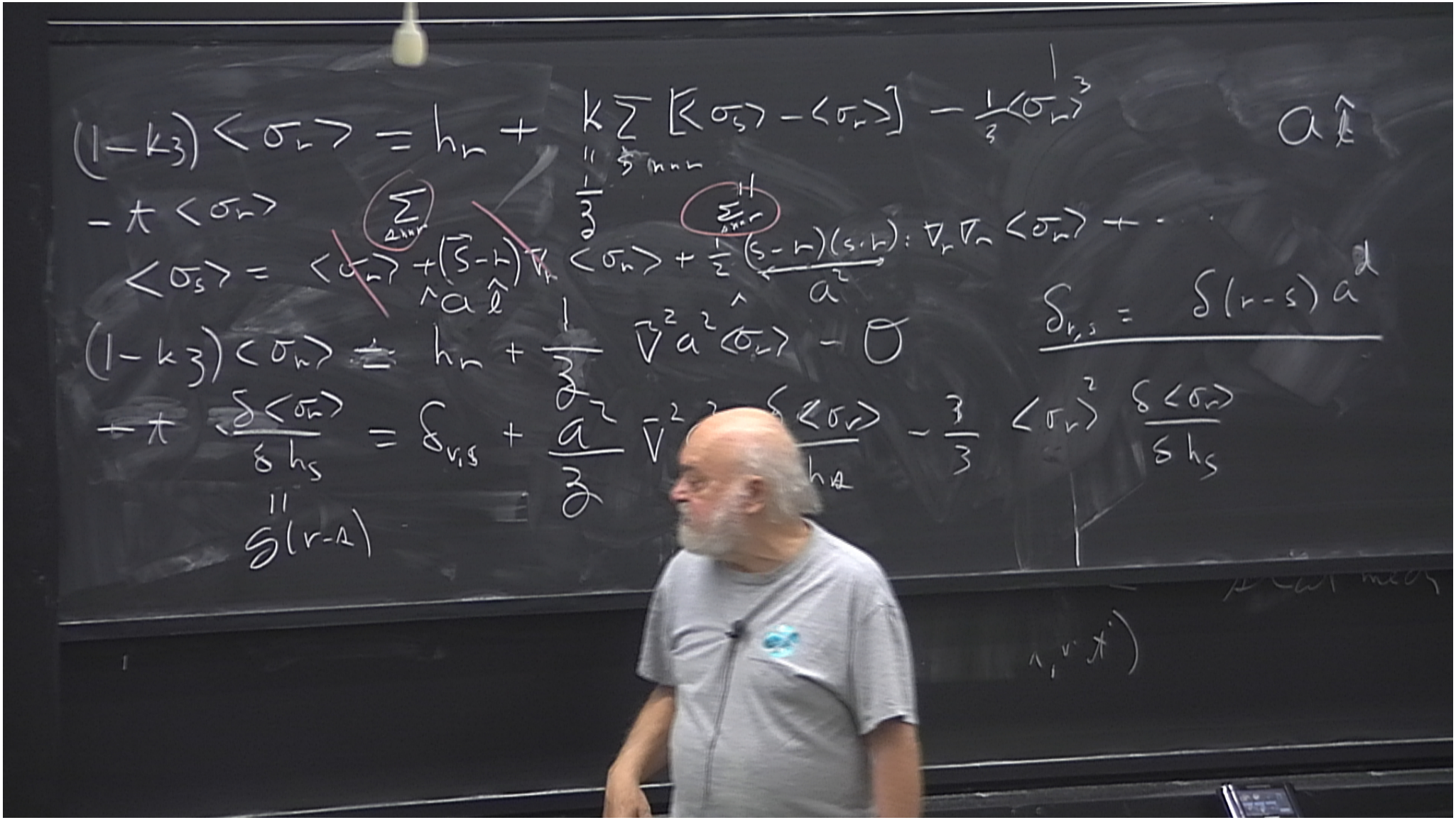

g(r-s)
g(r-s) = a^d δ(r-s)
D(rt, r't)
D = δ(r-r')
b.c.
Z
stat

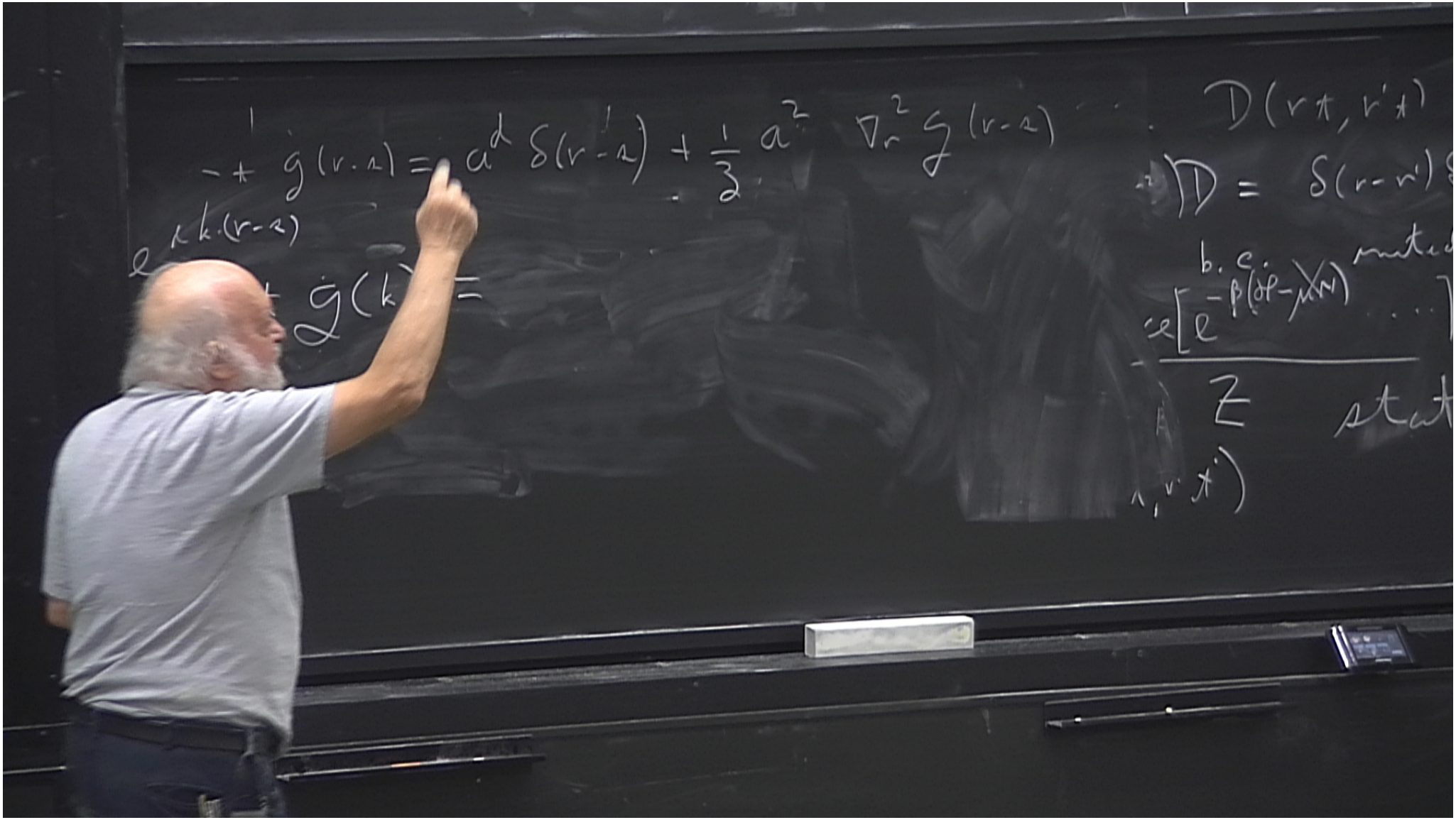

δ(r-r')
g(r,r') = a^d δ(r-r') + ½ a² ∇²_r g(r-r')
D(r*, r'*)
D = δ(r-r') δ(
b.c.
mutual
Z
stat

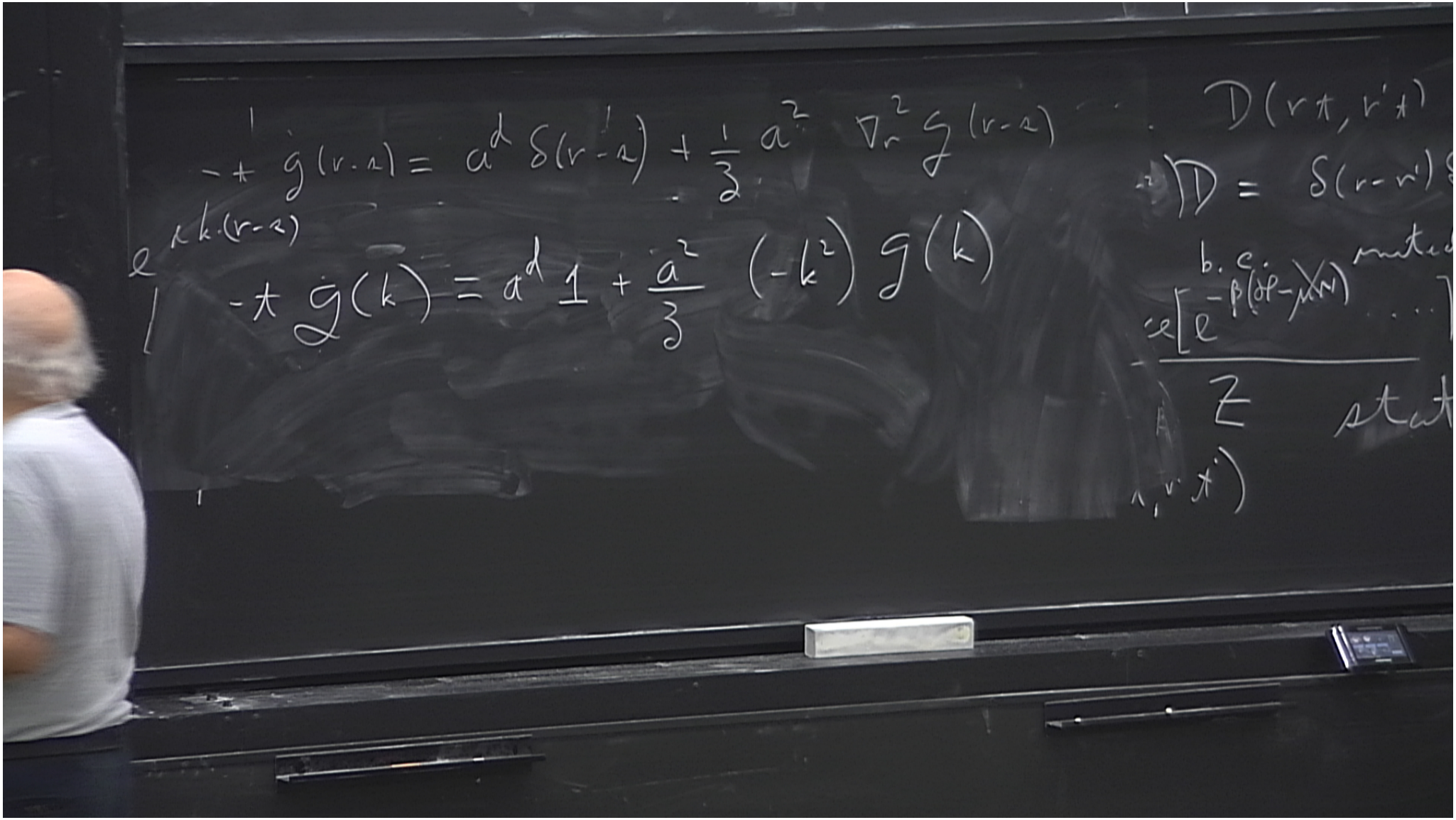

g(r-s)
g(r-s) = a^d δ(r-s) + 1/3 a^2 ∇_r^2 g(r-s)
D(rt, r't)
D = δ(r-r') δ(
b.c.
Z
stat

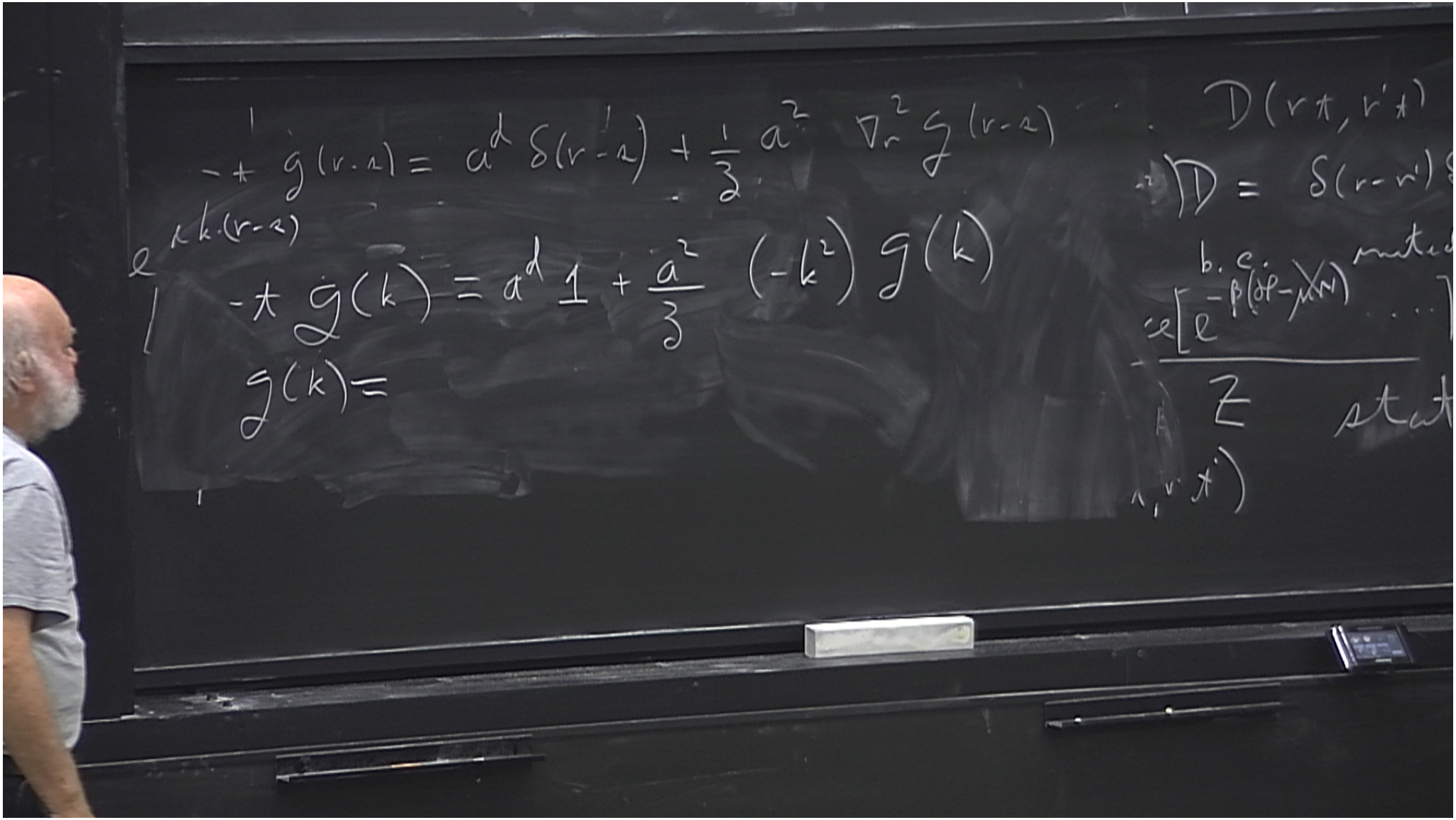

$(1-k_3)\langle\sigma_r\rangle = h_r +$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\nabla_r\langle\sigma_r\rangle + \frac{1}{2}\frac{(s-r)(s-r)}{a^2}:\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$(1-k_3)\langle\sigma_r\rangle = h_r + \frac{1}{3}\nabla^2 a^2\langle\sigma_r\rangle - 0$
$\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} + \frac{a^2}{3}\nabla^2 a^2 \frac{\delta\langle\sigma_r\rangle}{\delta h_r}$
$\delta_{r,s} = \delta(r-s)$

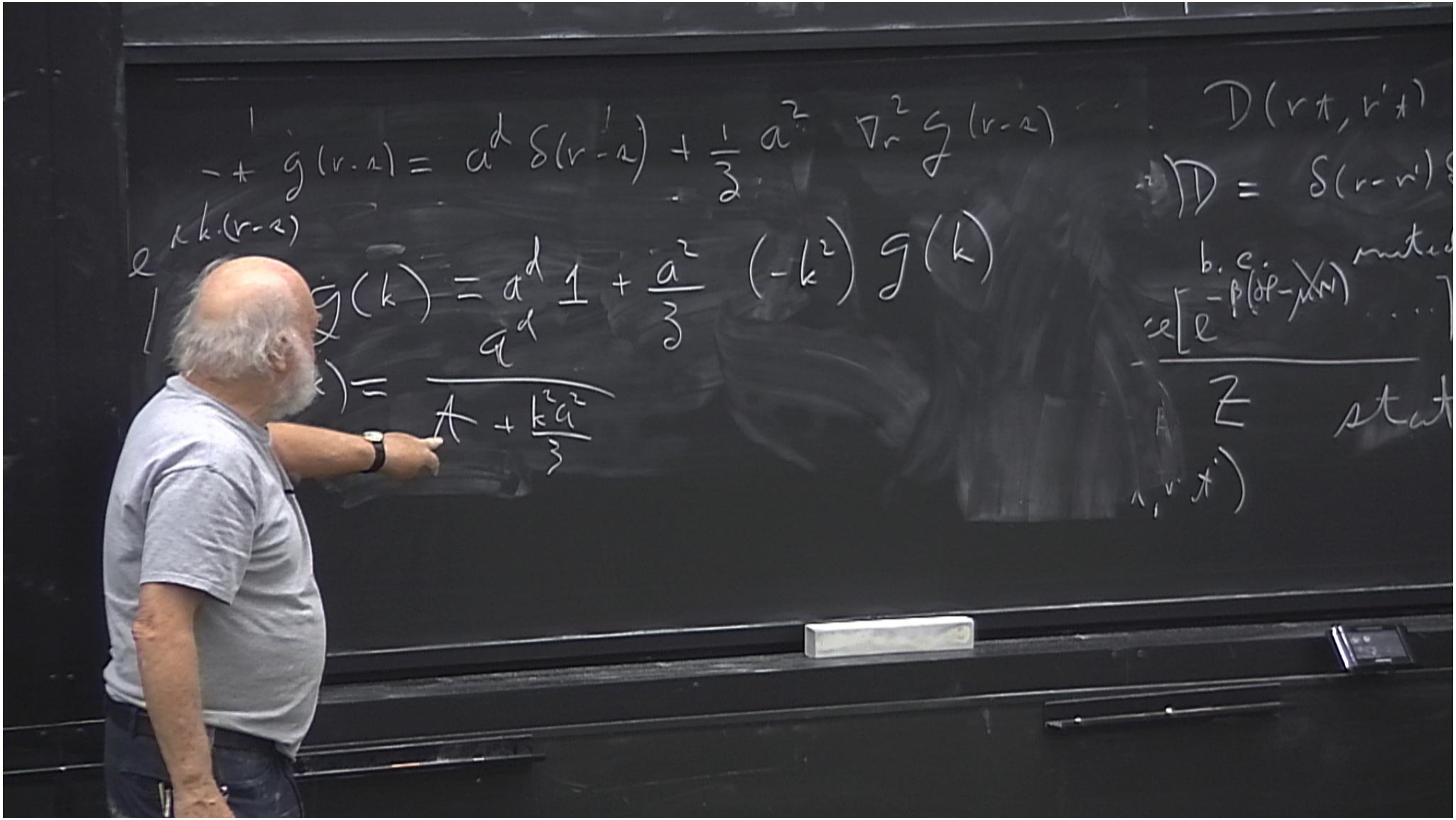

(1-kz) <σr> = hr + k Σ [<σs> - <σr>]
- t <σr>
<σs> = <σr> + (s-r) ∇r <σr> + 1/2 (s-r)(s-r) : ∇r ∇r <σr> + ...
(1-kz) <σr> = hr + 1/z ∇²a² <σr> - 0
+ t δ<σr>/δhs = δr,s + a²/z ∇²a² δ<σr>/δhs - 3/3
δ(r-s)
δr,s = δ(r-s) a

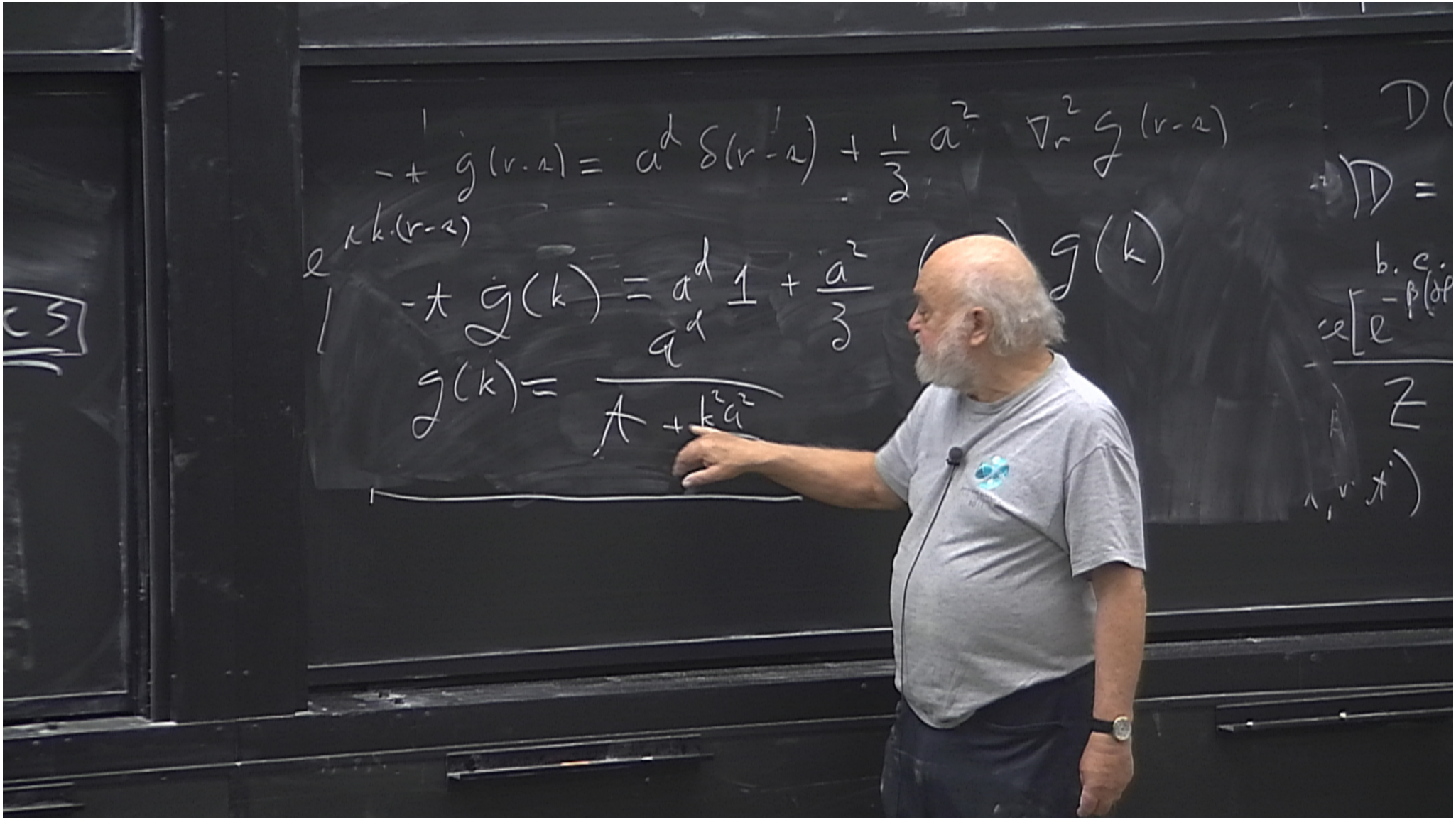

$(1-k_3)\langle\sigma_r\rangle = h_r + \frac{k}{3}\sum_s [K\sigma_s\rangle - \langle\sigma_r\rangle] - \frac{1}{3}\langle\sigma_r\rangle^3$
$\langle\sigma_s\rangle = \langle\sigma_r\rangle + (\vec{s}-\vec{r})\nabla_r\langle\sigma_r\rangle + \frac{1}{2}(s-r)(s-r):\nabla_r\nabla_r\langle\sigma_r\rangle + \cdots$
$(1-k_3)\langle\sigma_r\rangle = h_r + \frac{1}{3}\nabla^2 a^2\langle\sigma_r\rangle - 0$
$\delta_{r,s} = \delta(r-s)\,a^d$
$-k\frac{\delta\langle\sigma_r\rangle}{\delta h_s} = \delta_{r,s} + \frac{a^2}{3}\nabla^2 \frac{\delta\langle\sigma_r\rangle}{\delta h_s} - \frac{3}{3}\langle\sigma_r\rangle^2 \frac{\delta\langle\sigma_r\rangle}{\delta h_s}$
$\delta(r-s)$

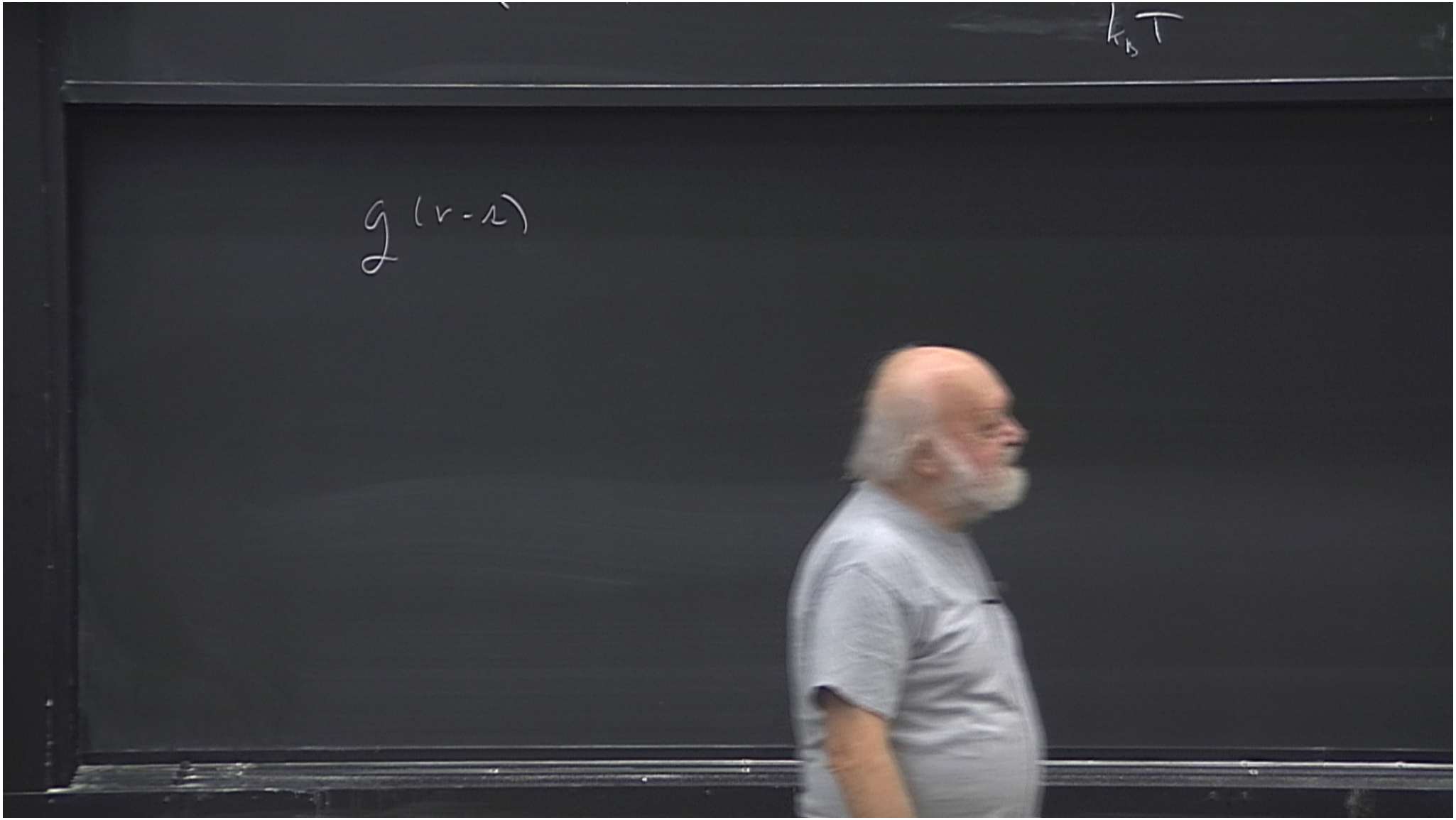

D(rt, r't)
b.c.
Z

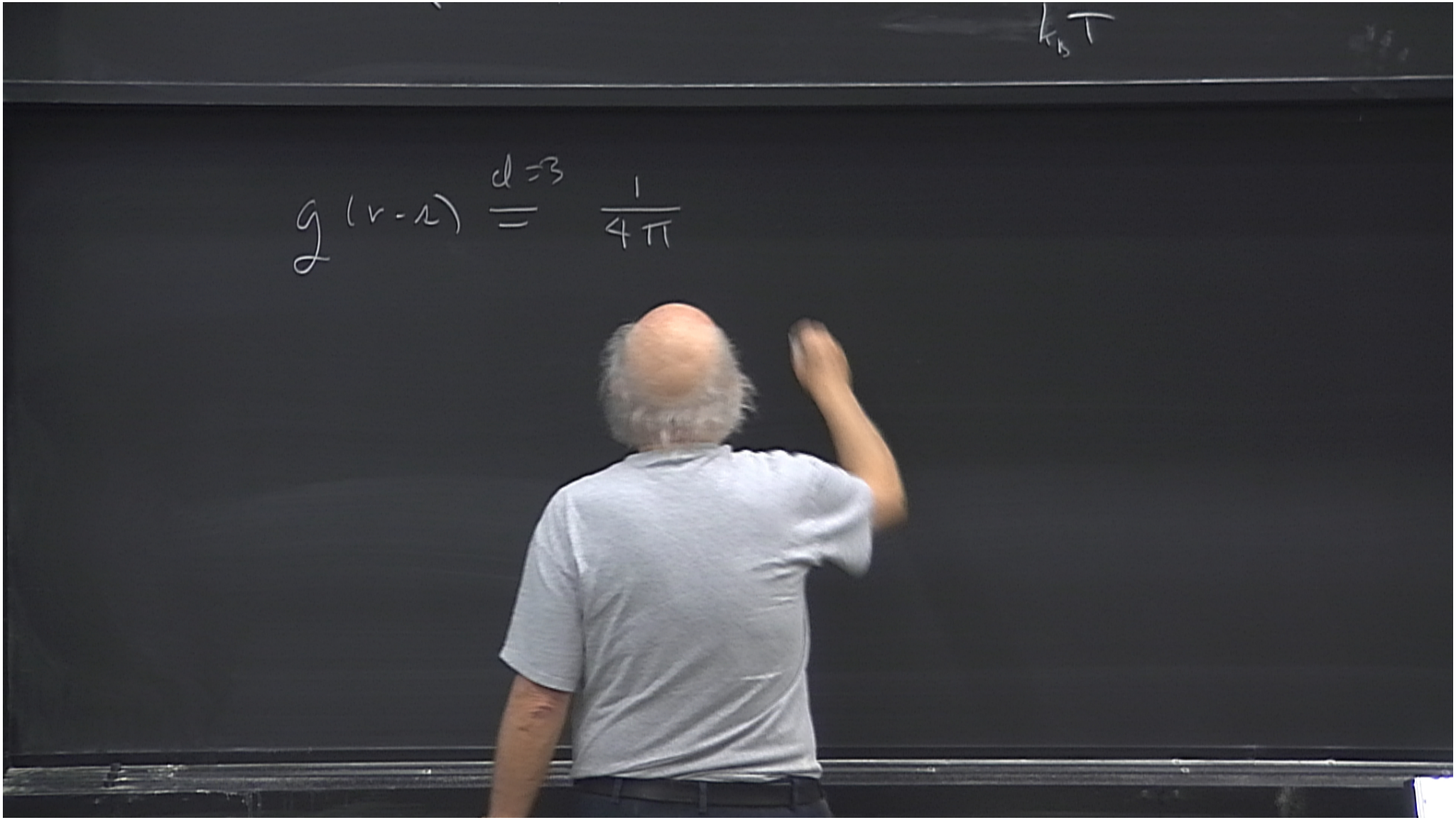

$-t\, g(r-s) = a^d \delta(r-s) + \frac{1}{3} a^2 \nabla_r^2 g(r-s)$
$e^{ik\cdot(r-s)}$
$-t\, g(k) = a^d 1 + \frac{a^2}{3} (-k^2)\, g(k)$
$D(rt, r't)$
$D = \delta(r-r')$
b.c.
Z
stat

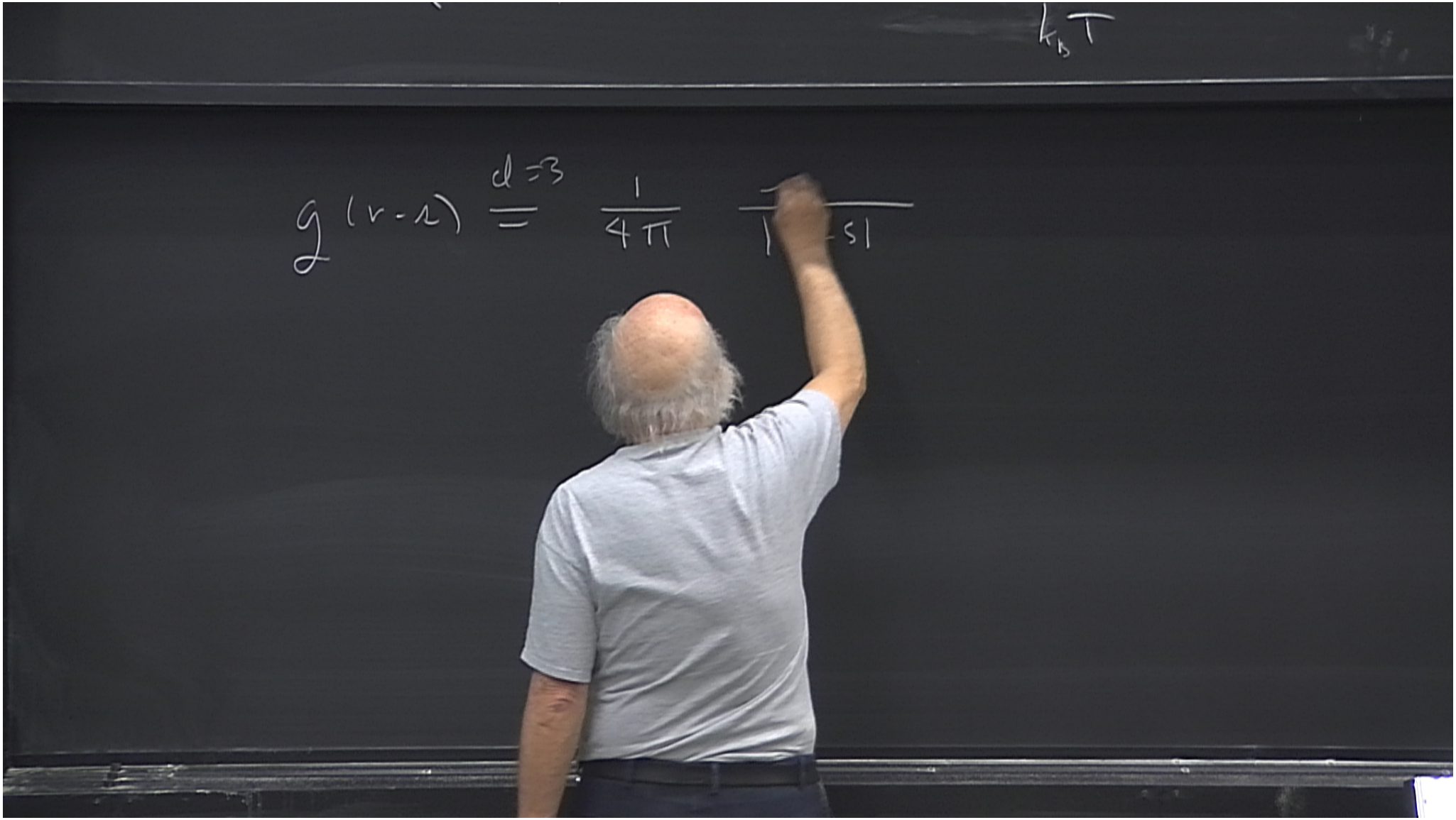

$-t\, g(r-s) = a^d \delta(r-s) + \frac{1}{3} a^2 \nabla_r^2 g(r-s)$
$e^{ik\cdot(r-s)}$
$-t\, g(k) = a^d 1 + \frac{a^2}{3} (-k^2)\, g(k)$
$g(k) =$
$D(rt, r't)$
$D = \delta(r-r')$
b.c.
Z


g(r-s) = a^d δ(r-s) + 1/3 a^2 ∇_r^2 g(r-s)
g(k) = a^d 1 + a^2/3 (-k^2) g(k)
D(rt, r't)
b.c.
Z


$-\nabla^2 g(r-r') = a^d \delta(r-r') + \frac{1}{3} a^2 \nabla_r^2 g(r-r')$
$e^{ik\cdot(r-r')}$
$-k^2 g(k) = a^d 1 + \frac{a^2}{3} (\quad) g(k)$
$g(k) = \frac{a^d}{A + k^2 a^2}$
b. c.

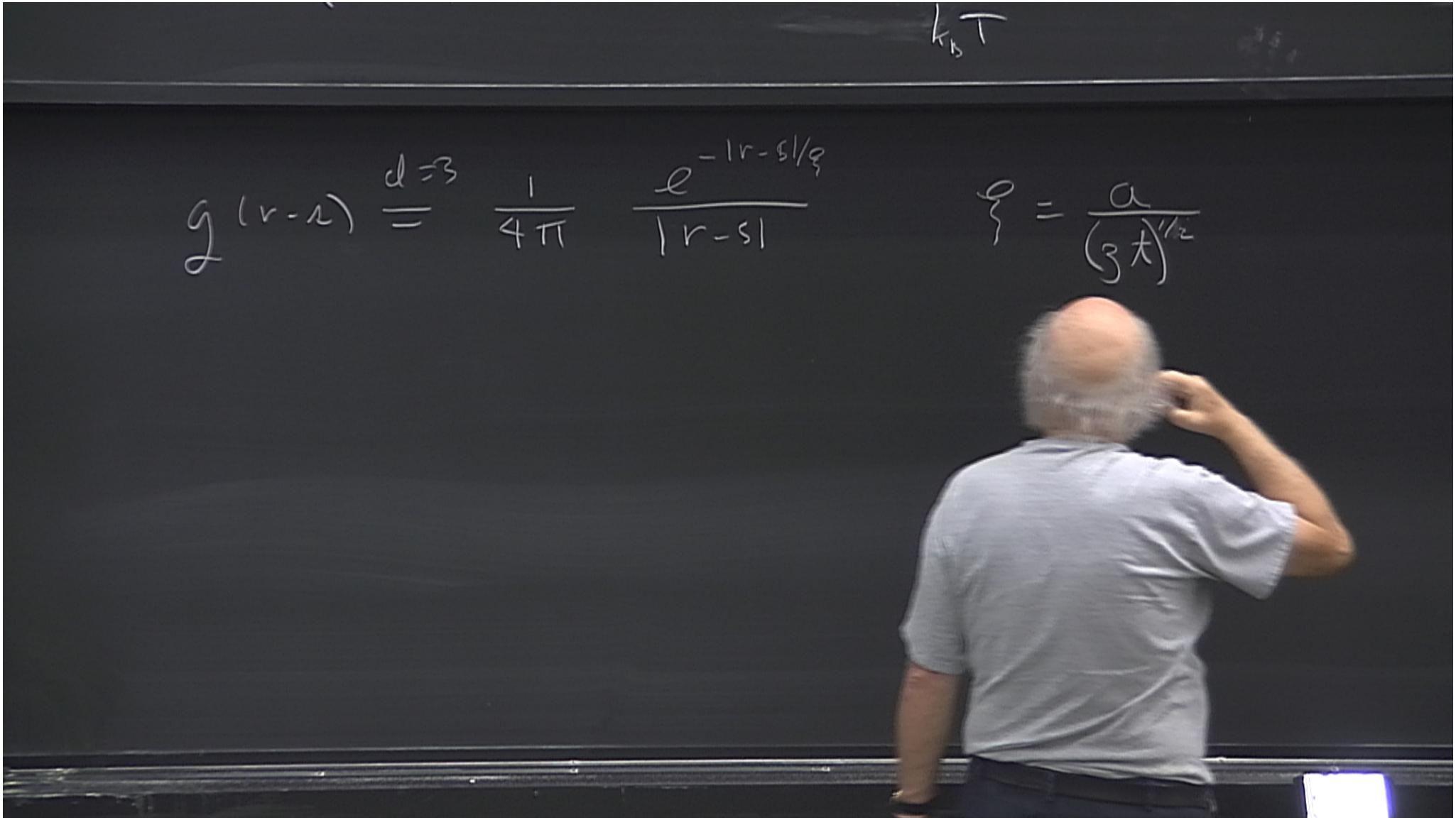

$k_B T$
$g(r-\lambda)$

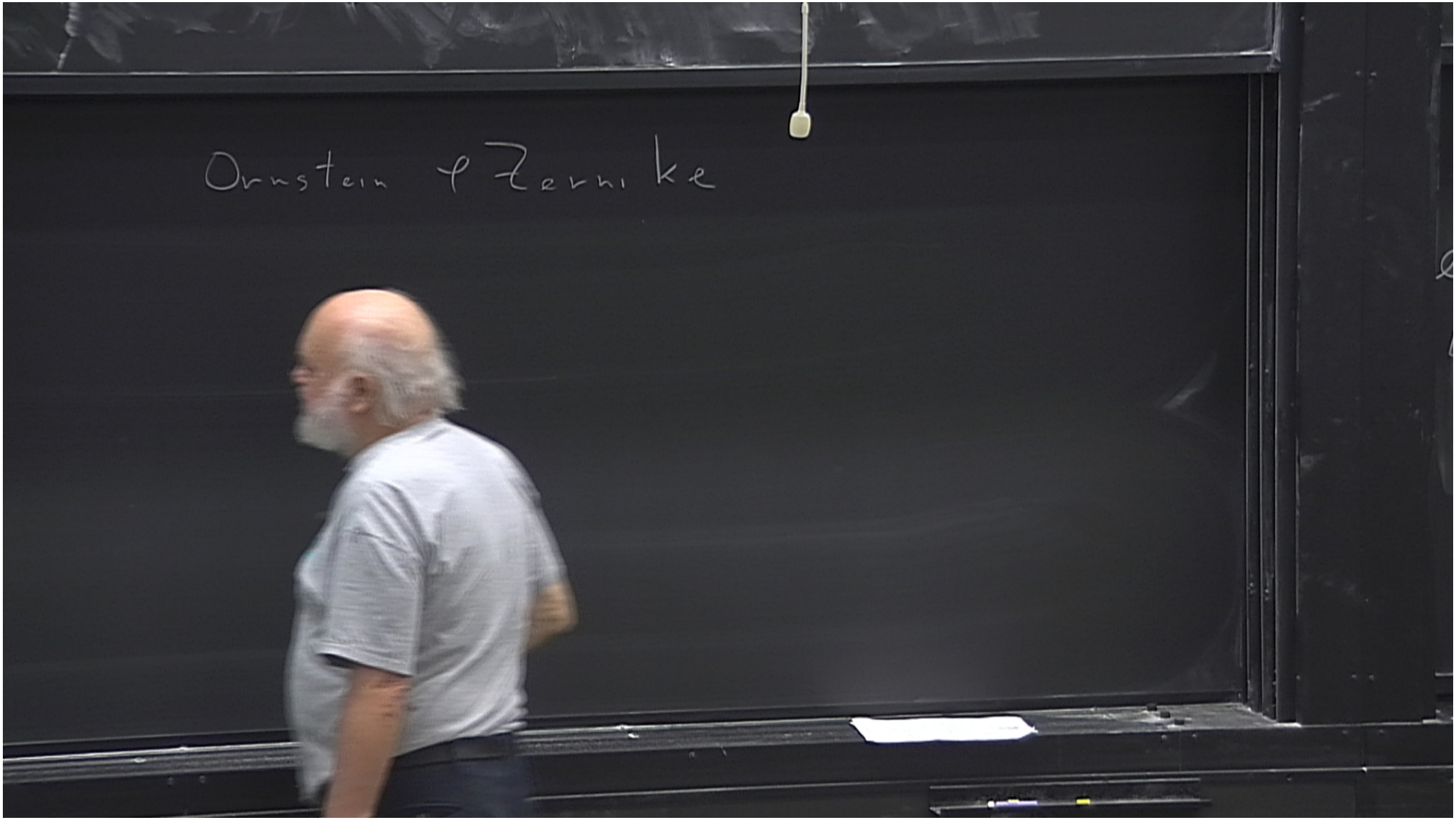

$k_B T$
$g(r-r') \overset{d=3}{=} \frac{1}{4\pi}$


$k_B T$
$g(r-r') \overset{d=3}{=} \frac{1}{4\pi}$

$k_B T$

$$g(r-s) \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|} \qquad \xi$$


$k_B T$
$g(r-s) \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(3\lambda)^{1/2}}$


Ornstein & Zernike

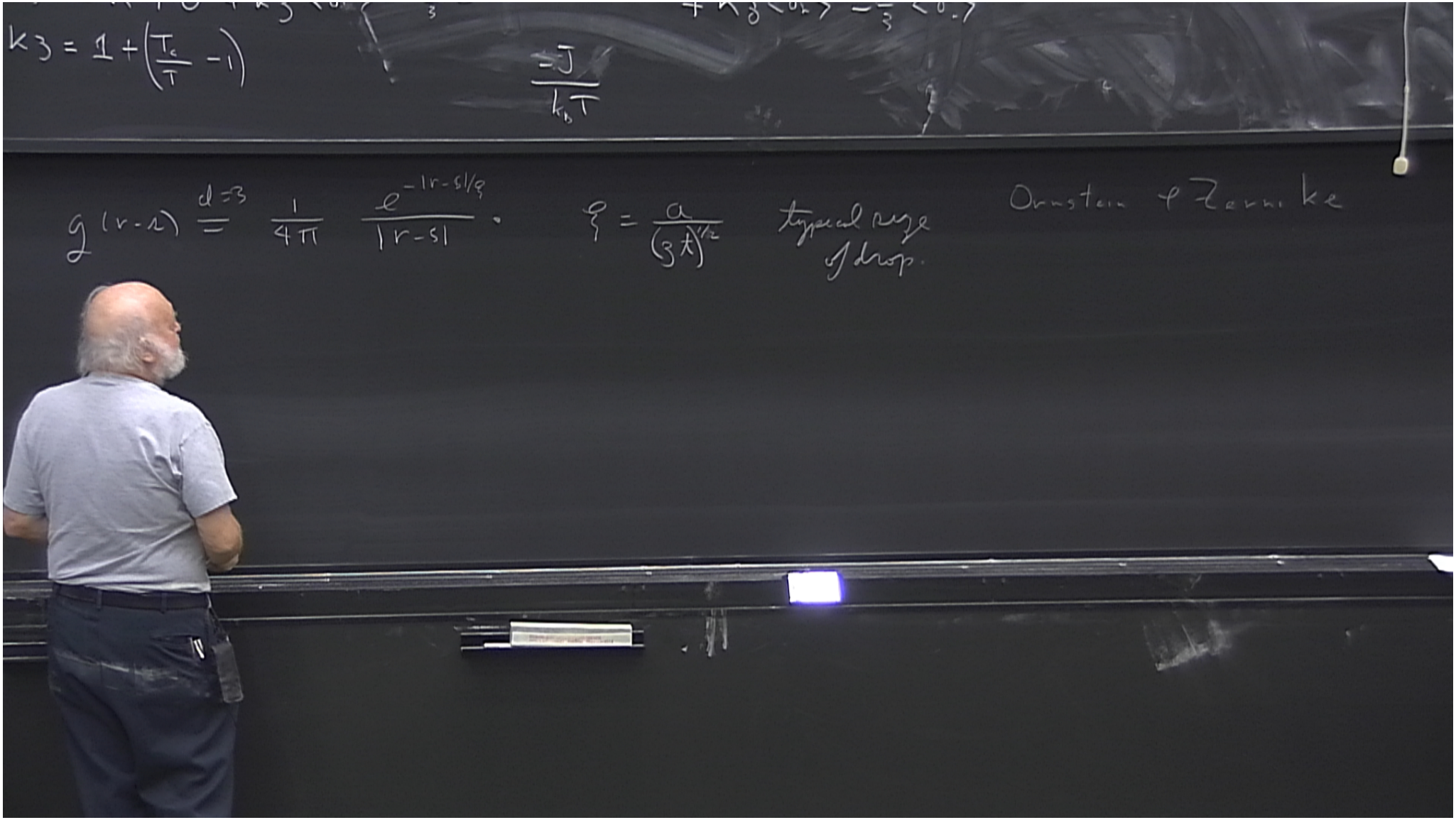
k_B

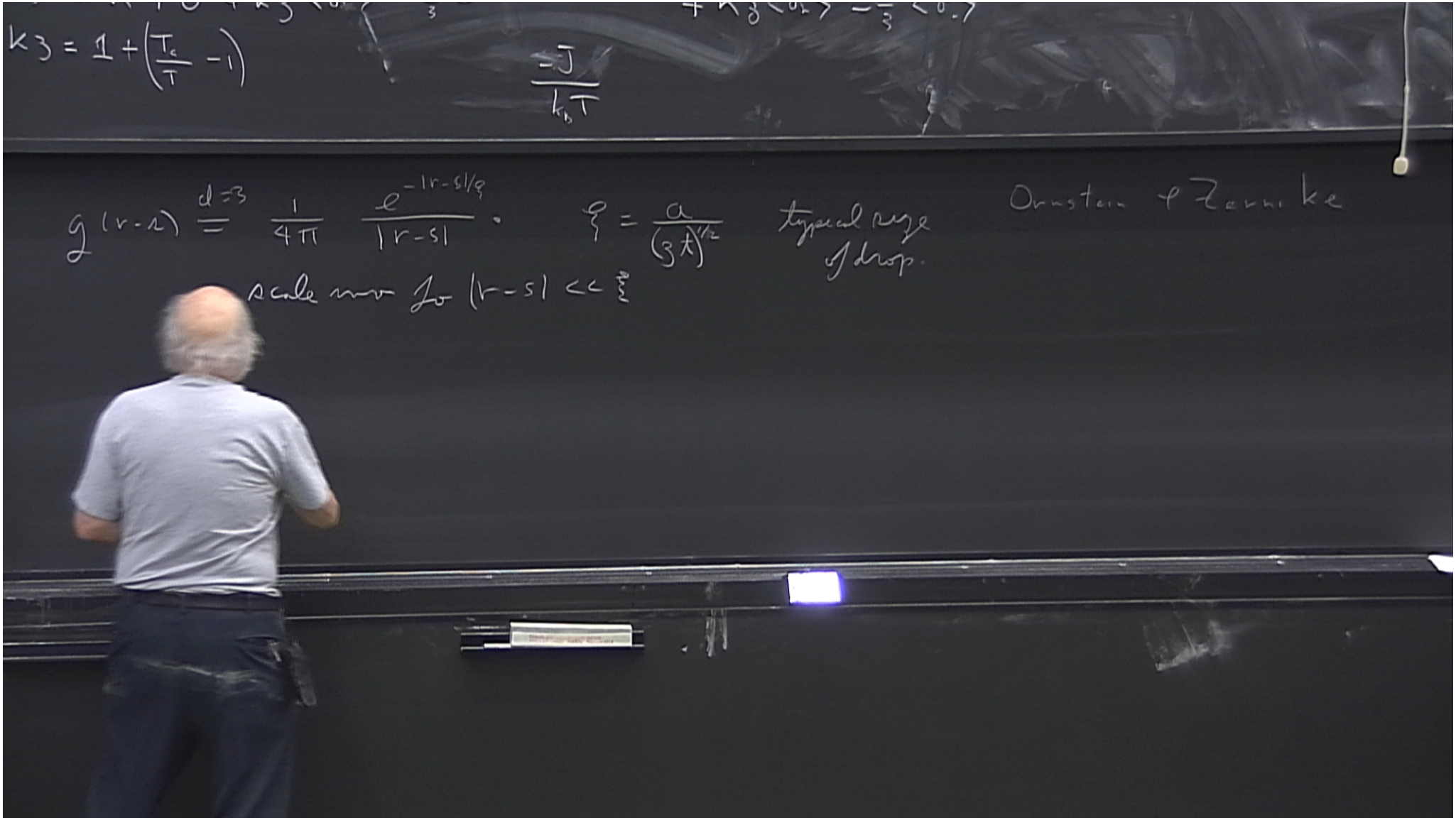
$$\frac{e^{-|r-s|/\xi}}{|r-s|}$$

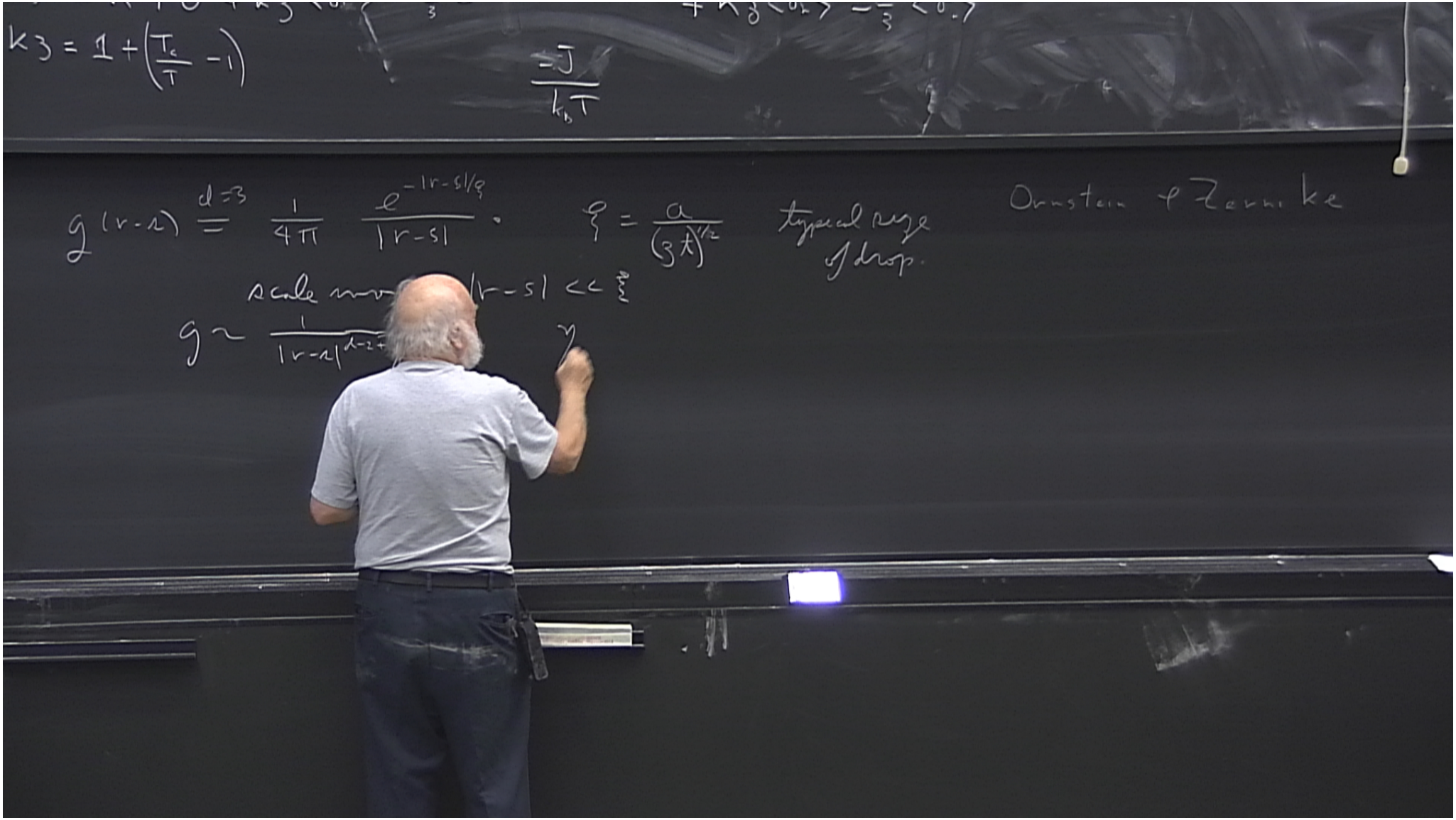
$$\xi = \frac{a}{(3t)^{1/2}}$$

typical size of drop.

Ornstein & Zern


$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$g(r-r') \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(3t)^{1/2}}$
typical range of drop.
Ornstein & Zernike


$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$g(r-s) \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(3t)^{1/2}}$
typical range of drop.
Ornstein + Zernike
scale now for $|r-s| \ll \xi$


$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$g(r-r') \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(3t)^{1/2}}$
typical range of drop.
Ornstein & Zernike
scale
$|r-s| \ll$
$g \sim \frac{1}{|r-r'|^{d-2+}}$

$k_3 = 1 + \left(\frac{T_c}{T} - 1\right)$

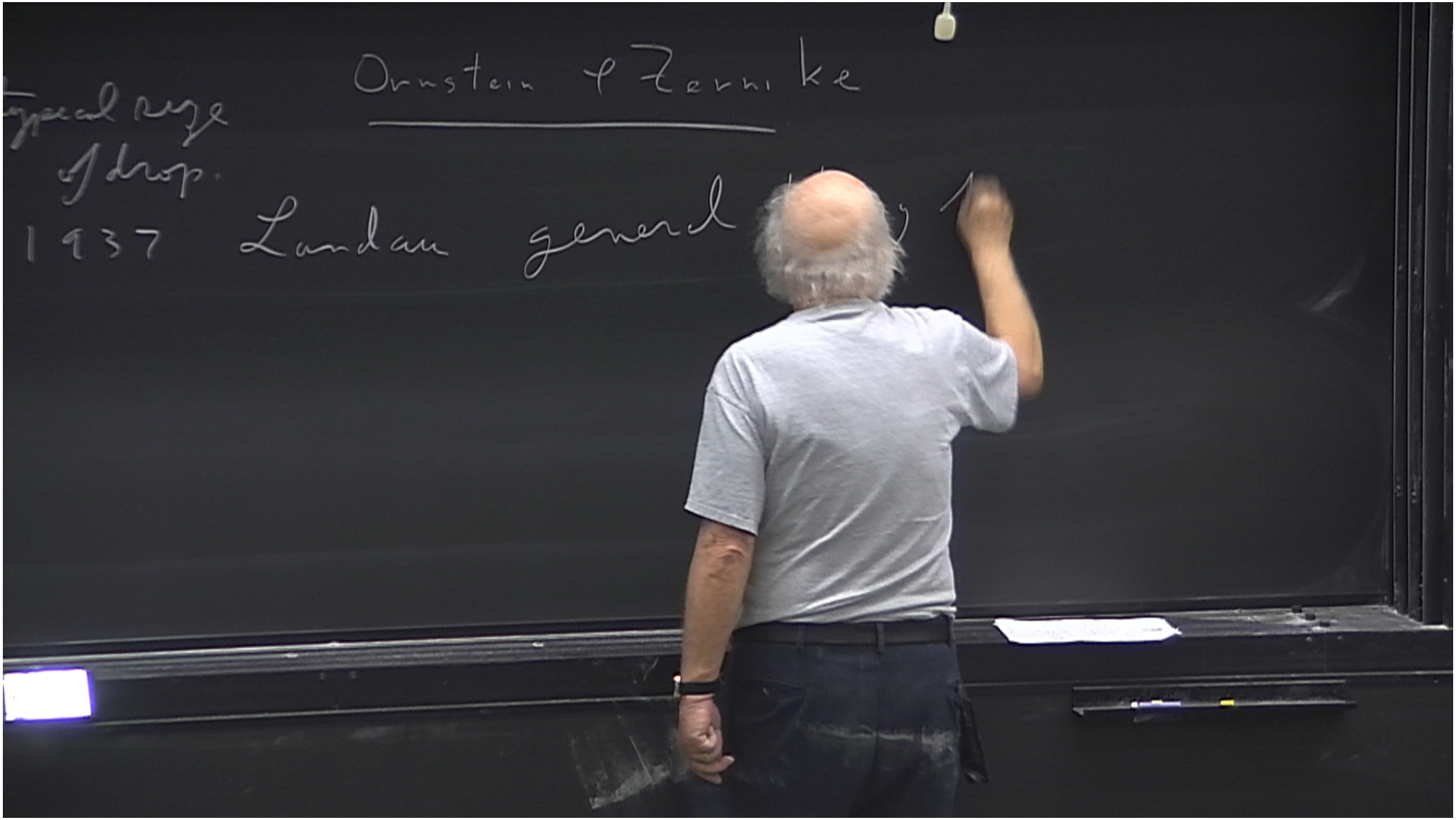
$\frac{-J}{k_B T}$

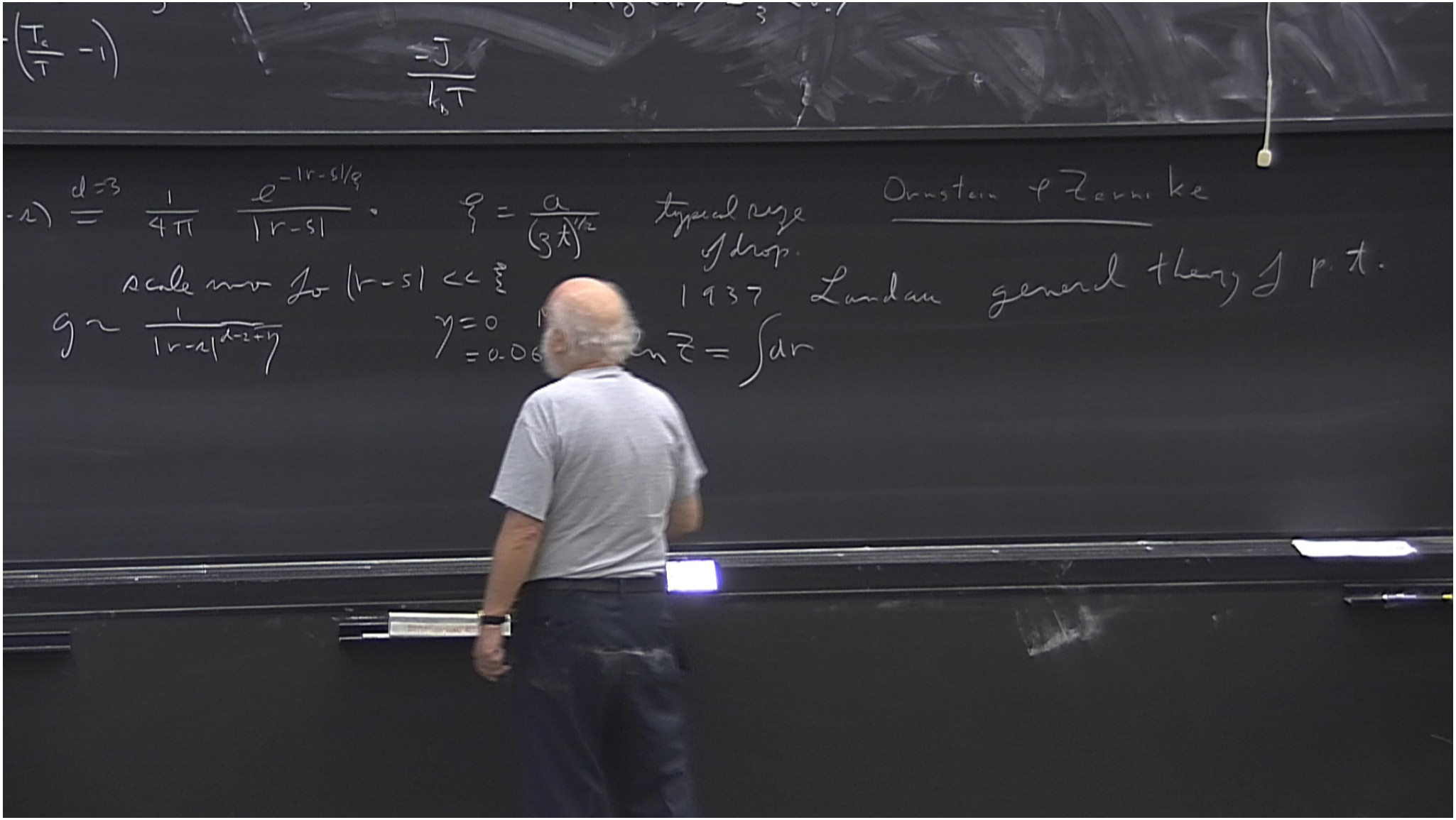
$g(r-r') \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$. $\xi = \frac{a}{(3t)^{1/2}}$ typical range of drop.

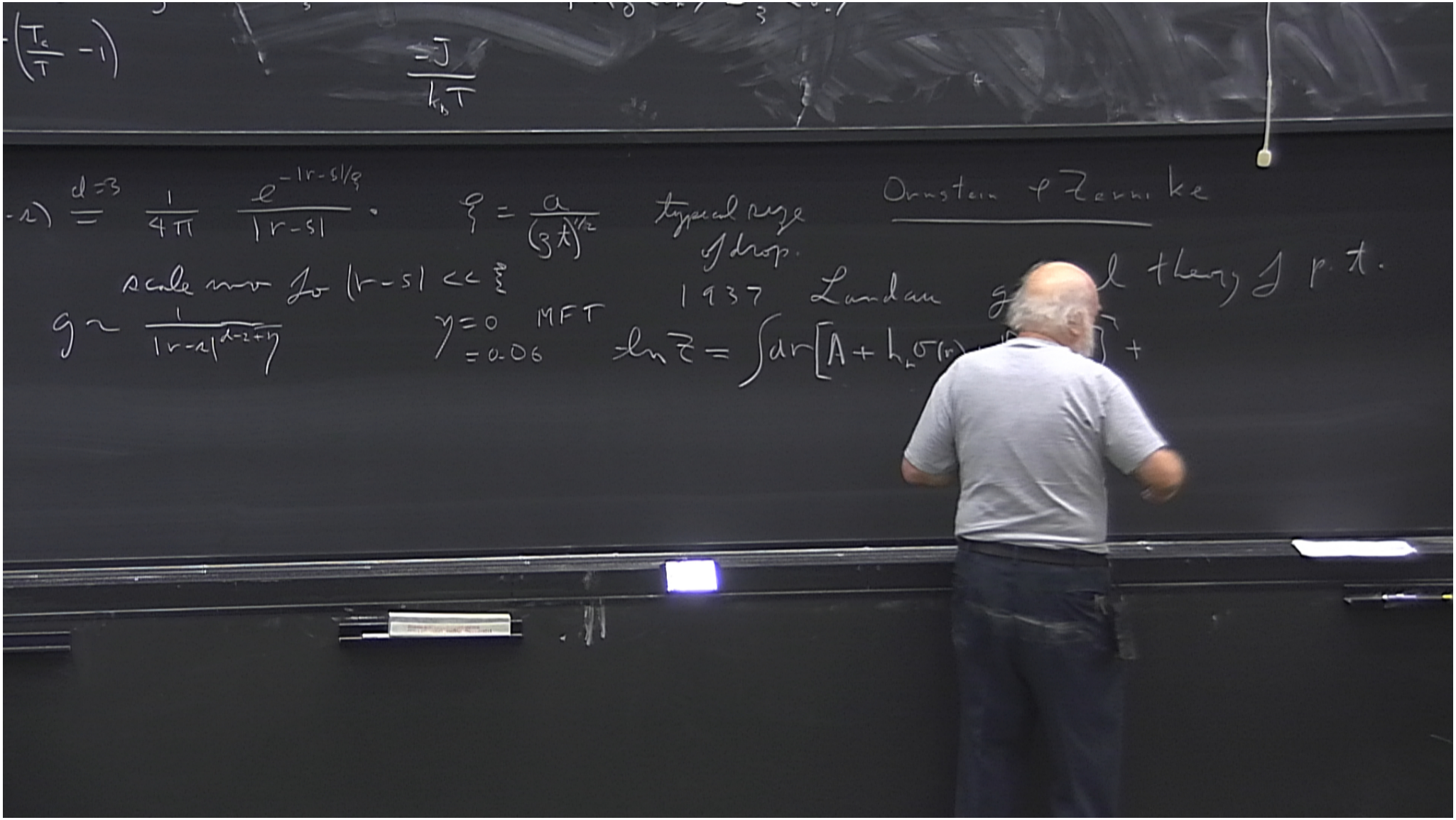
Ornstein + Zernike

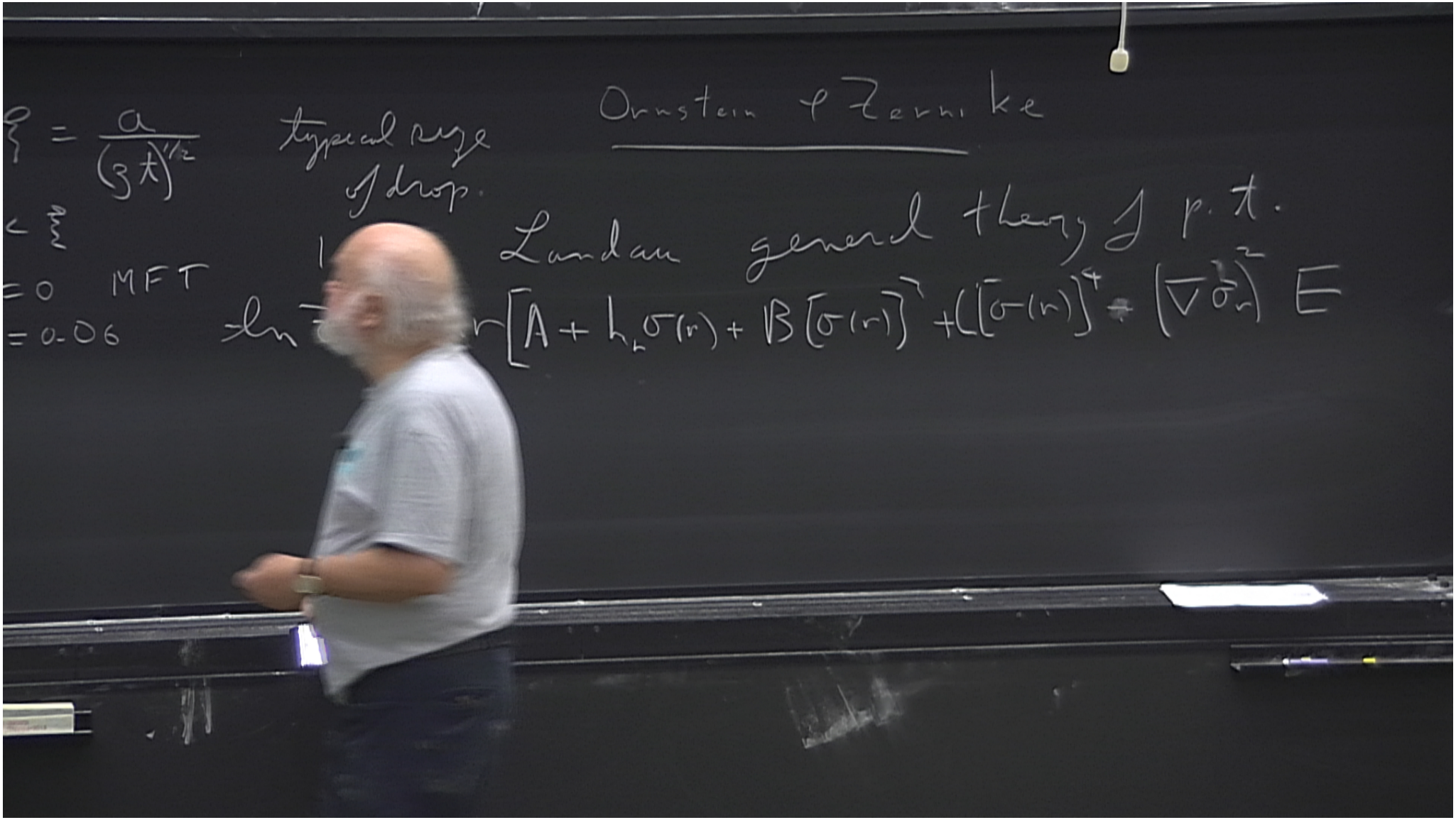
scale inv for $|r-s| \ll \xi$

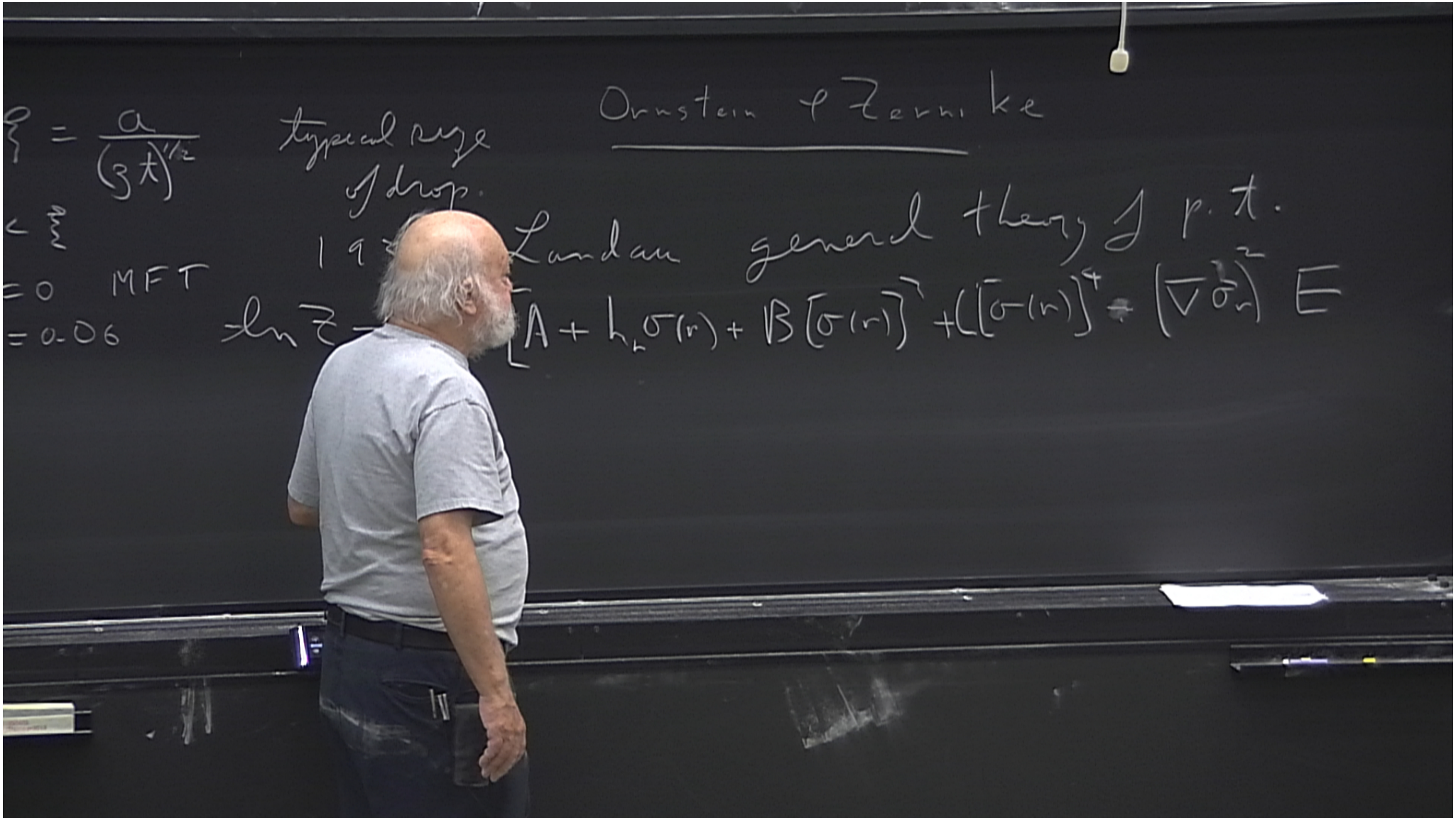
$g \sim \frac{1}{|r-r'|^{d-2+\eta}}$ $\eta = 0$ MFT $= 0.06$

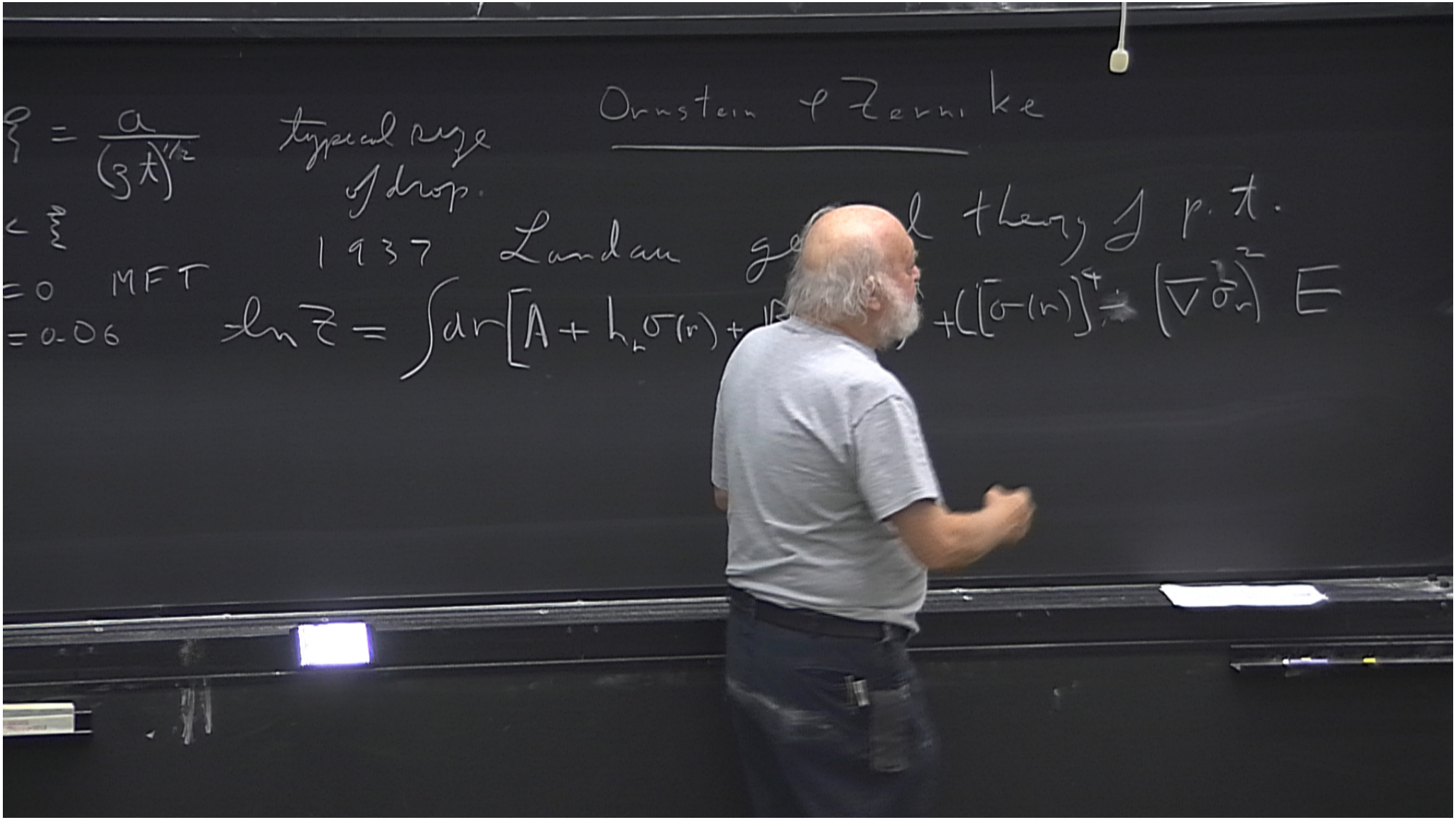

Ornstein + Zernike
1937 Landau

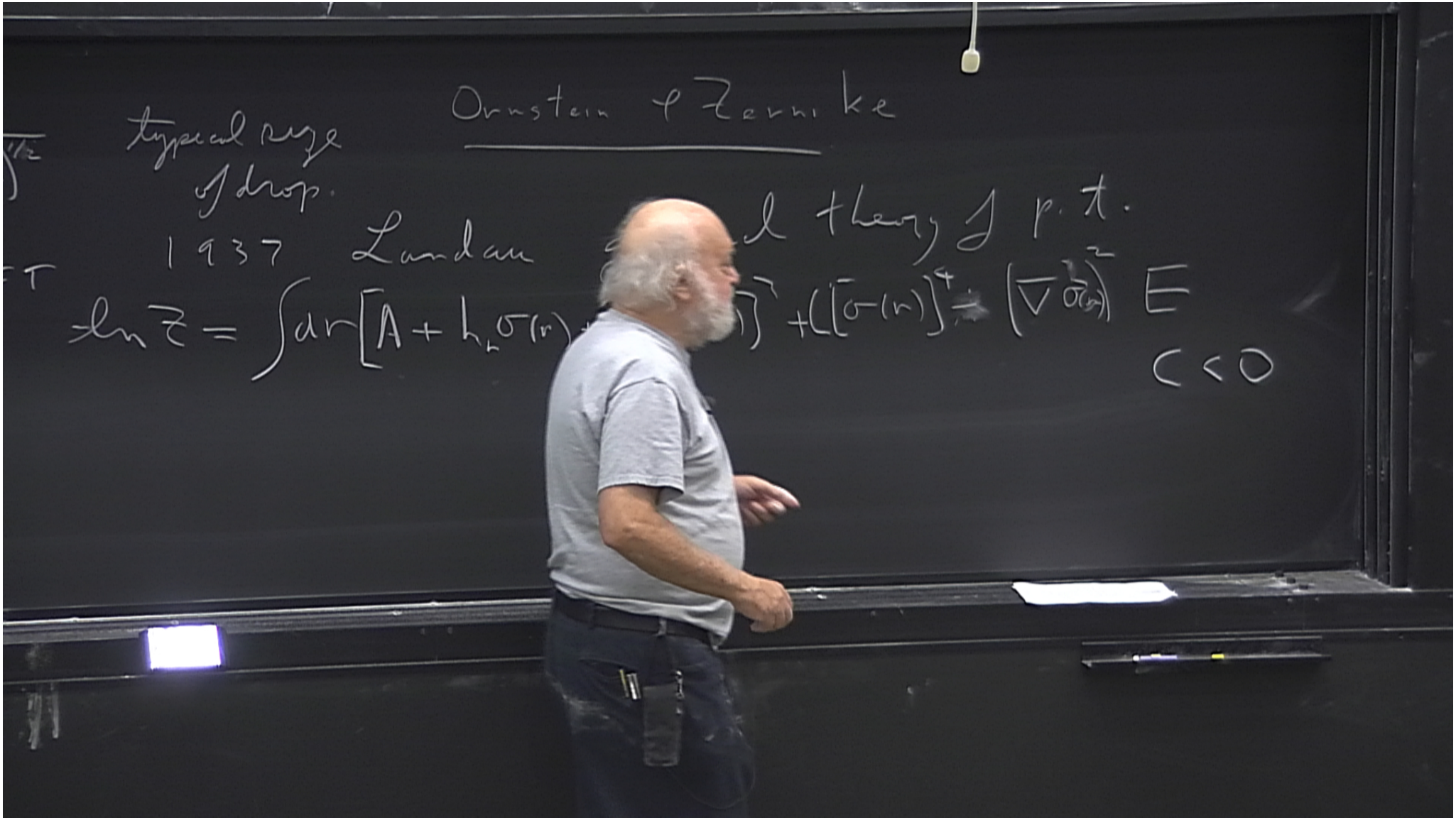

$\left(\frac{T_c}{T} - 1\right)$
$\frac{-J}{k_B T}$
$\frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(\beta t)^{1/2}}$
typical range of drop.
Ornstein + Zernike
1937 Landau general theory of p.t.
scale inv for $|r-s| \ll \xi$
$g \sim \frac{1}{|r-s|^{d-2+\eta}}$
$\eta = 0$
$= 0.06$
$\ln \mathcal{Z} = \int dr$

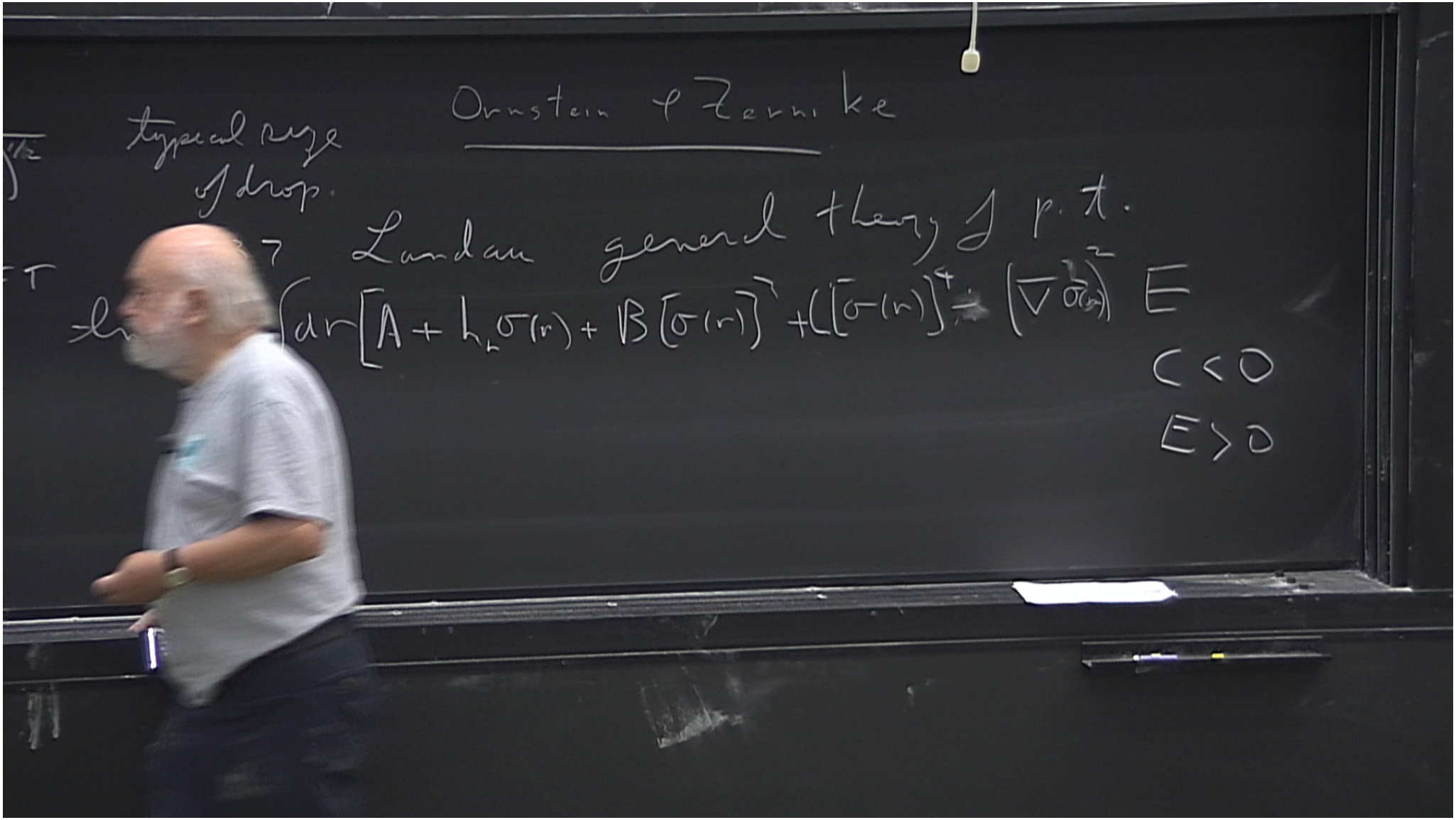

$\left(\frac{T_c}{T}-1\right)$
$\frac{-J}{k_B T}$
$\frac{1}{4\pi}\frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(\beta t)^{1/2}}$
typical range of drop.
Ornstein + Zernike
1937 Landau
scale inv for $|r-s| \ll \xi$
$g \sim \frac{1}{|r-s|^{d-2+\eta}}$
$\eta = 0$ MFT
$= 0.06$
$-\ln Z = \int dr [A + h_r \sigma(r)$

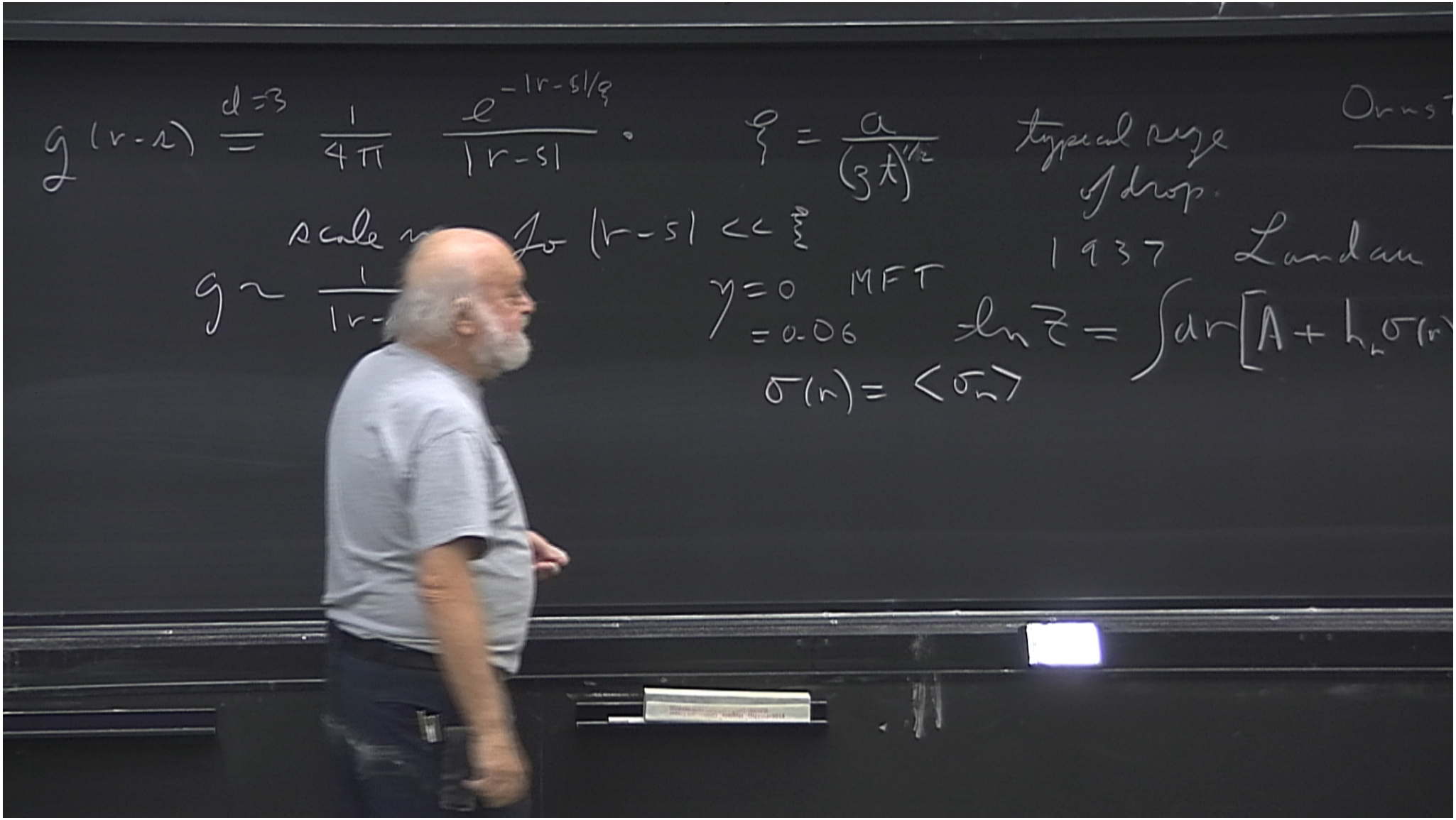

Ornstein & Zernike
typical size of drop.
Landau general theory of p.t.
MFT
= 0.06

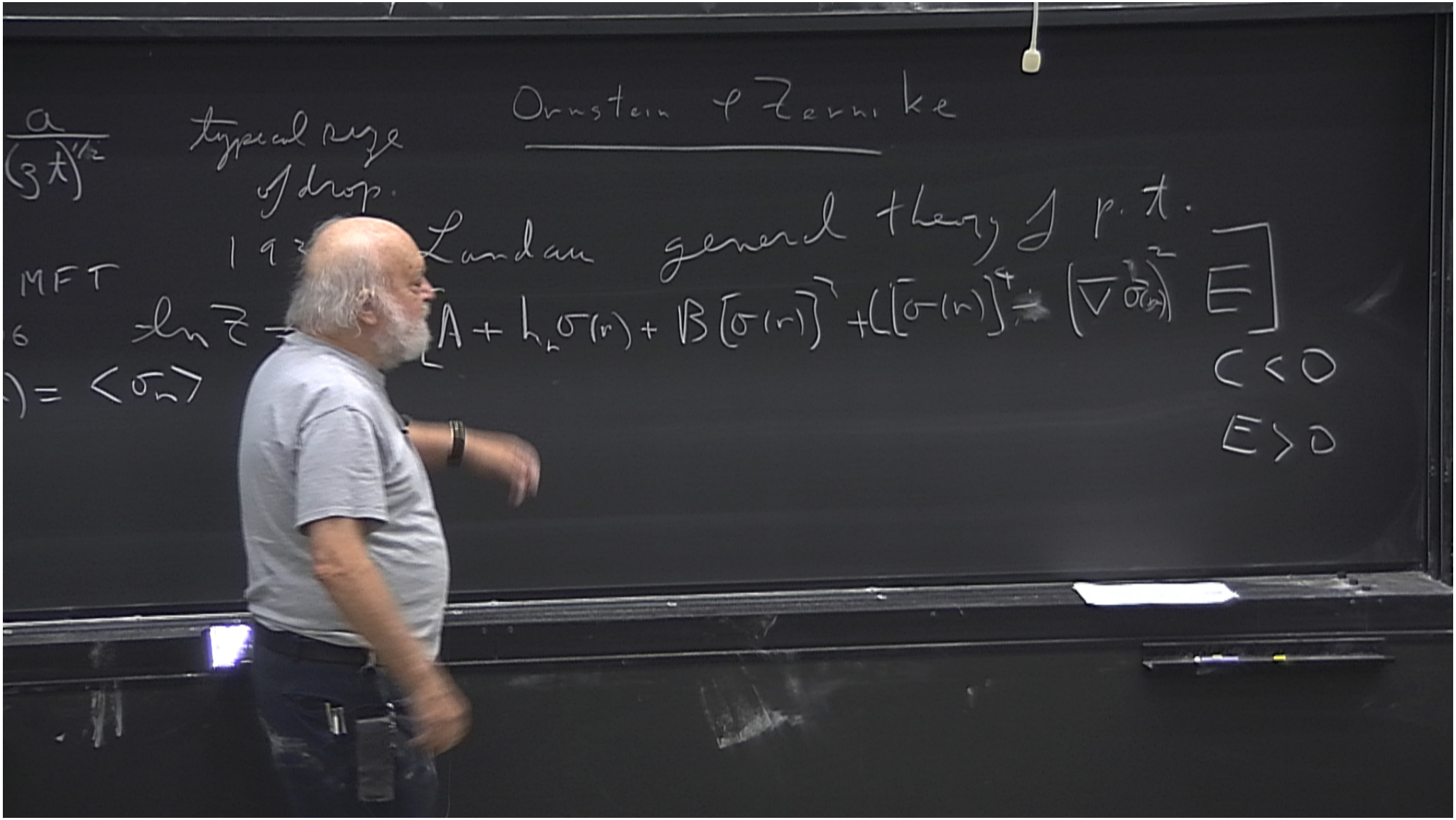

Ornstein & Zernike
typical size of drop.
Landau general theory of p.t.
MFT

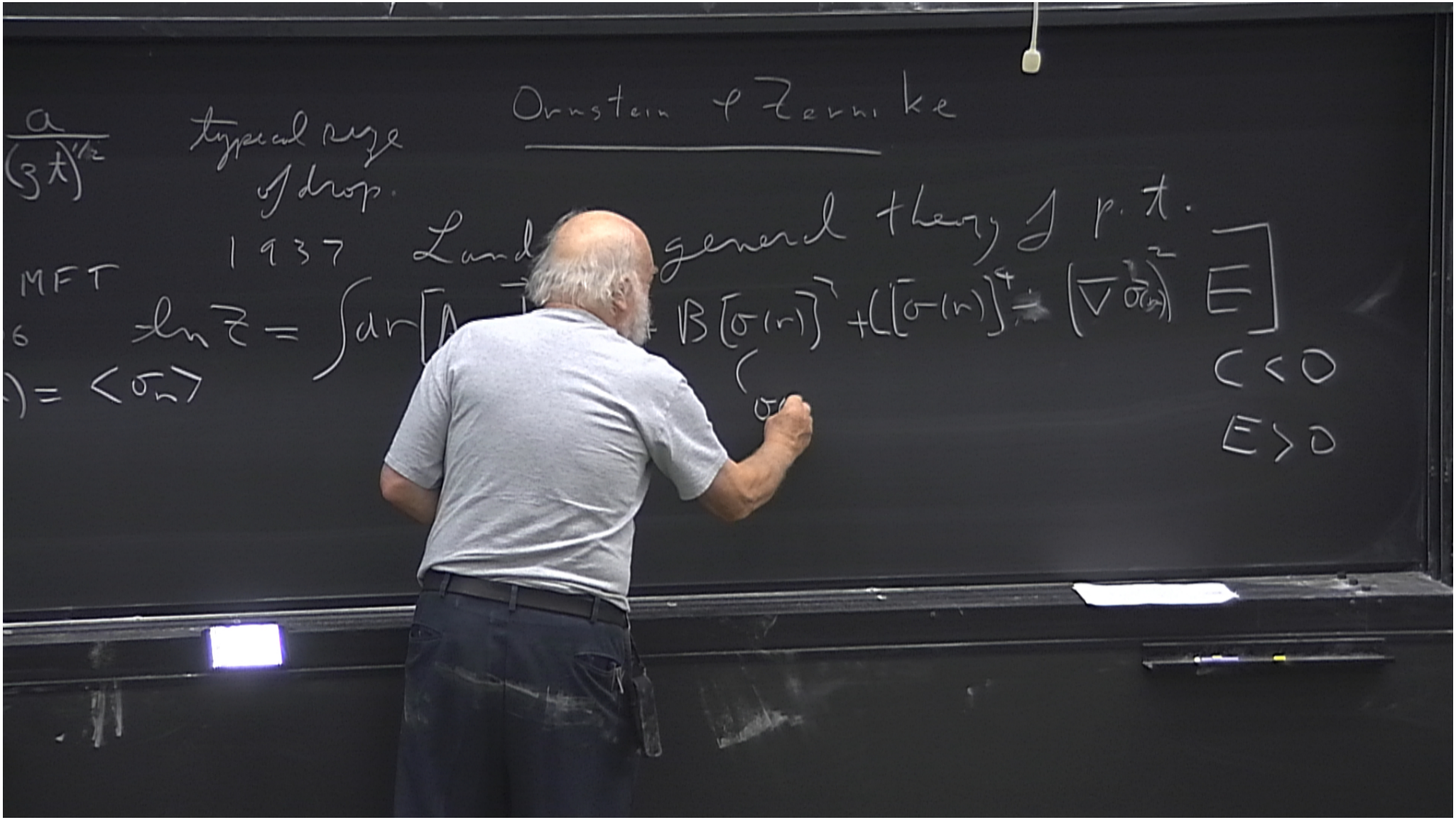

Ornstein & Zernike
typical size of drop.
1937 Landau
theory of p.t.
MFT
= 0.06

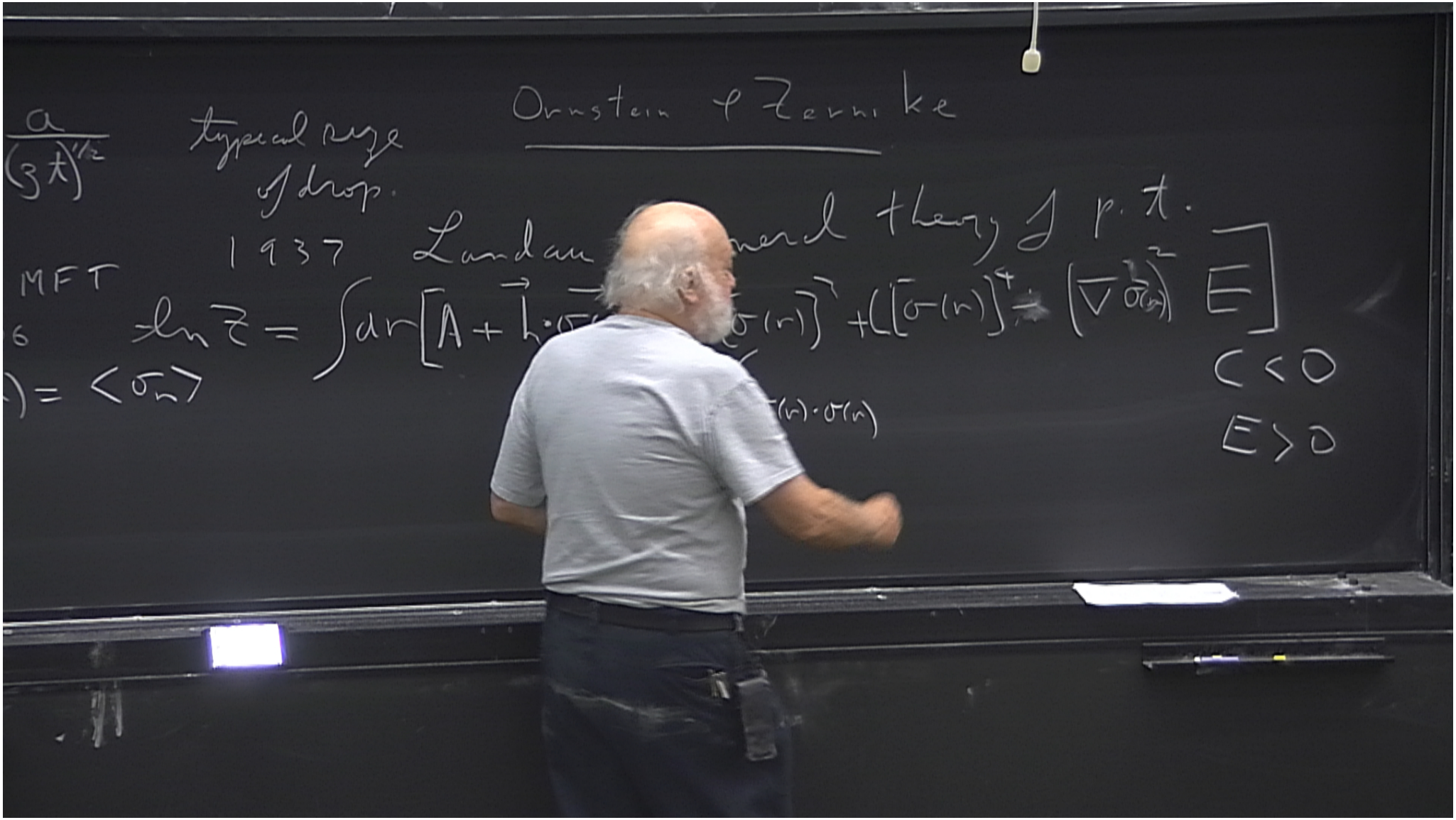

Ornstein + Zernike
typical range of drop.
1937 Landau
C<0

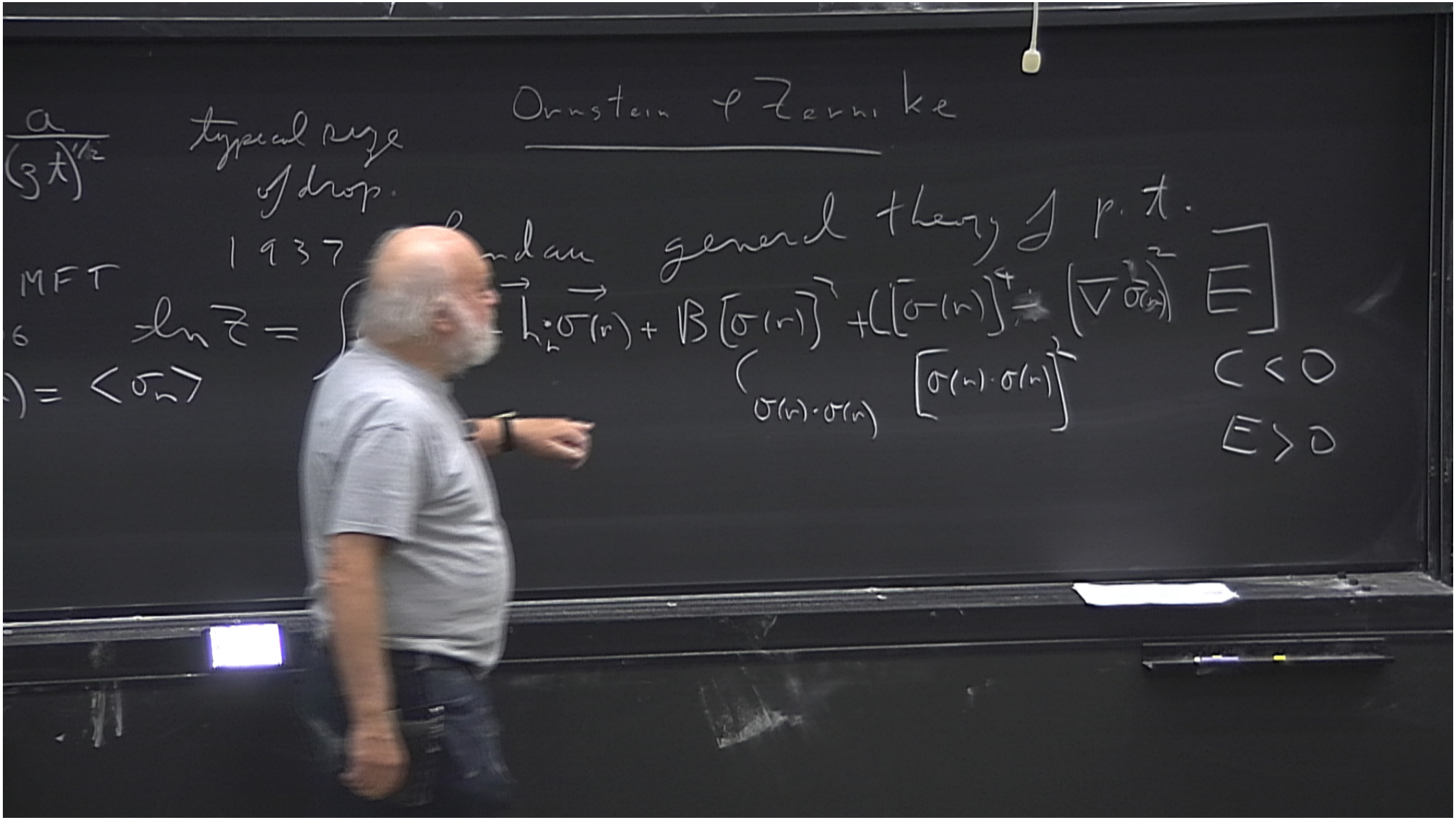

typical range of drop.
Ornstein + Zernike
Landau general theory f p.t.
C<0
E>0

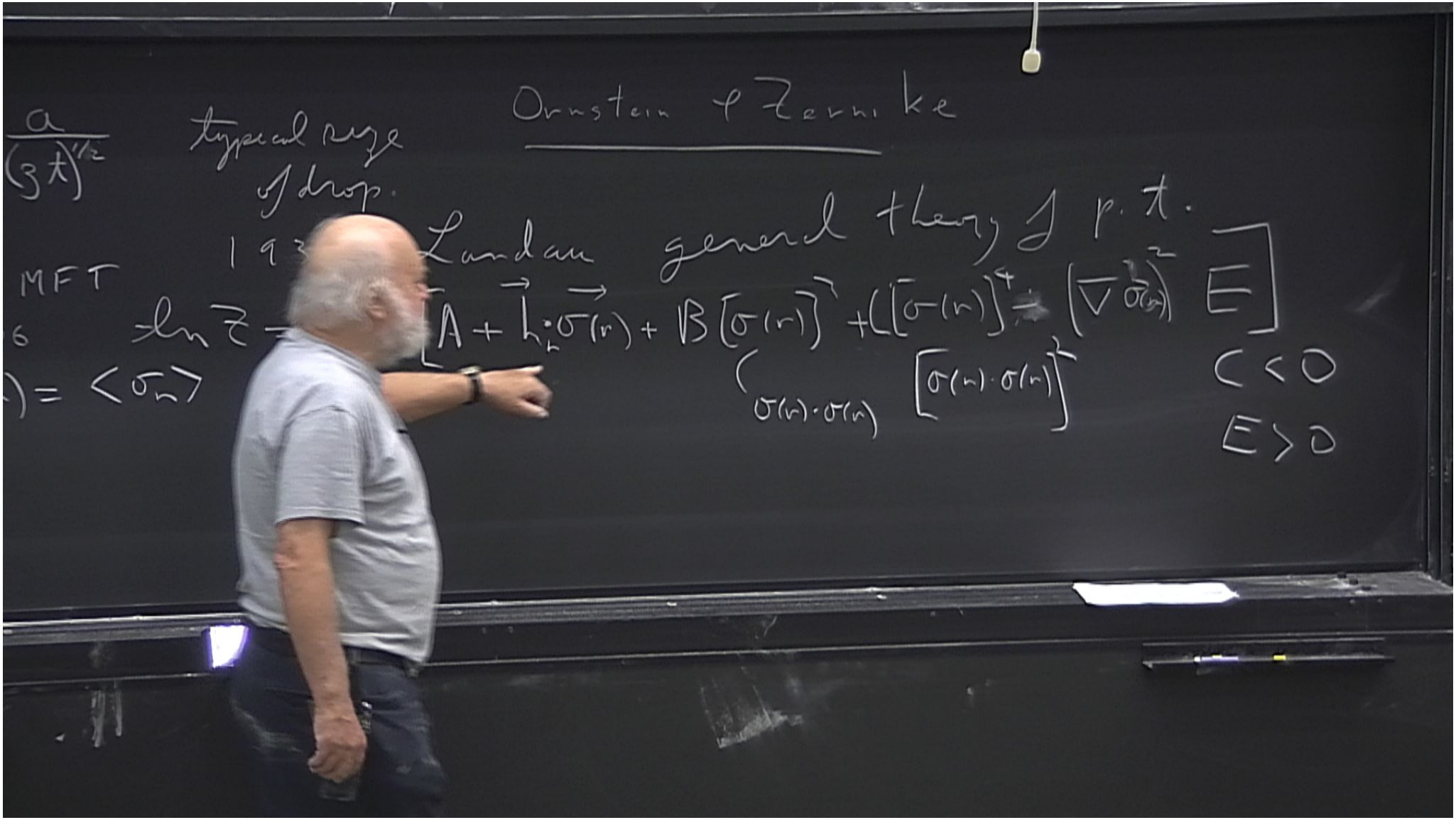

g(r-s) = 1/4π e^{-|r-s|/ξ} / |r-s| .
d=3
ξ = a/(ρt)^{1/2}
typical size of drop.
Ornst
scale
for |r-s| << ξ
1937 Landau
g ~ 1/|r-
η=0 MFT
=0.06
ln Z = ∫dr[A + h_r σ(r)
σ(r) = ⟨σ_r⟩

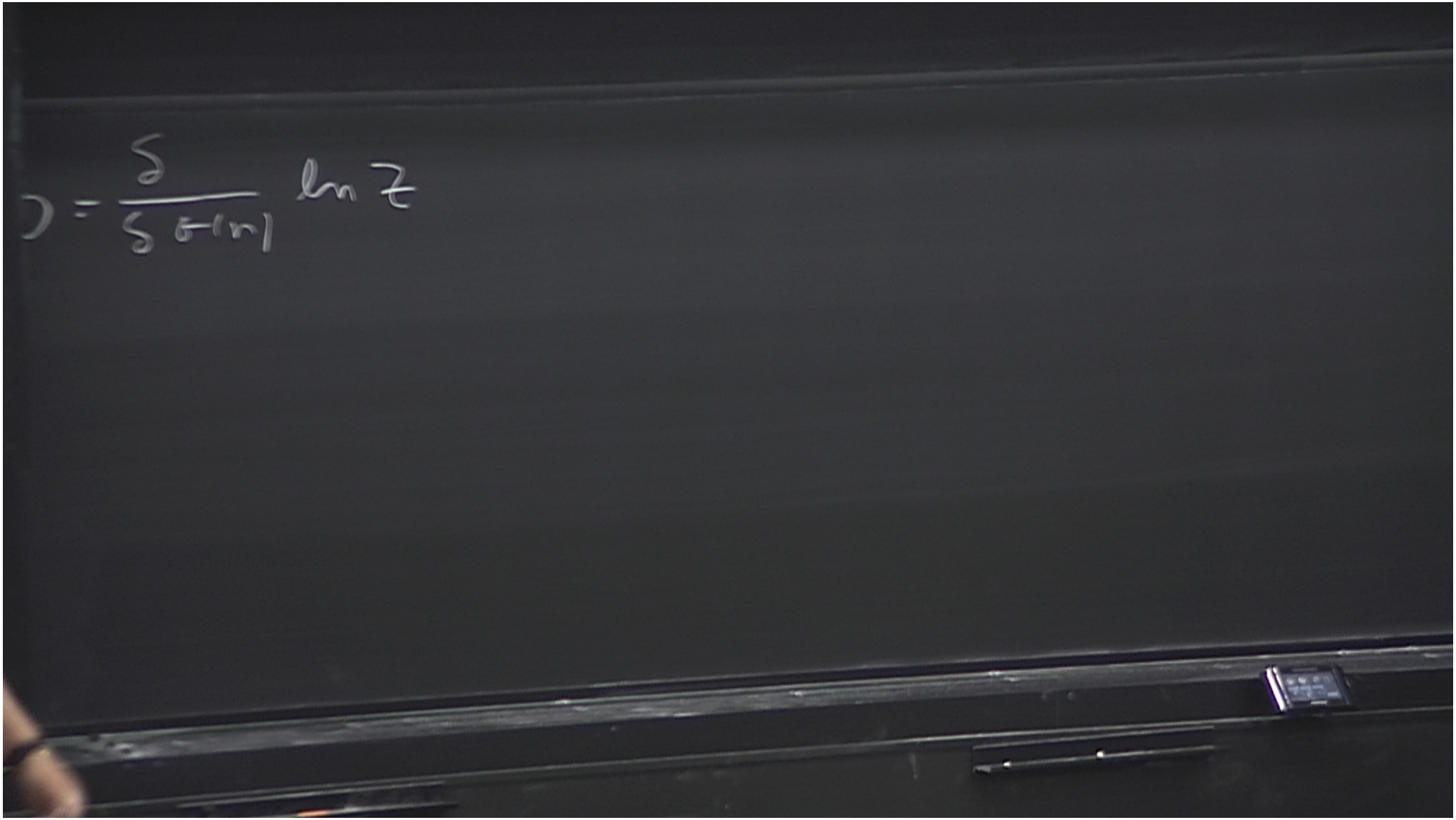

Ornstein + Zernike
typical size of drop.
Landau general theory of p.t.
MFT
C < 0
E > 0


Ornstein + Zernike
typical size of drop.
1937
MFT
C<0
E>0


Ornstein + Zernike
typical size of drop.
1937
MFT
C < 0
E > 0

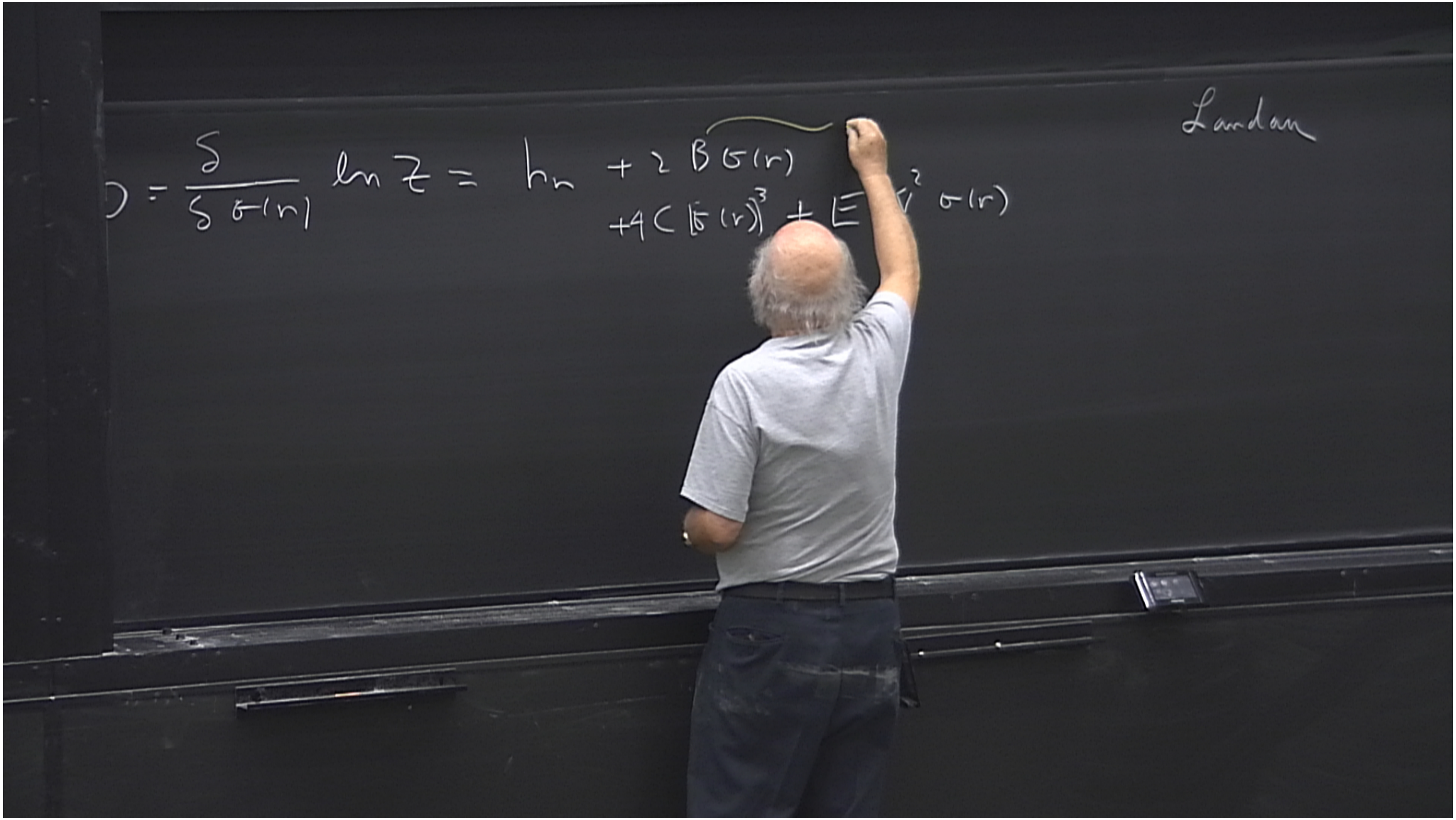

Ornstein & Zernike
typical size of drop.
1937
general theory of p.t.
MFT
C < 0
E > 0

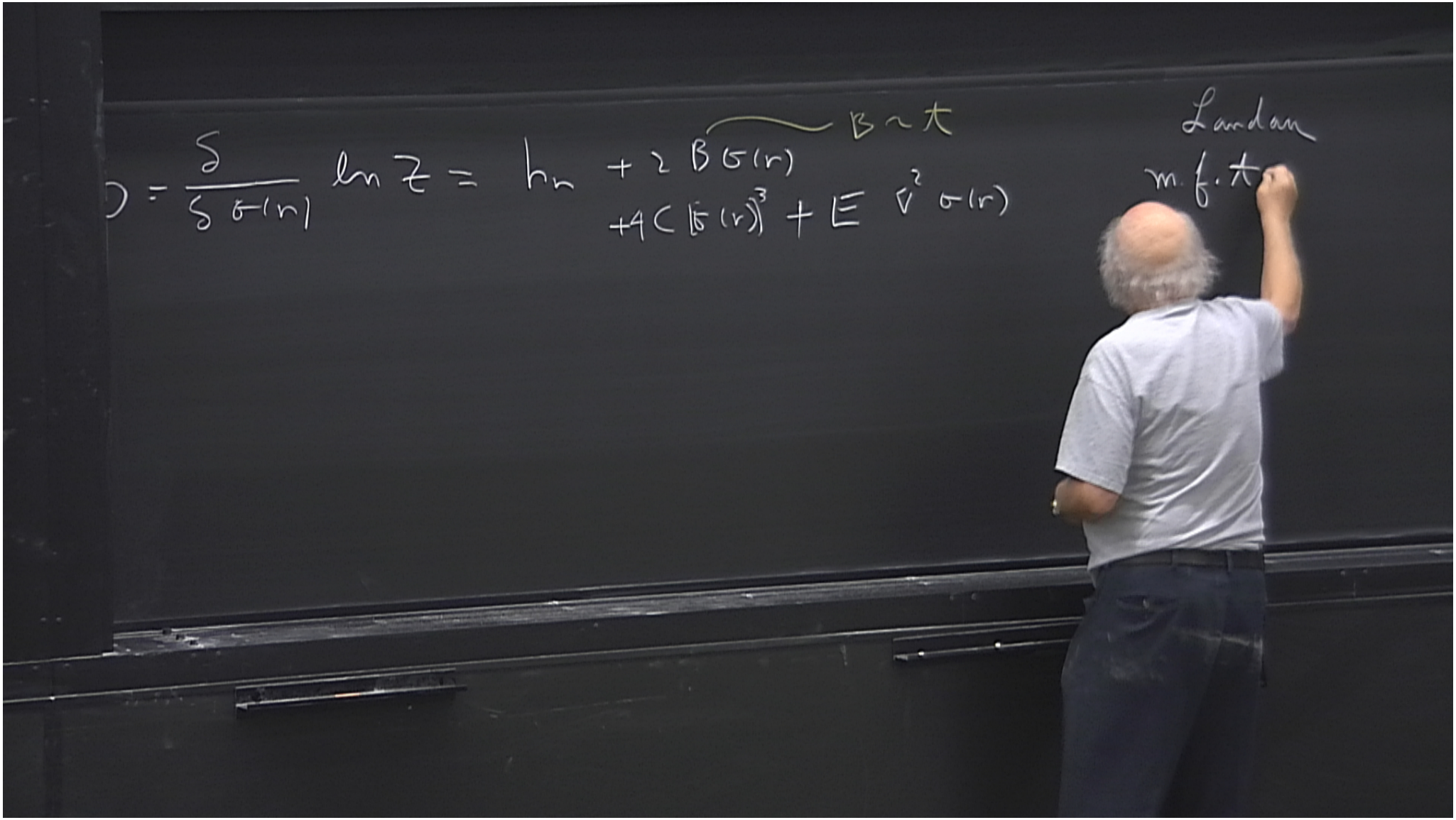

Ornstein + Zernike
typical size of drop.
Landau general theory of p.t.
MFT
C < 0
E > 0

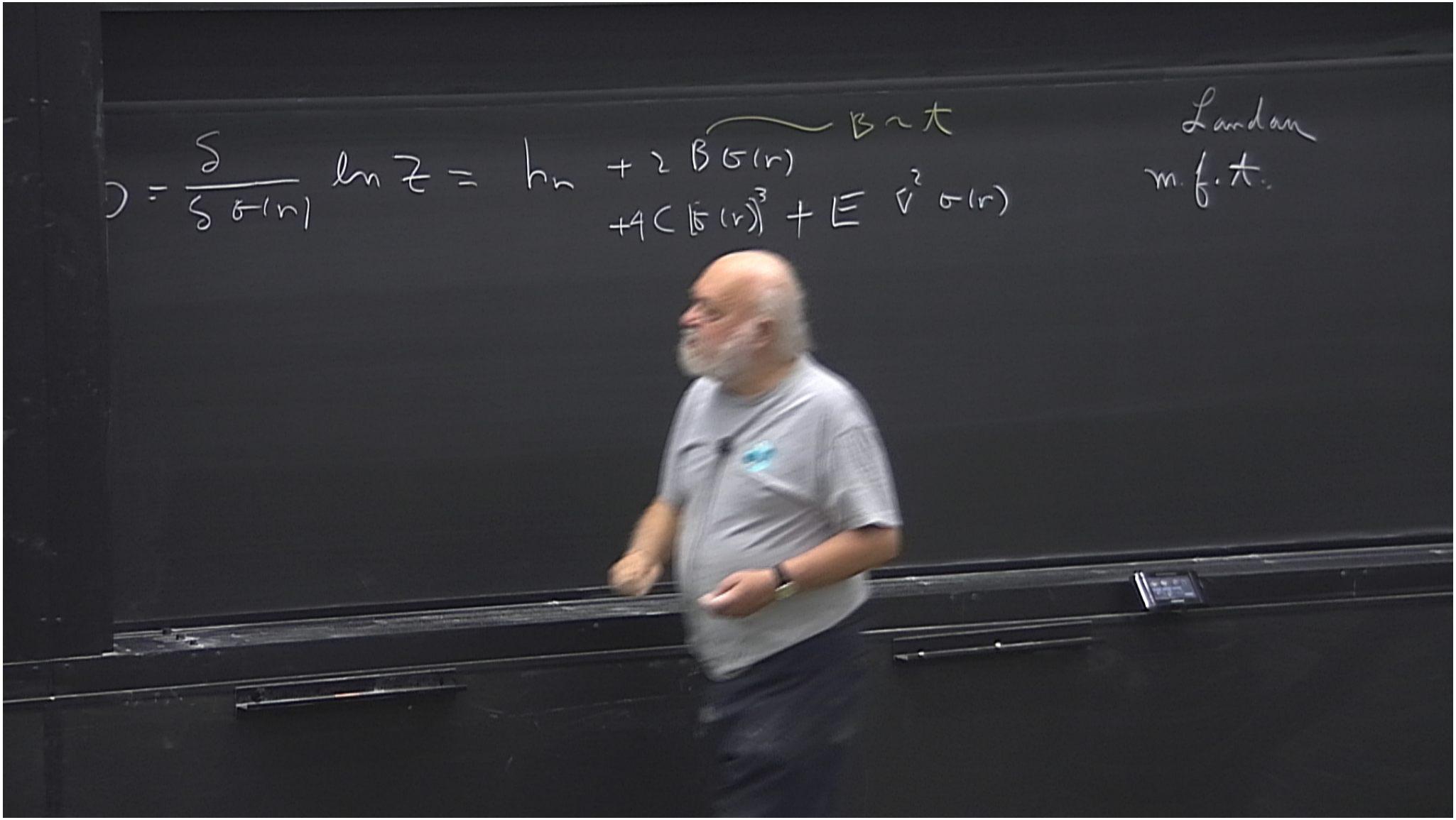

$= \frac{\delta}{\delta \sigma(n)} \ln Z$

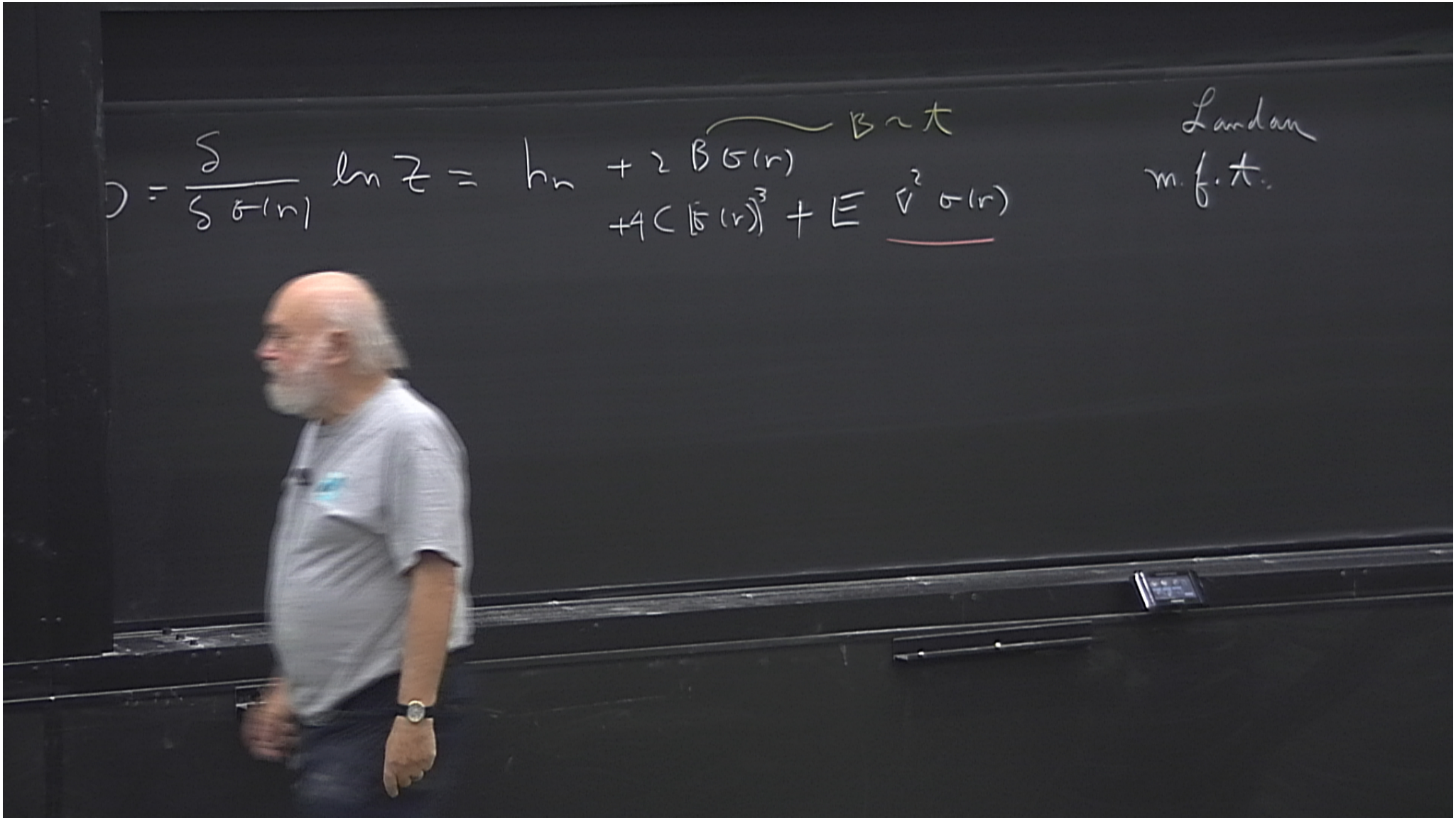
Landau

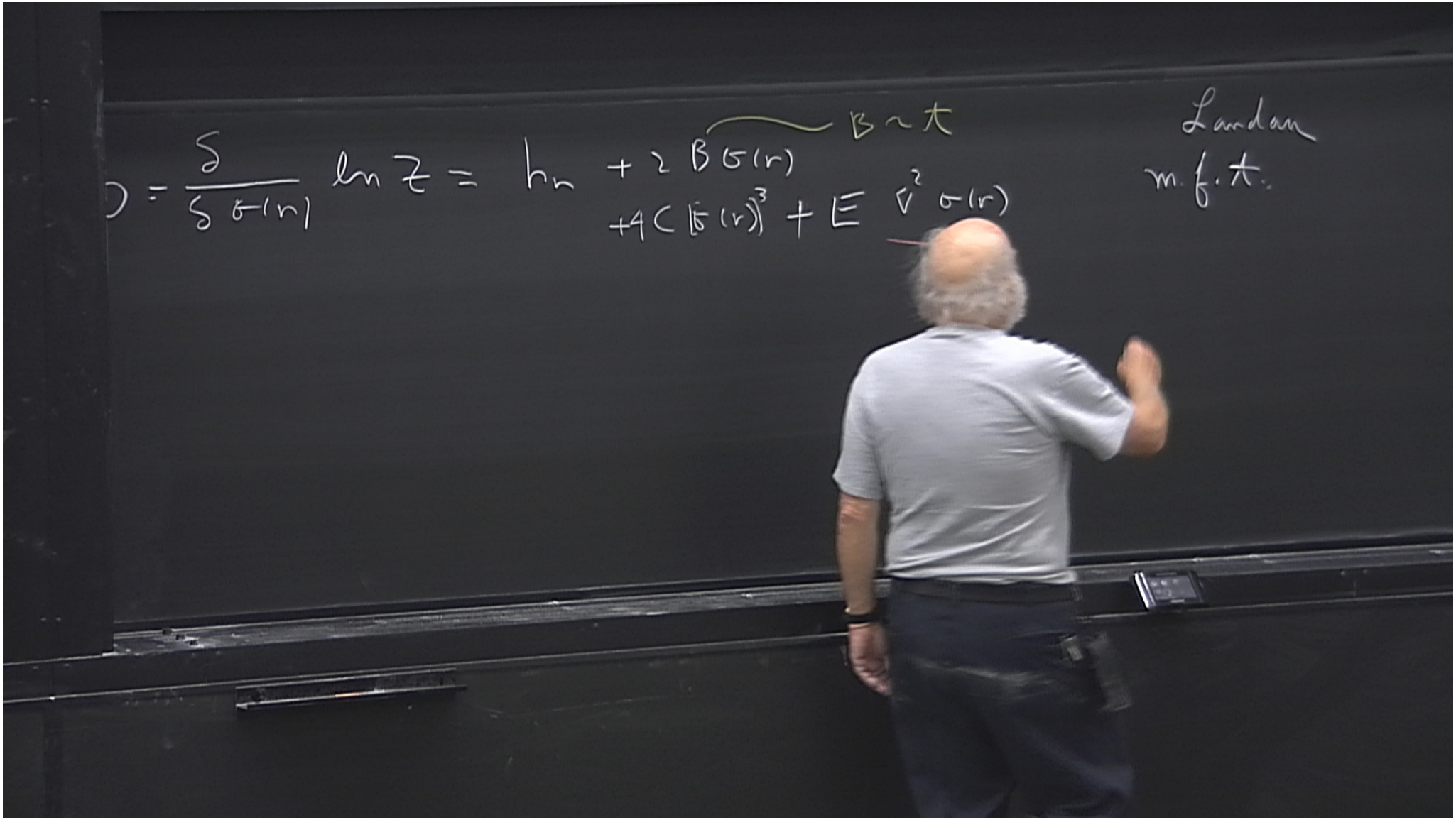
$$0 = \frac{\delta}{\delta \sigma(r)} \ln Z = h_r + 2B\sigma(r) + 4C(\sigma(r))^3 + E\nabla^2\sigma(r)$$

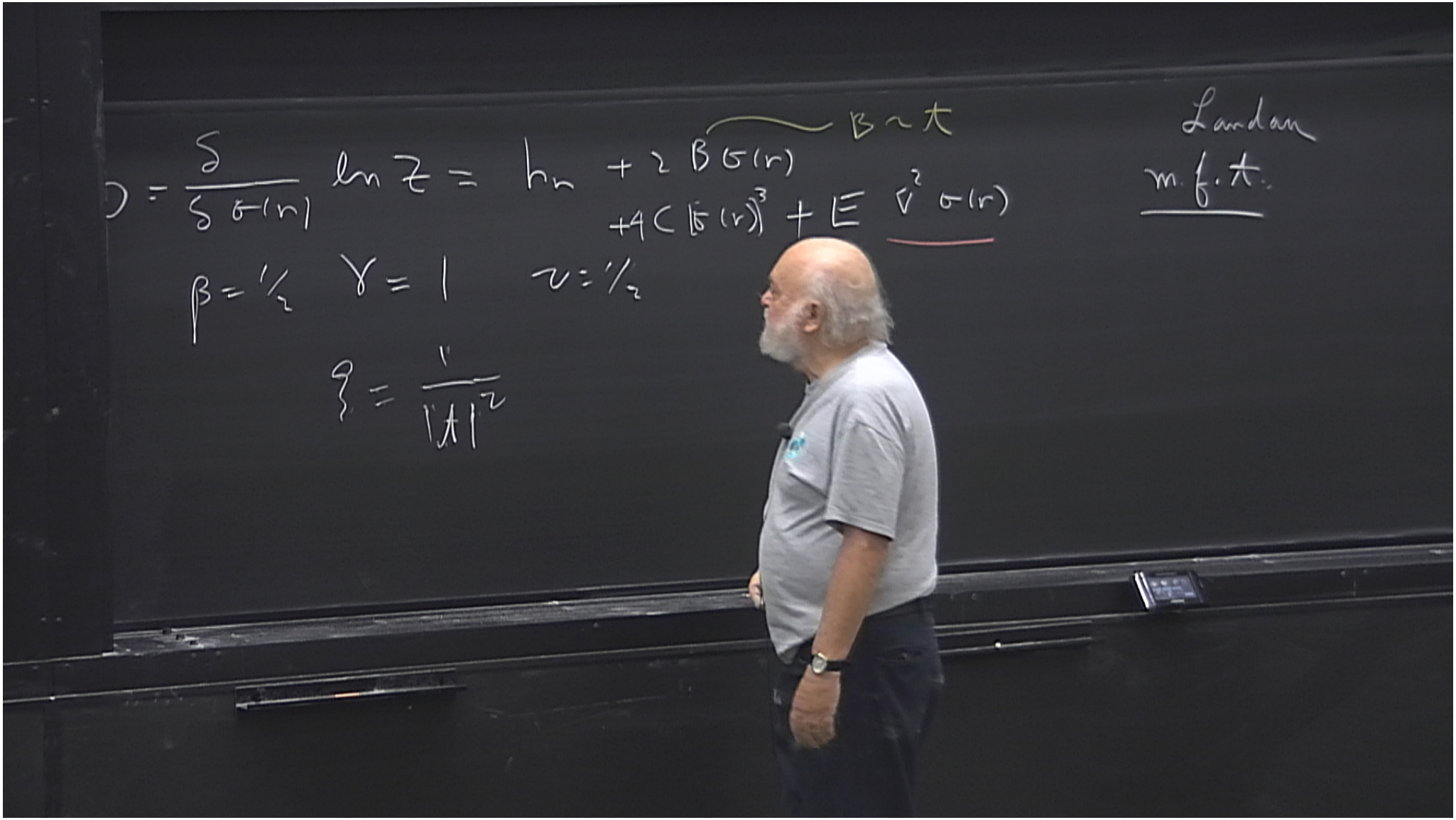

Landau

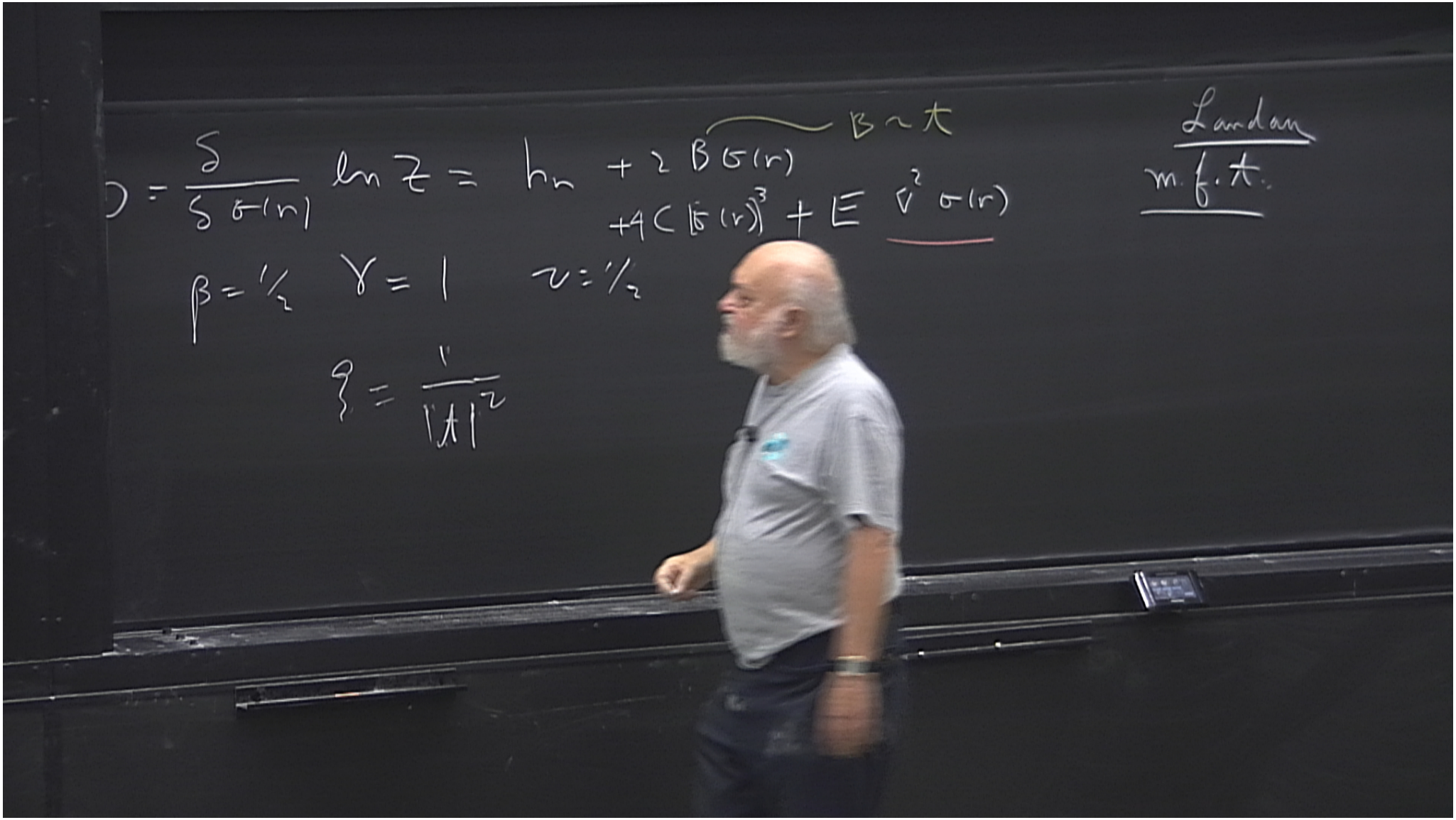

$0 = \frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(n) + 4C(\sigma(r))^3 + E\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t

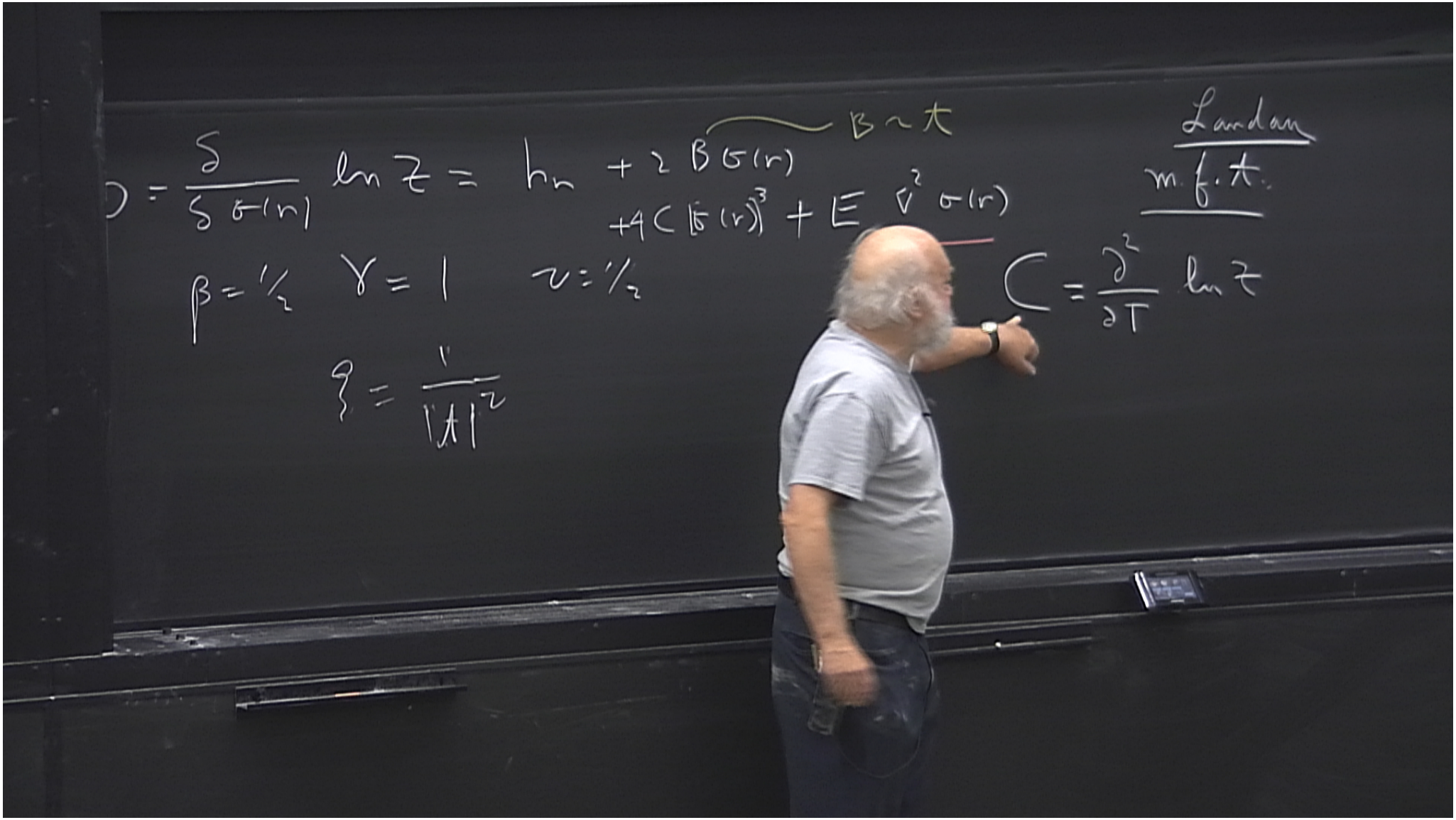

$0 = \frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(n) + 4C(\sigma(n))^3 + E\nabla^2\sigma(n)$
$B \sim t$
Landau
m.f.t.

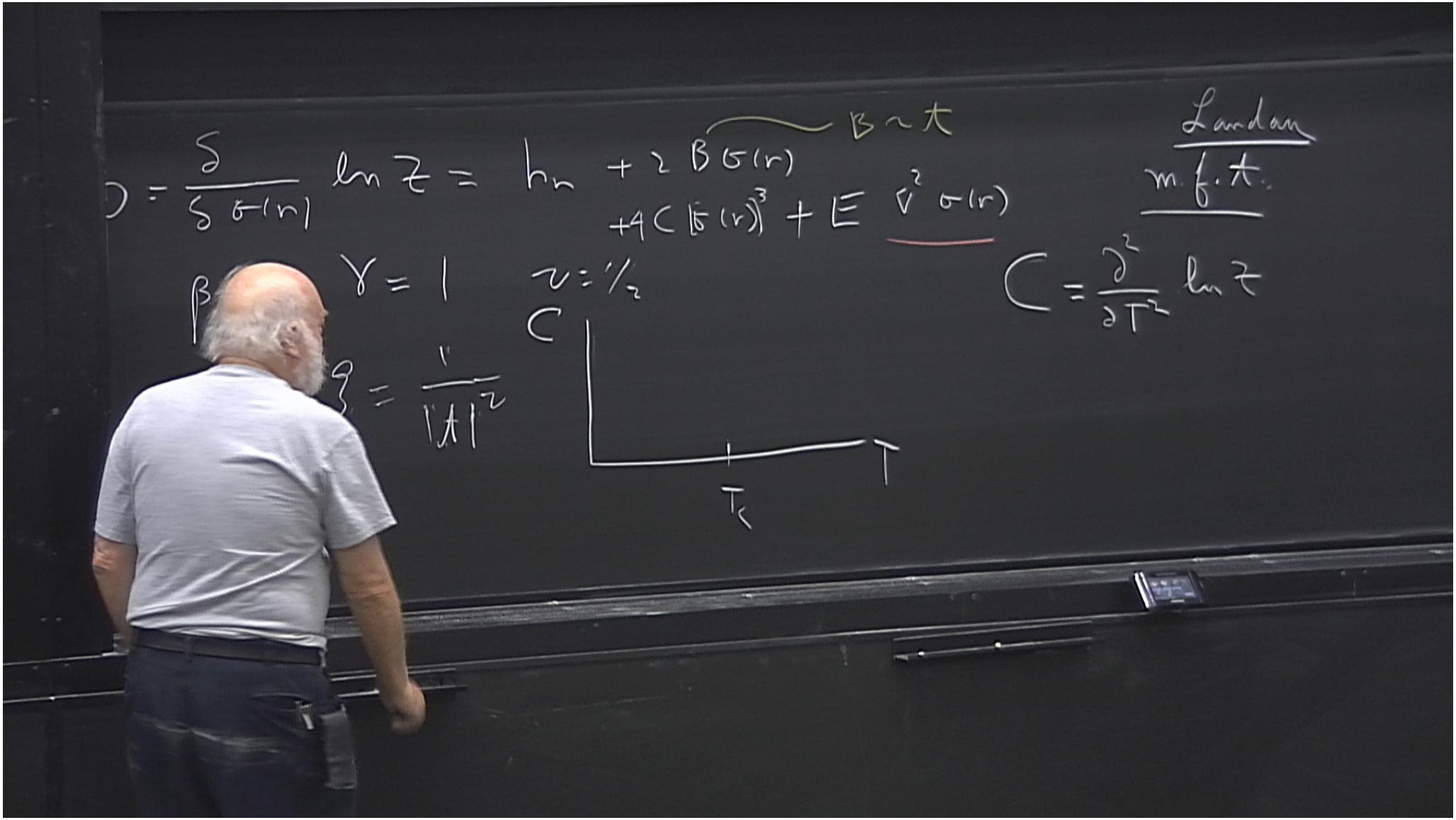

$0 = \frac{\delta}{\delta \sigma(r)} \ln Z = h_r + 2B\sigma(r) + 4C[\sigma(r)]^3 + E\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t.

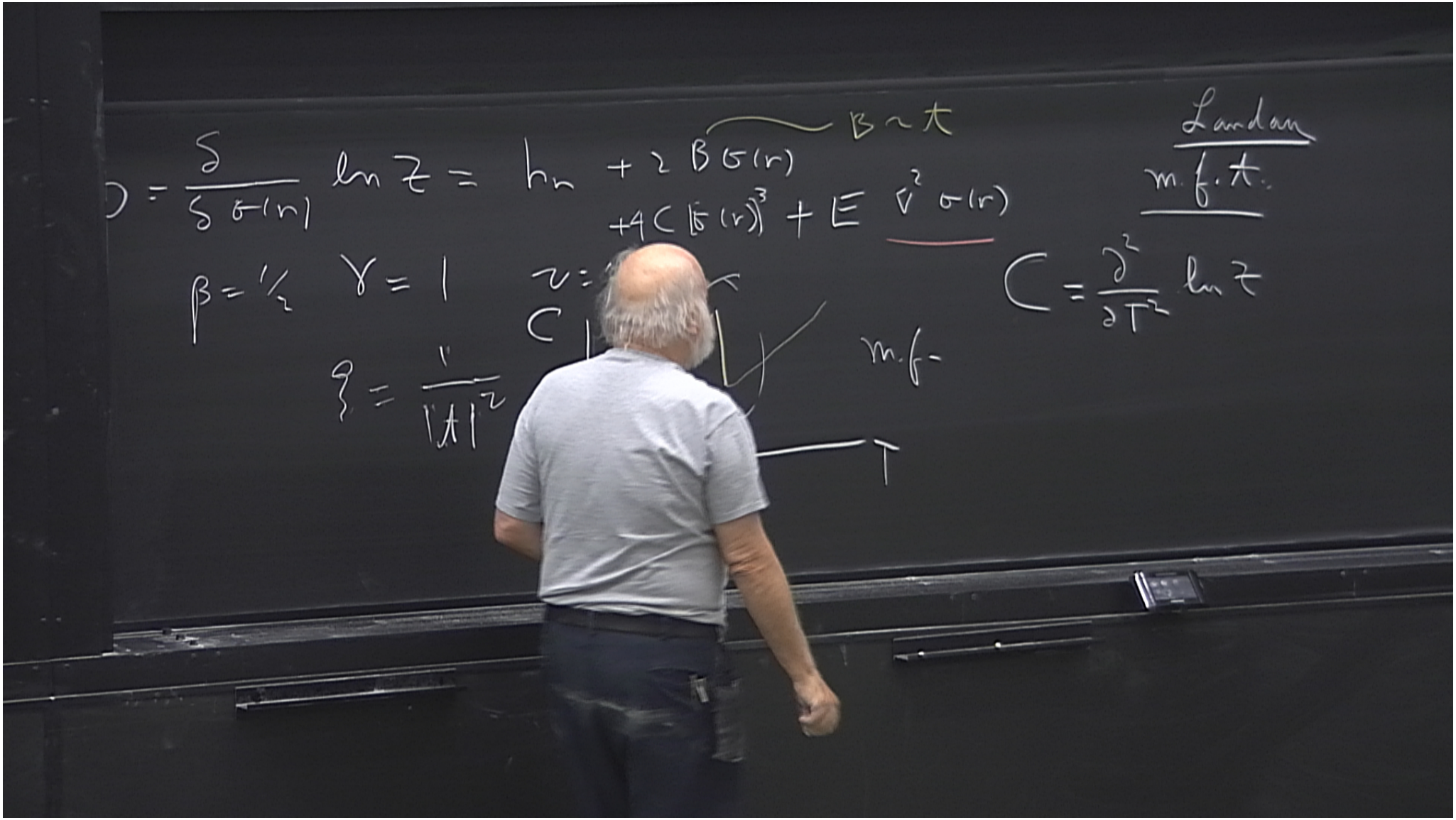

$0 = \frac{\delta}{\delta \sigma(r)} \ln Z = h_r + 2B\sigma(r) + 4C[\sigma(r)]^3 + E\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t.


$0 = \frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(r) + 4C(\sigma(r))^3 + E\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t.
$\beta = 1/2 \quad \gamma = 1 \quad \nu = 1/2$
$\xi = \frac{1}{|t|^2}$


$0 = \frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(n) + 4C[\sigma(n)]^3 + E\nabla^2\sigma(n)$
$B \sim t$
Landau
m.f.t.
$\beta = 1/2 \quad \gamma = 1 \quad \nu = 1/2$
$\xi = \frac{1}{|t|^2}$


$0 = \frac{\delta}{\delta \sigma(r)} \ln Z = h_r + 2B\sigma(r) + 4C[\sigma(r)]^3 + E\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t.
$\beta = 1/2 \quad \gamma = 1 \quad \nu = 1/2$
$C = \frac{\partial^2}{\partial T} \ln Z$
$\xi = \frac{1}{|t|^2}$


$0 = \frac{\delta}{\delta \sigma(r)} \ln Z = h_r + 2B\sigma(r) + 4C[\sigma(r)]^3 + E\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t.
β $\gamma = 1$ $\nu = 1/2$
$C = \frac{\partial^2}{\partial T^2} \ln Z$
$\xi = \frac{1}{|t|^2}$
C
T
T_c


$0 = \frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(n)$
$+4C(\sigma(r))^3 + E\,\nabla^2\sigma(r)$
$B \sim t$
Landau
m.f.t.
$\beta = 1/2 \quad \gamma = 1$
$\xi = \frac{1}{|t|^2}$
$C = \frac{\partial^2}{\partial T^2} \ln Z$
m.f.
T

$$0 = \frac{\delta}{\delta \sigma(r)} \ln Z = h_r + 2B\sigma(r) + 4C[\sigma(r)]^3 + E\nabla^2\sigma(r)$$

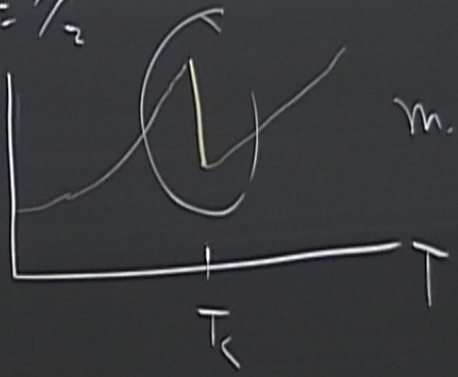
$B \sim t$

Landau

m.f.t.

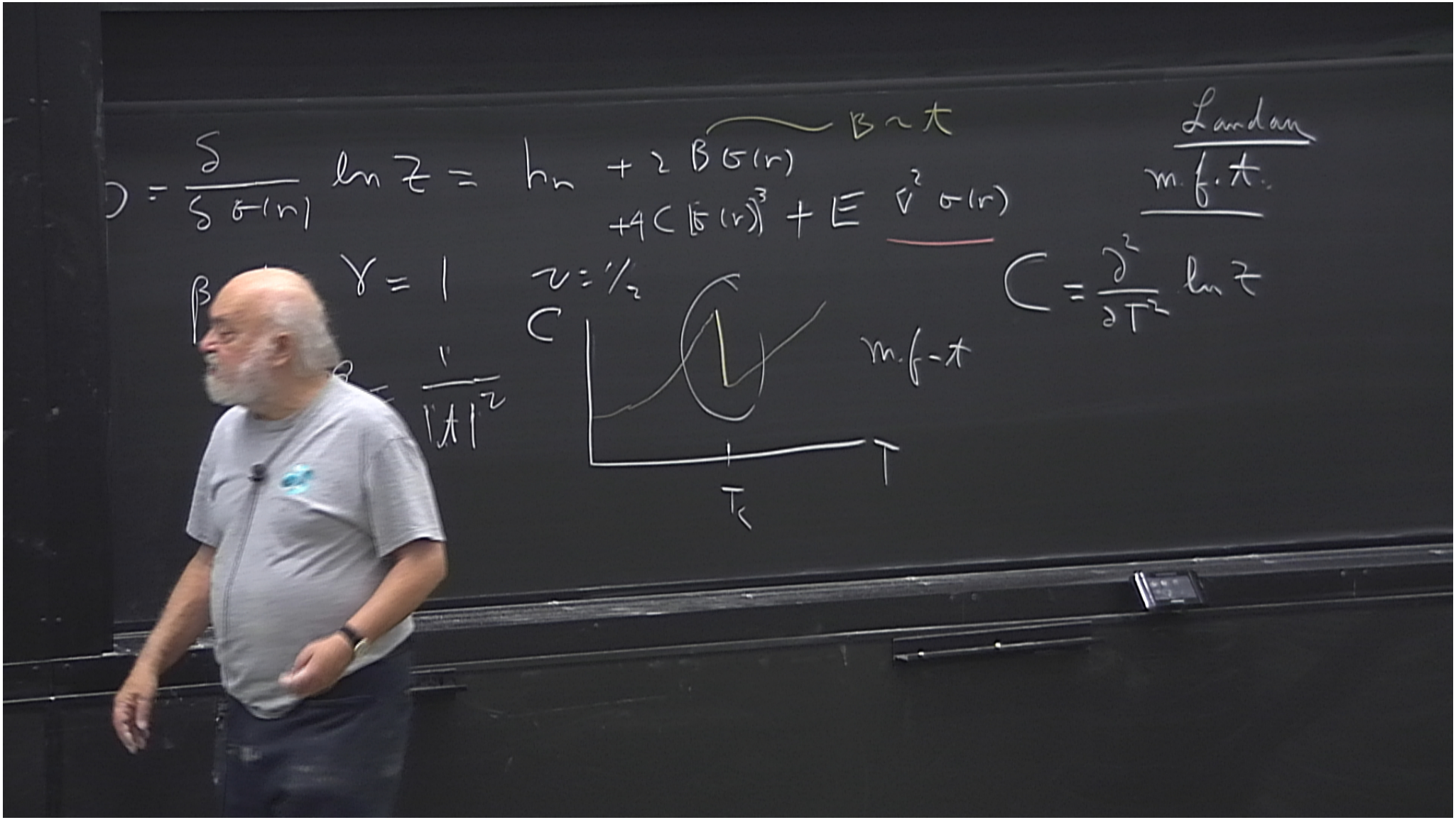
$\beta = 1/2 \quad \gamma = 1 \quad \nu = 1/2$

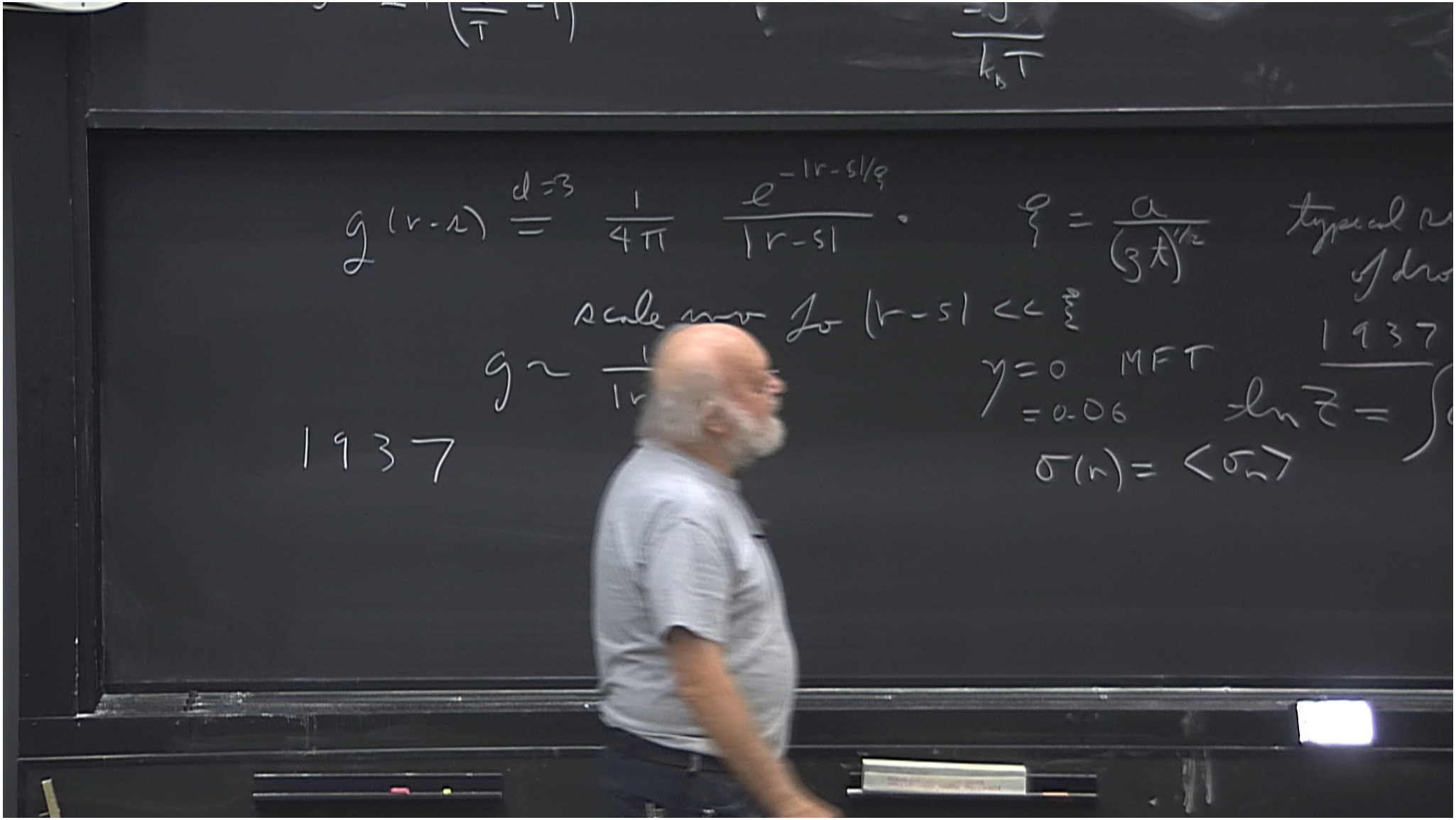
$$\xi = \frac{1}{|t|^{\nu}}$$

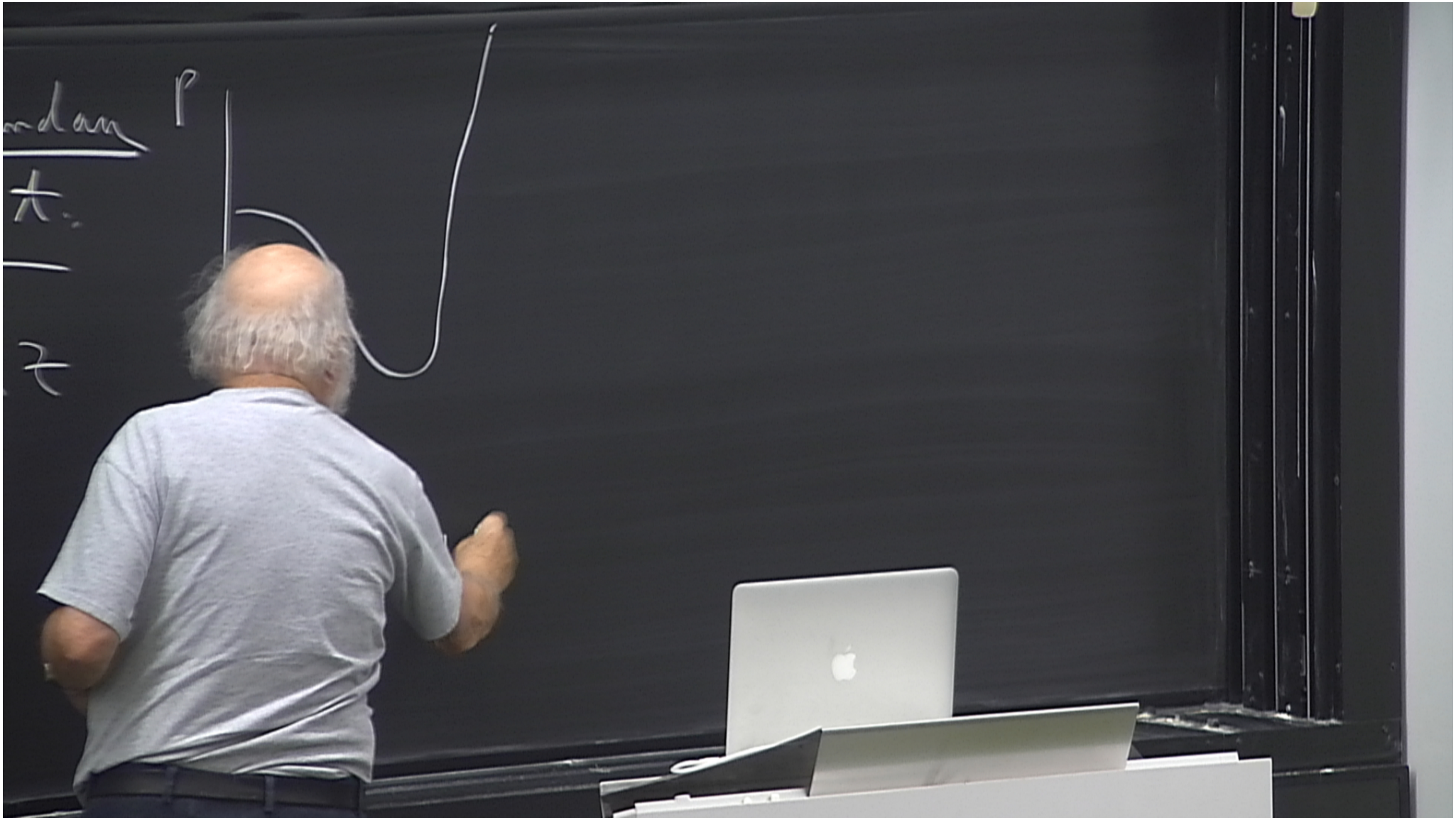


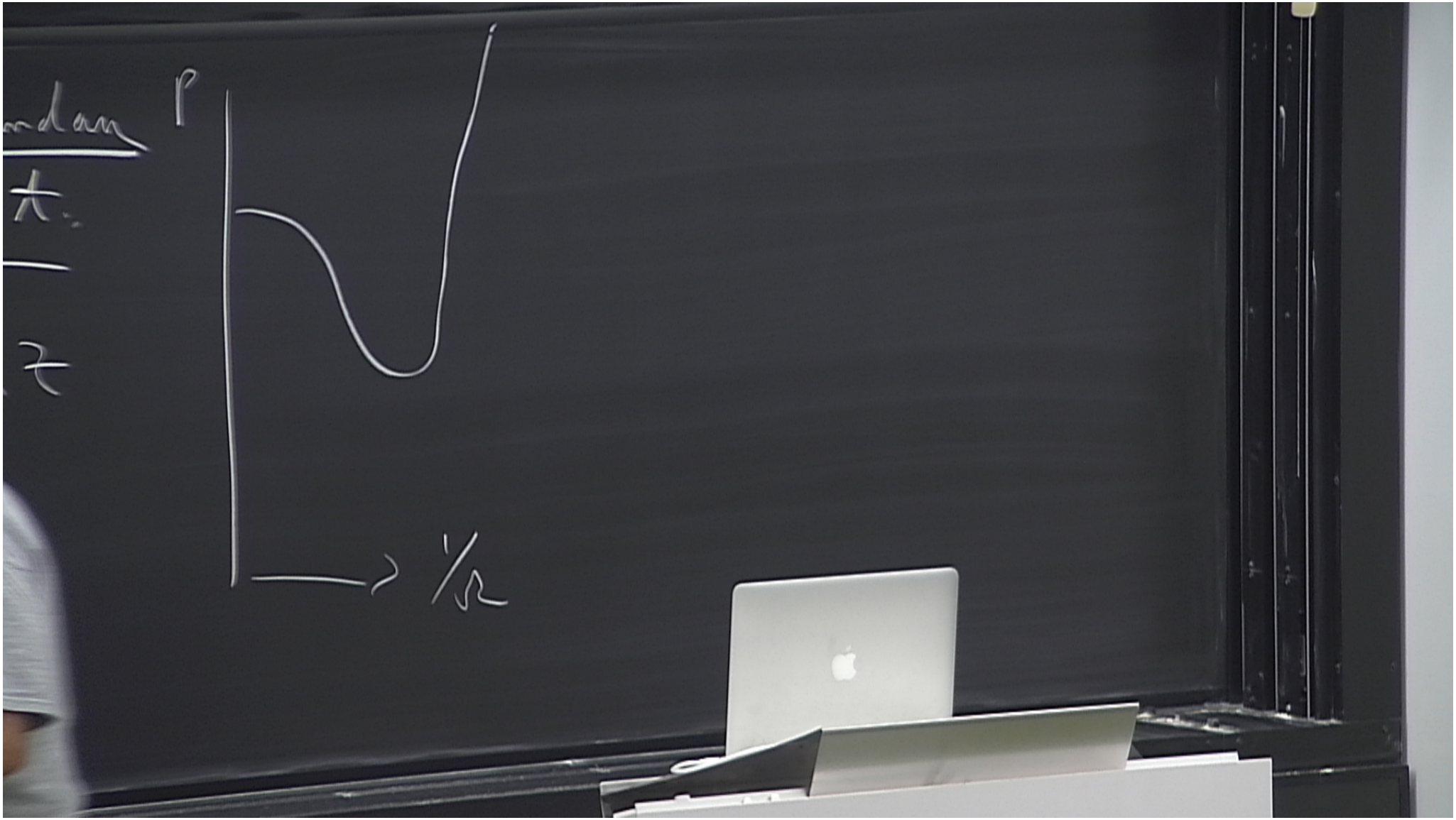
m.f.-t

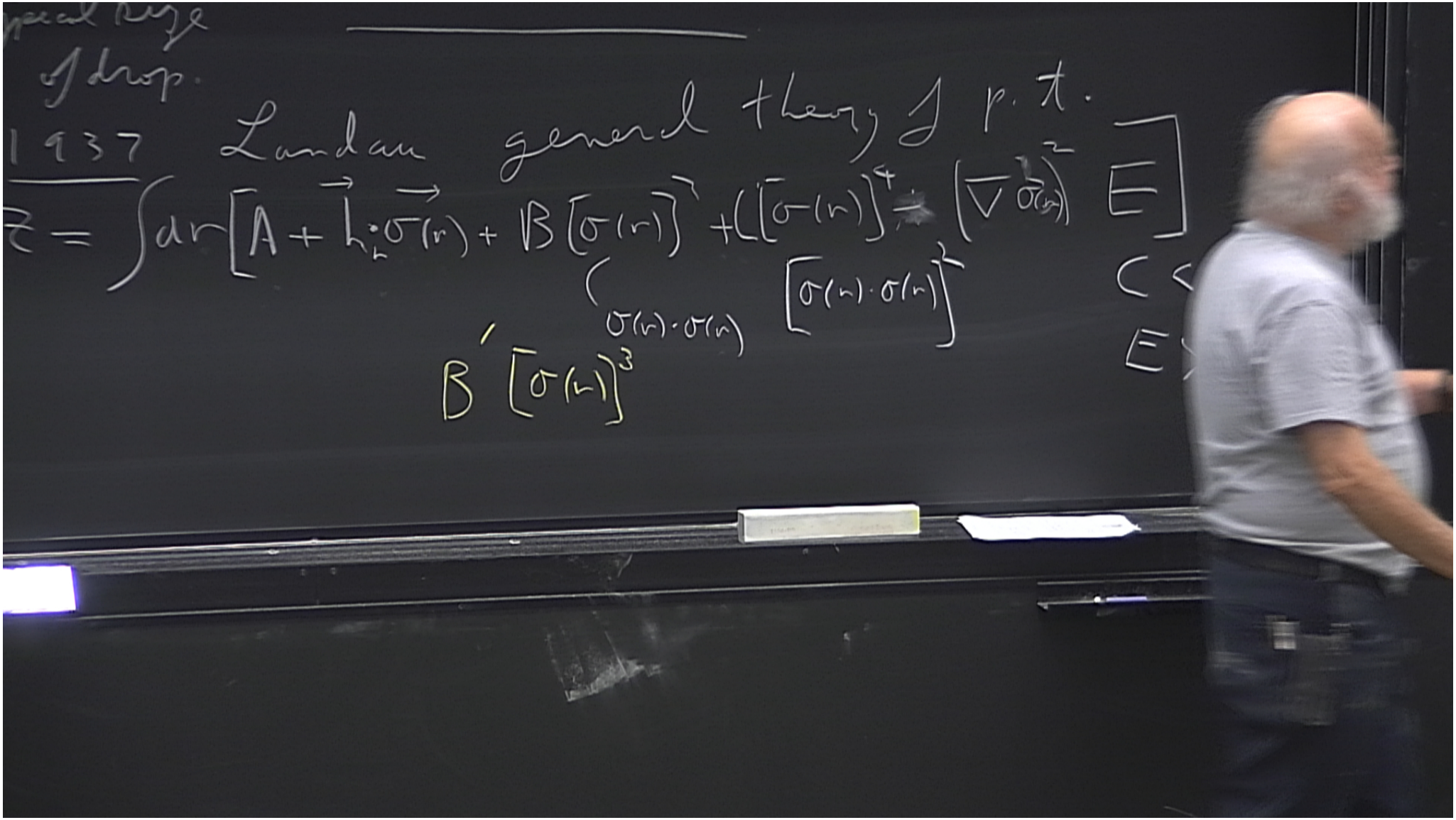
$$C = \frac{\partial^2}{\partial T^2} \ln Z$$

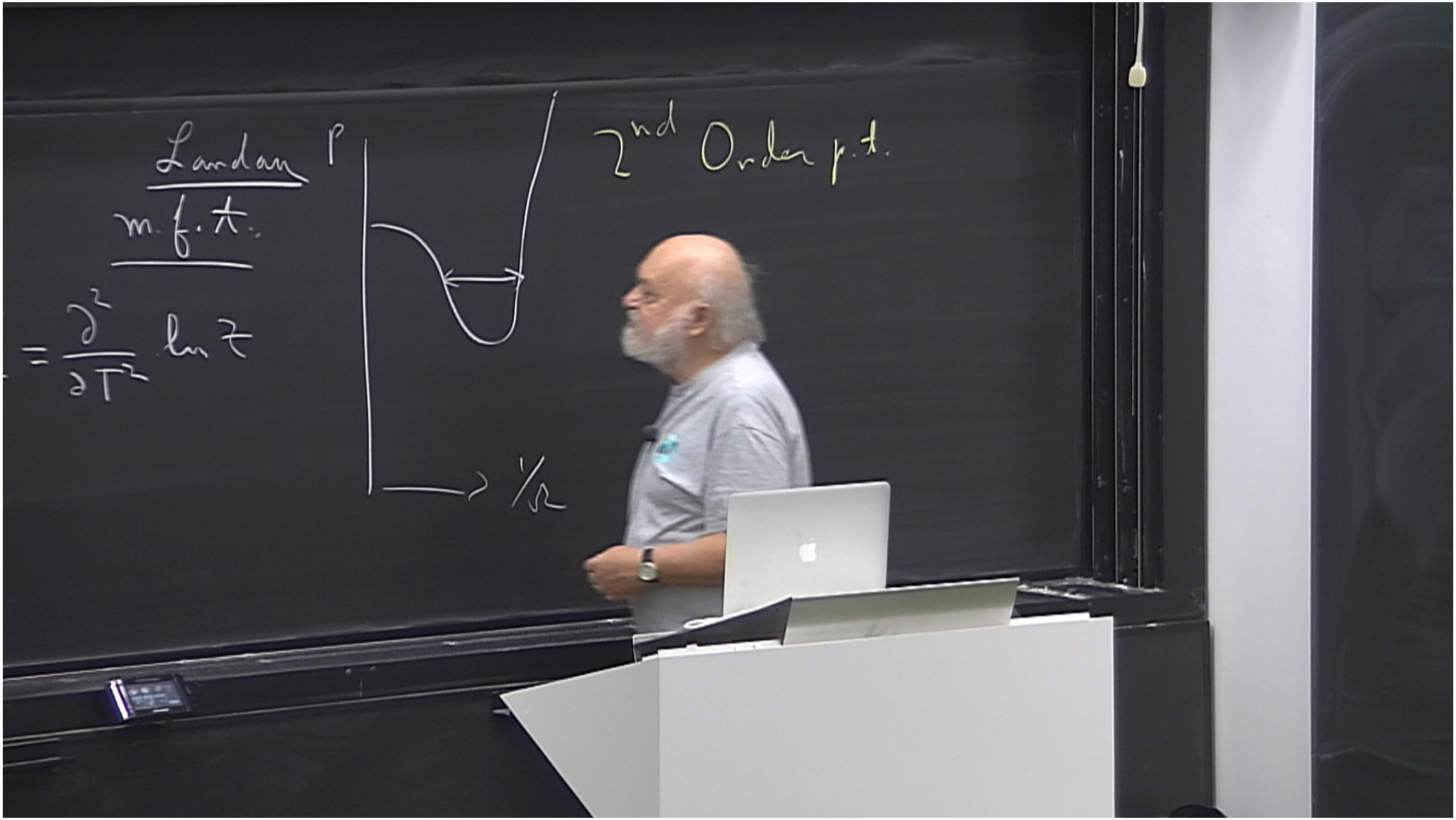

$\frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(n) + 4C[\sigma(n)]^3 + E\nabla^2\sigma(n)$
$B \sim t$
Landau
m.f.t.
$\gamma = 1$
$\nu = 1/2$
$C = \frac{\partial^2}{\partial T^2} \ln Z$
$\frac{1}{|t|^2}$
C
m.f.-t
T
T_c

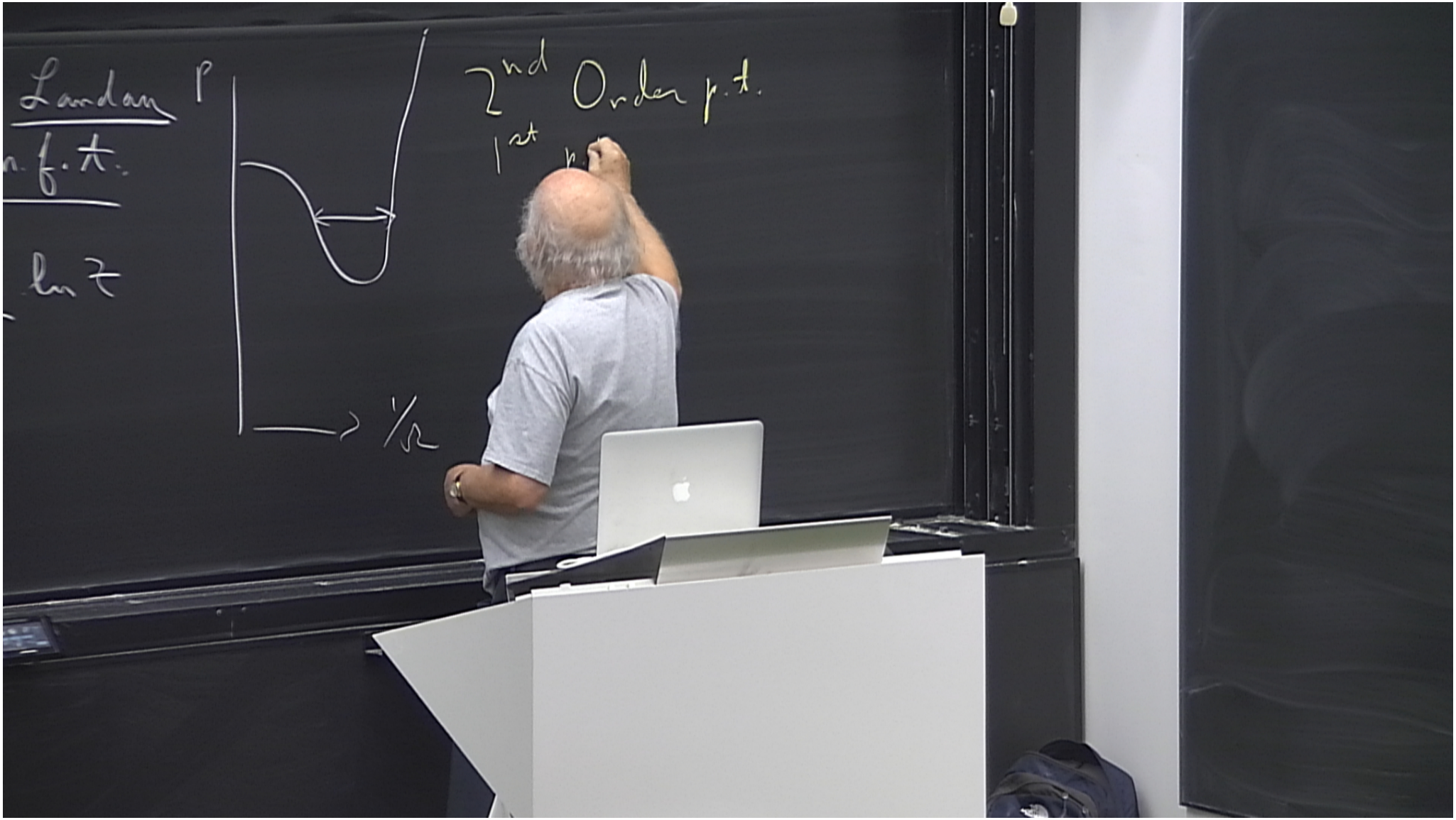

$\frac{-J}{k_B T}$
$g(r-s) \overset{d=3}{=} \frac{1}{4\pi} \frac{e^{-|r-s|/\xi}}{|r-s|}$
$\xi = \frac{a}{(3t)^{1/2}}$
scale
$|r-s| \ll$
$g \sim$
$\gamma = 0$ MFT
$= 0.06$
$\sigma(n) = \langle \sigma_n \rangle$
1937
1937

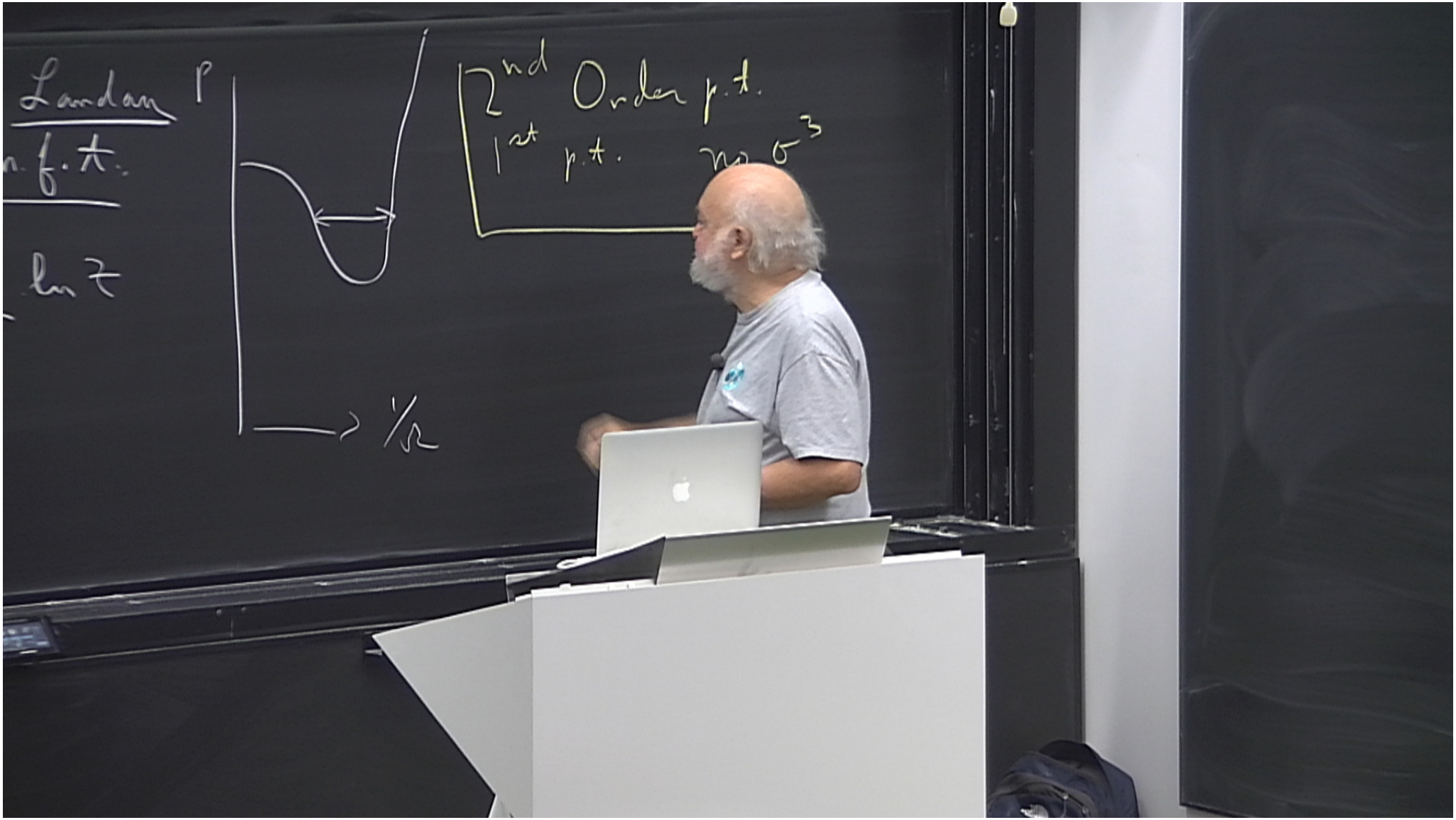


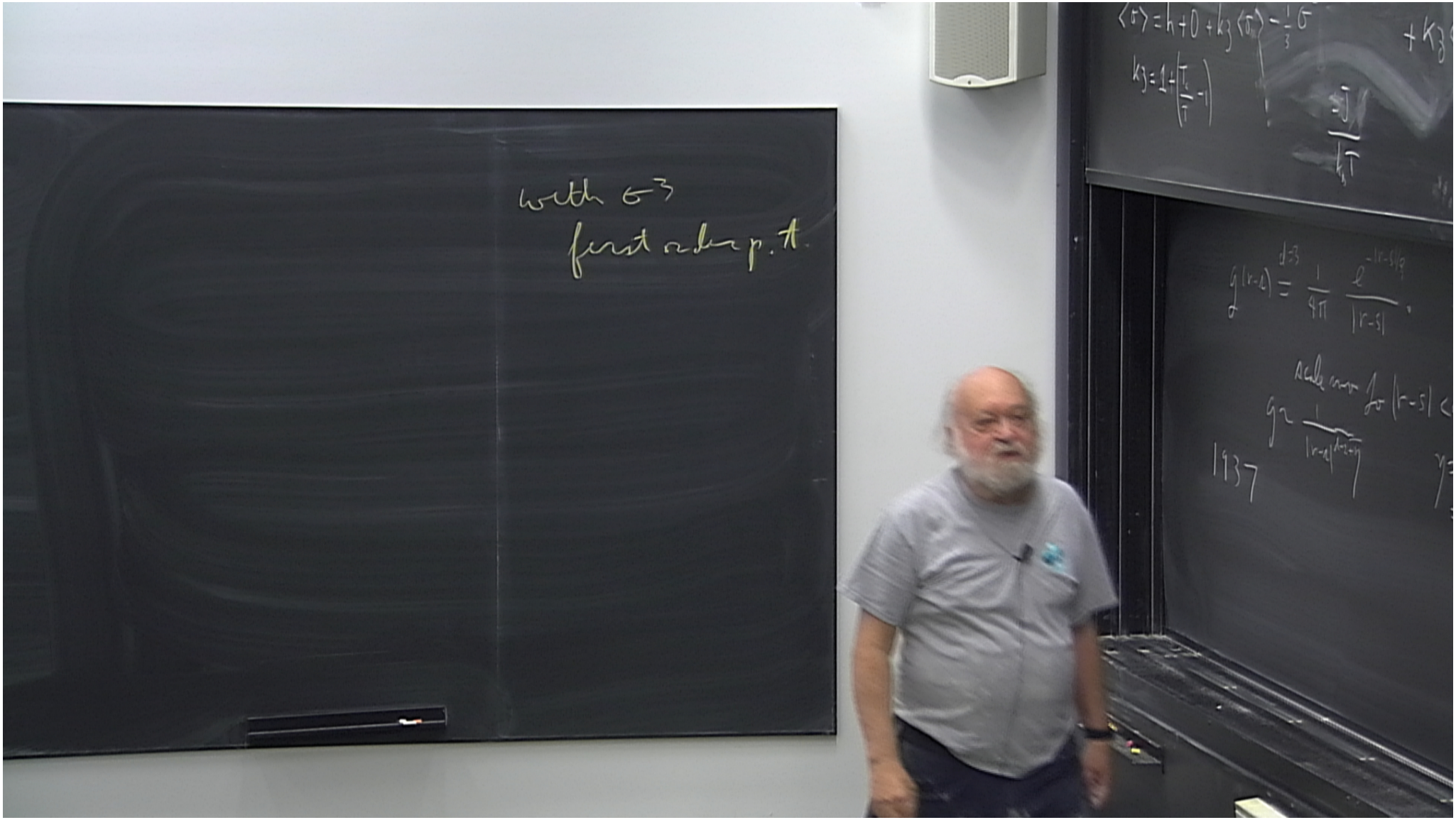

P
1/2

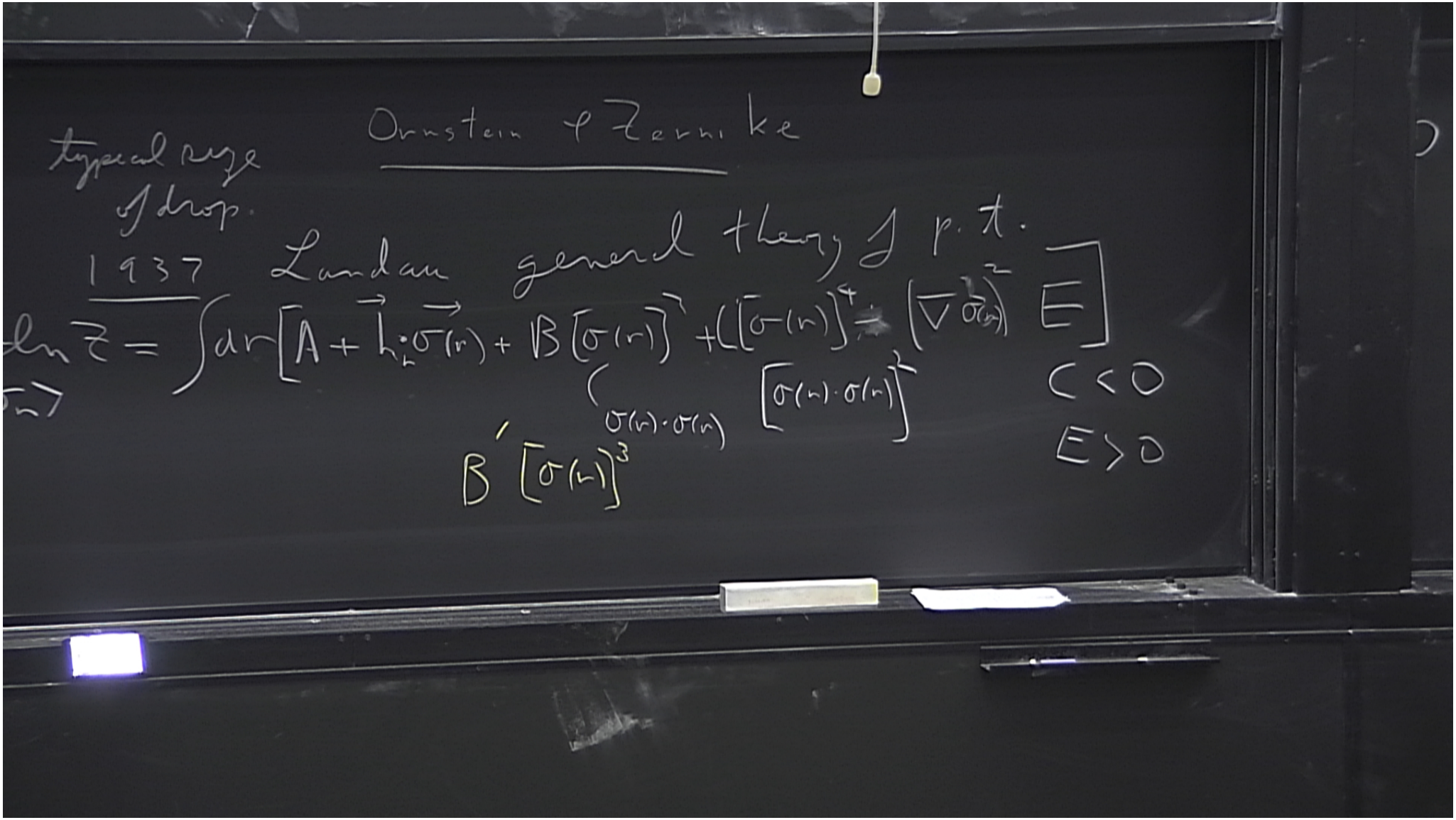

of drop.
1937 Landau general theory of p.t.
Z = ∫dr [A + h_r · σ(r) + B [σ(r)]^2 + C [σ(r)]^4 + (∇σ(r))^2 E]
σ(r)·σ(r)
[σ(r)·σ(r)]^2
B' [σ(r)]^3

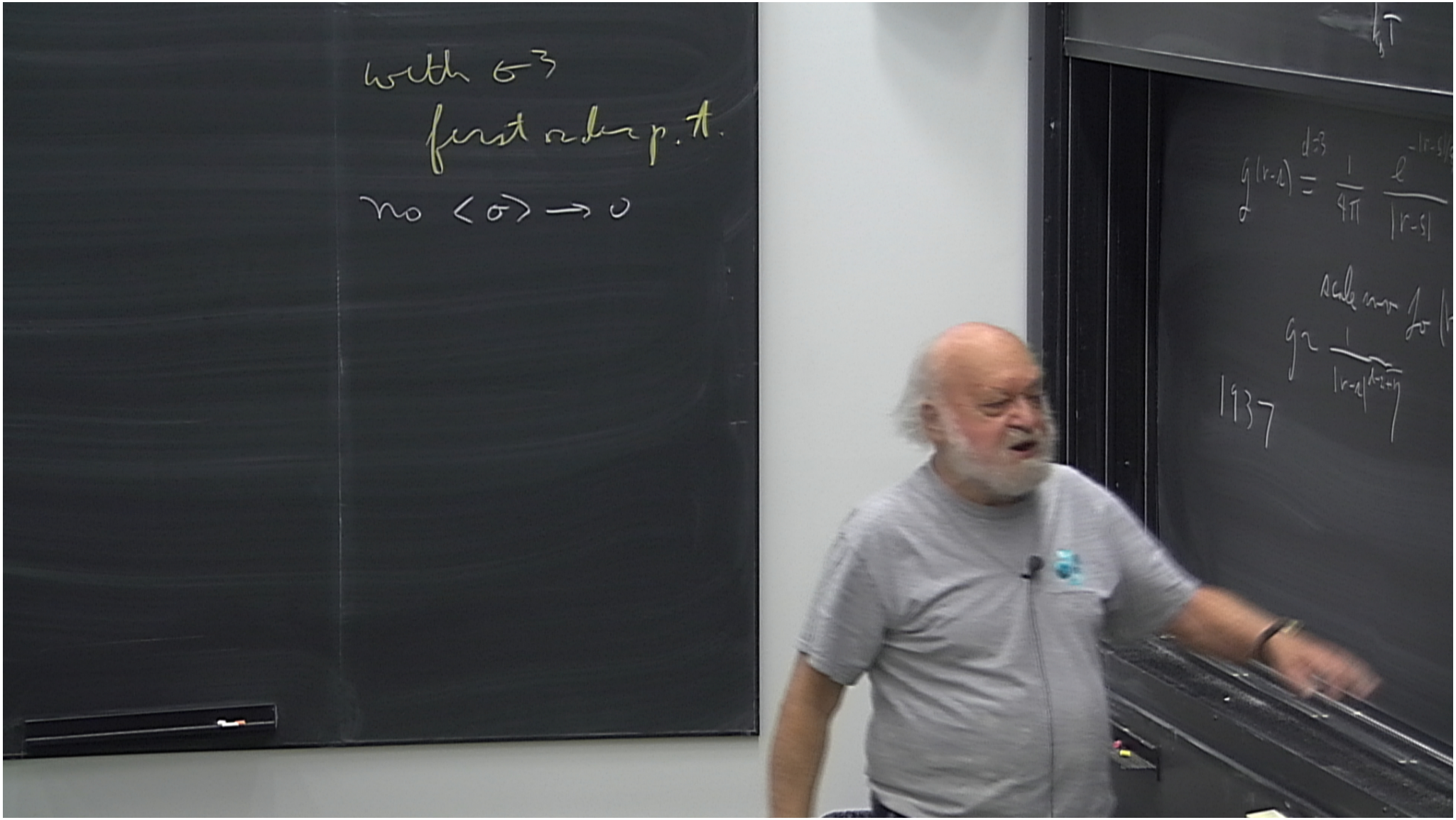

Landau
m.f.t.
$= \frac{\partial^2}{\partial T^2} \ln Z$
P
2nd Order p.t.
1/2

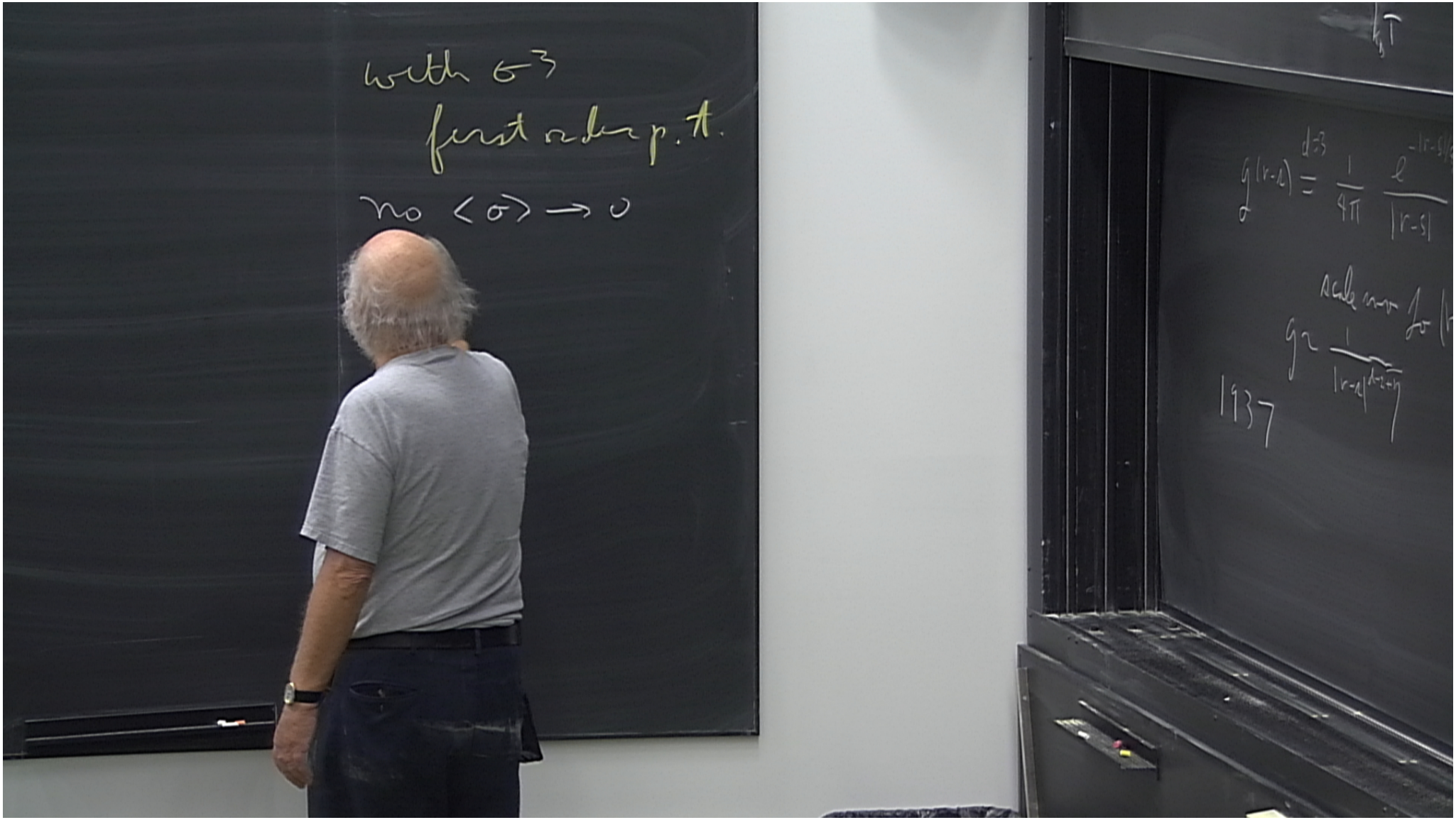

Landau
2nd Order p.t.
1st
ln Z
1/Ω

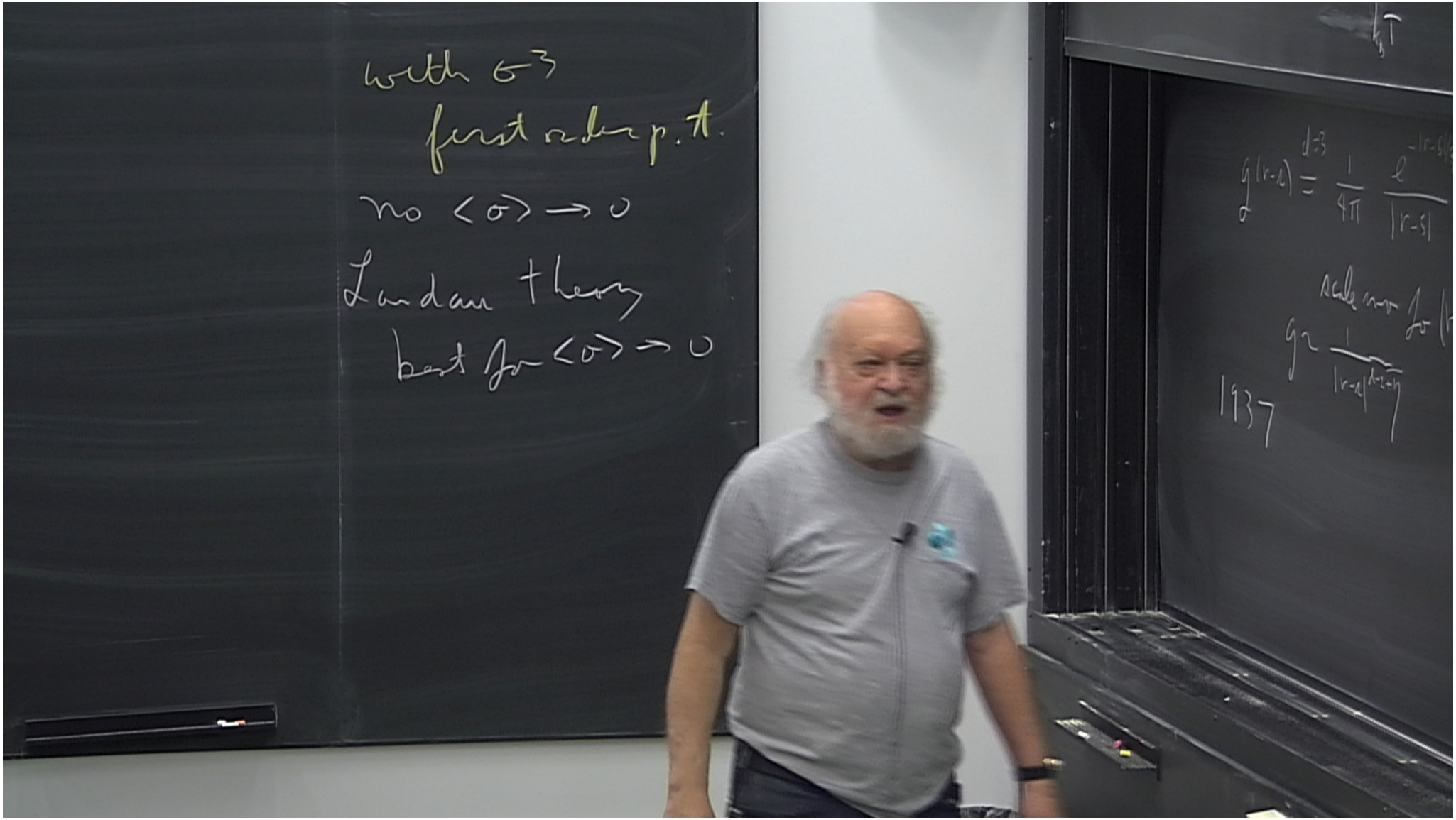

Landau
n.f.t.
ln Z
2nd Order p.t.
1st p.t.
1/2

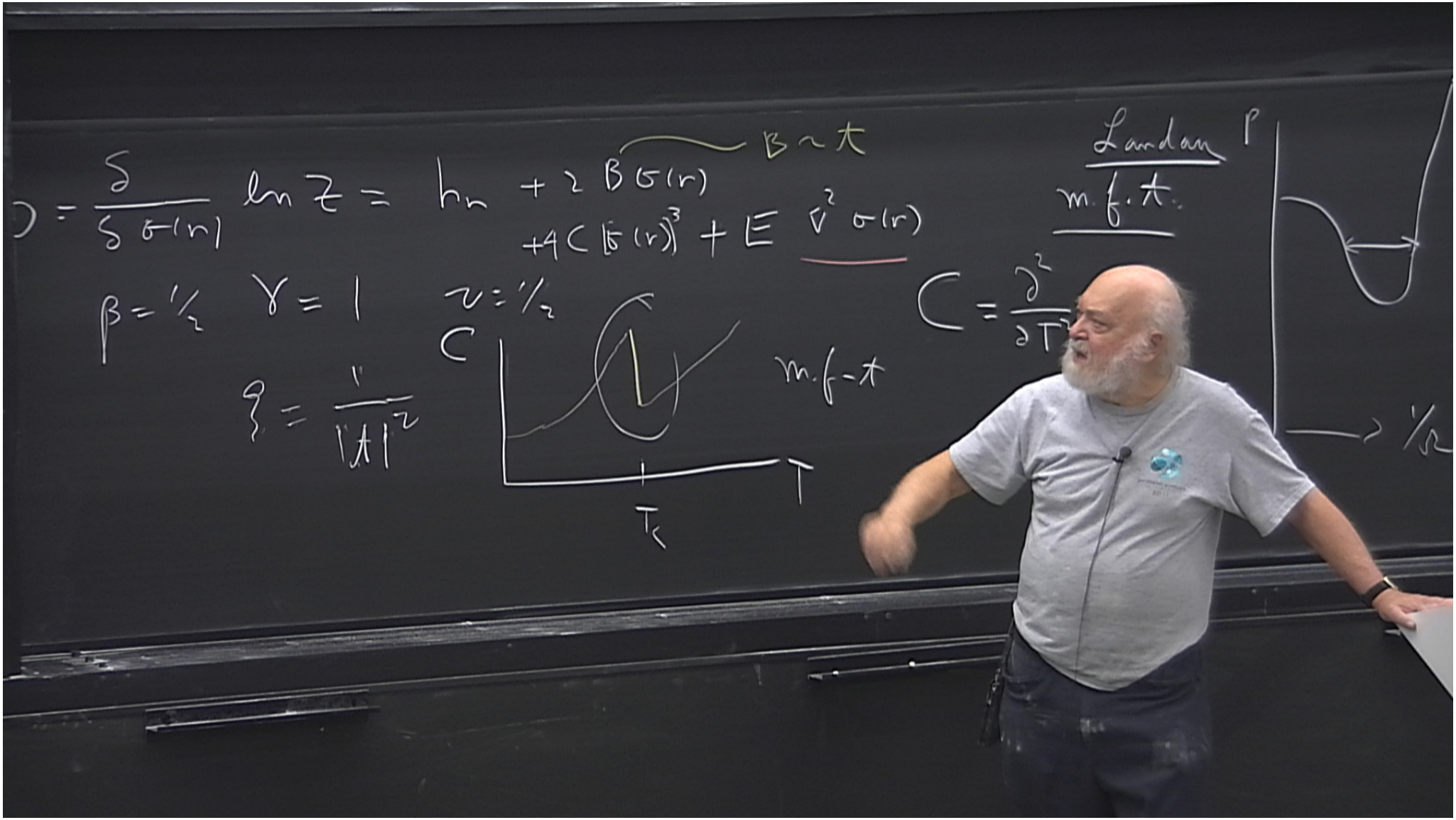

with σ=3
first order p.t.
1937

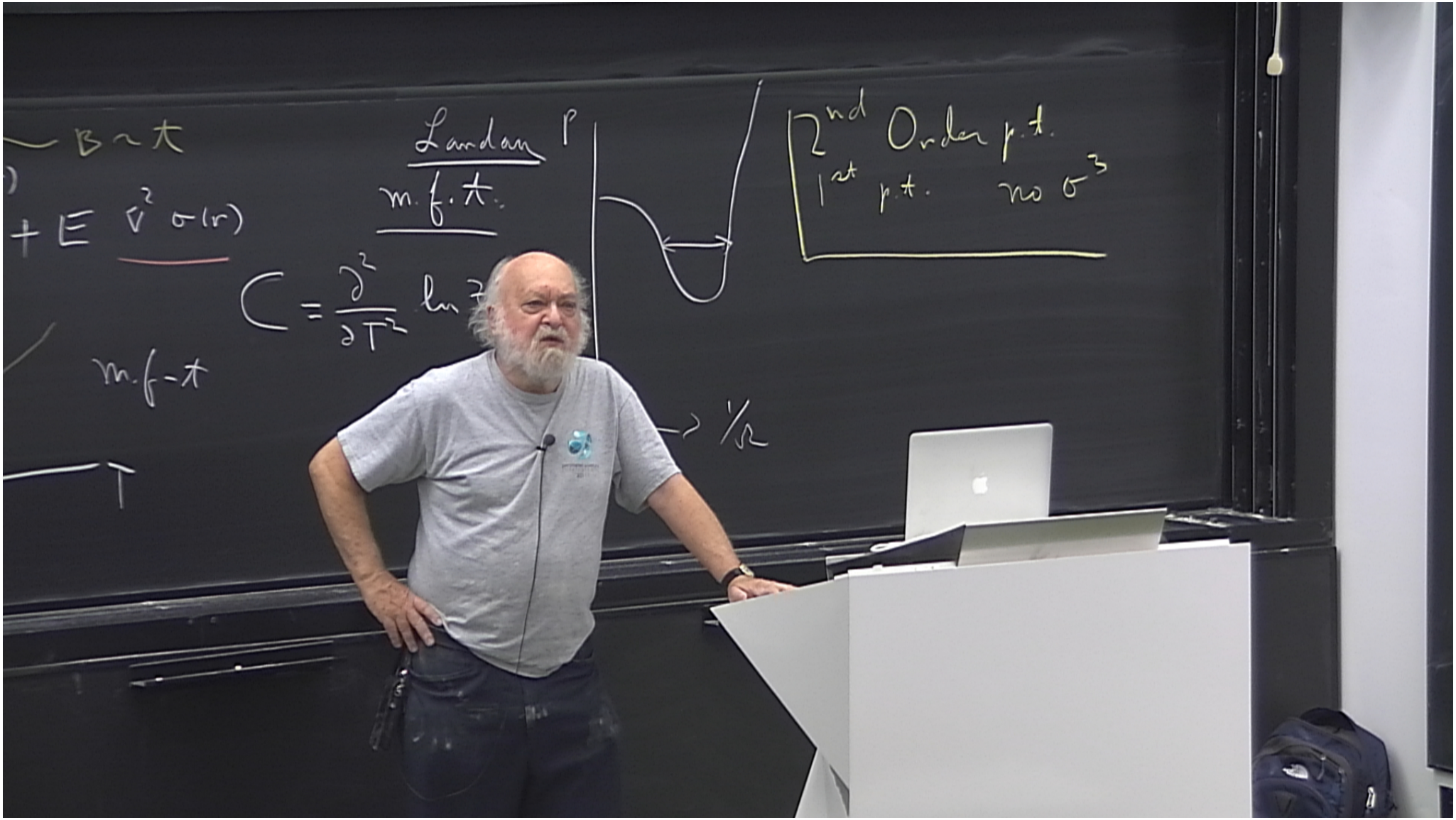

typical range of drop.
Ornstein & Zernike
1937 Landau general theory of p.t.
$\ln Z = \int dr \left[A + \vec{h} \cdot \vec{\sigma}(r) + B[\sigma(r)]^2 + C[\sigma(r)]^4 + (\nabla \sigma(r))^2 E \right]$
$\sigma(r) \cdot \sigma(r)$
$[\sigma(r) \cdot \sigma(r)]^2$
$B'[\sigma(r)]^3$
$C < 0$
$E > 0$


with σ>3
first order p.t.
no <σ> → 0
1937


with G3
first order p.t.
no <σ> → 0
1937


with G>3
first order p.t.
no <σ> → 0
Landau theory
best for <σ> → 0
1937


$\frac{\delta}{\delta \sigma(n)} \ln Z = h_n + 2B\sigma(n) + 4C(\sigma(n))^3 + E\nabla^2\sigma(n)$
B ~ t
Landau
m.f.t.
$\beta = 1/2$
$\gamma = 1$
$\nu = 1/2$
$C = \frac{\partial^2}{\partial T^2}$
$\xi = \frac{1}{|t|^2}$
C
m.f-t
T_c
T
P
$\rightarrow 1/2$


Landau
m.f.t.
2nd Order p.t.
1st p.t. no σ³
m.f.-t
½