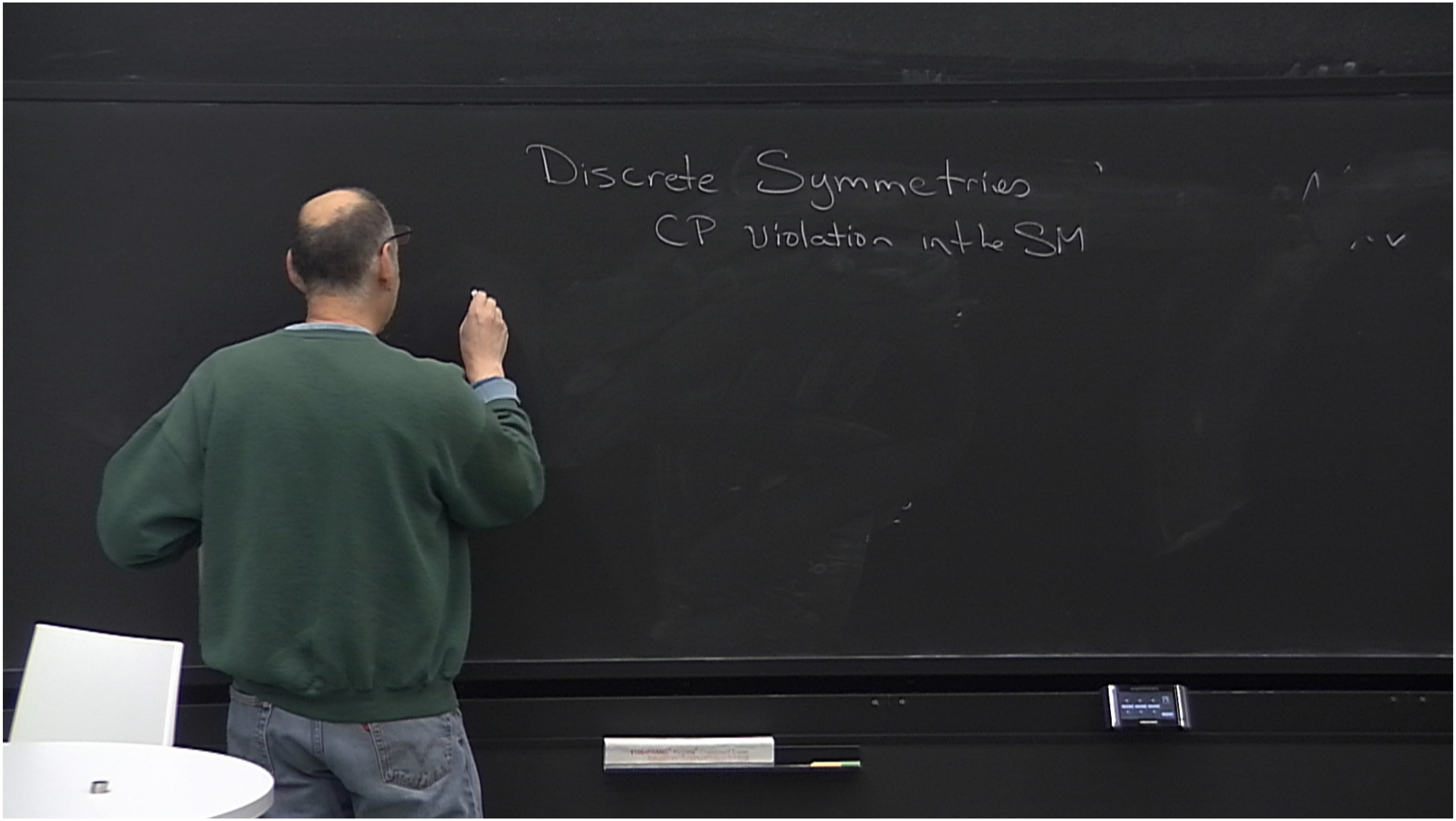
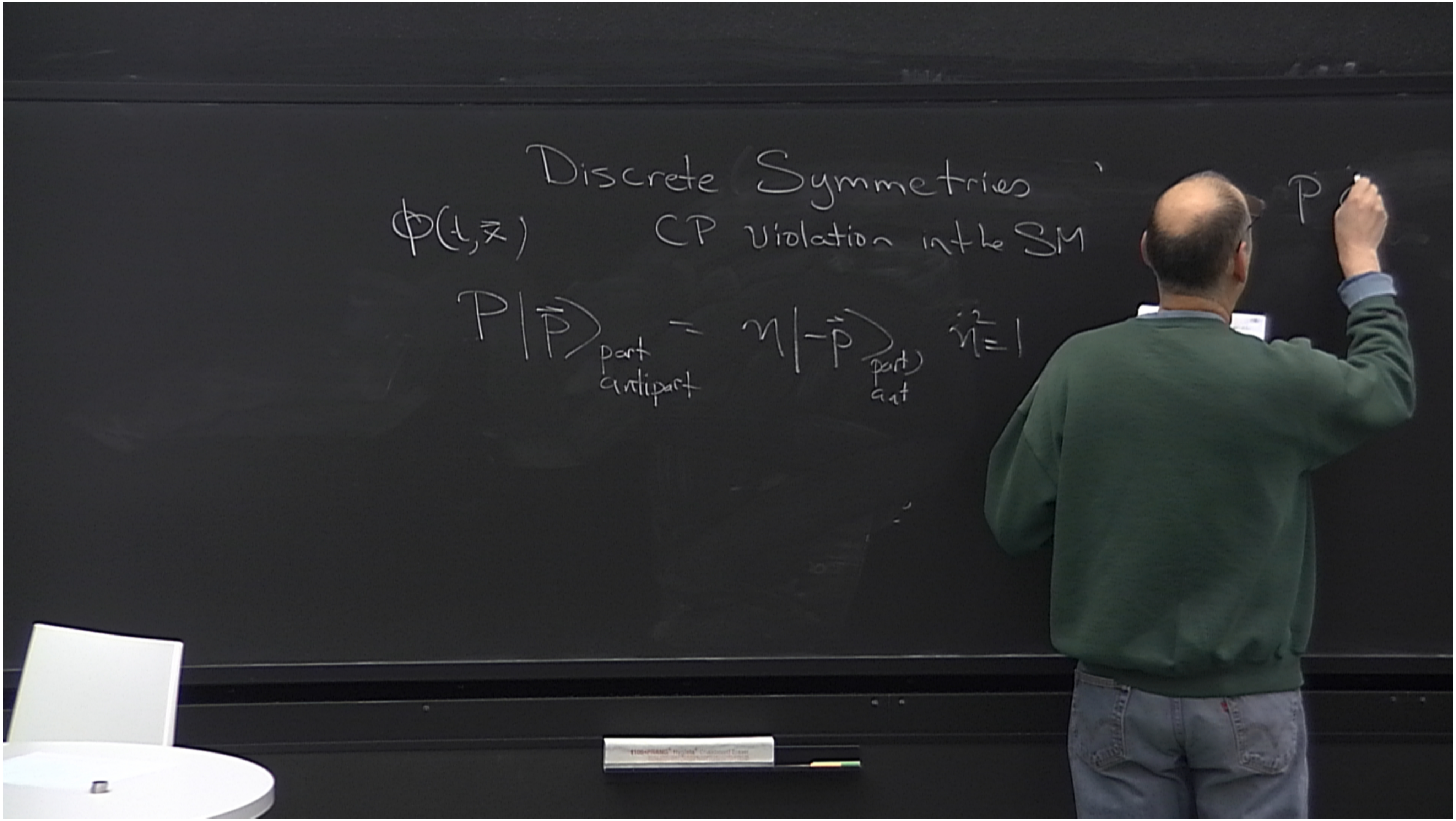
Title: 12/13 PSI - Standard Model Review Lecture 15

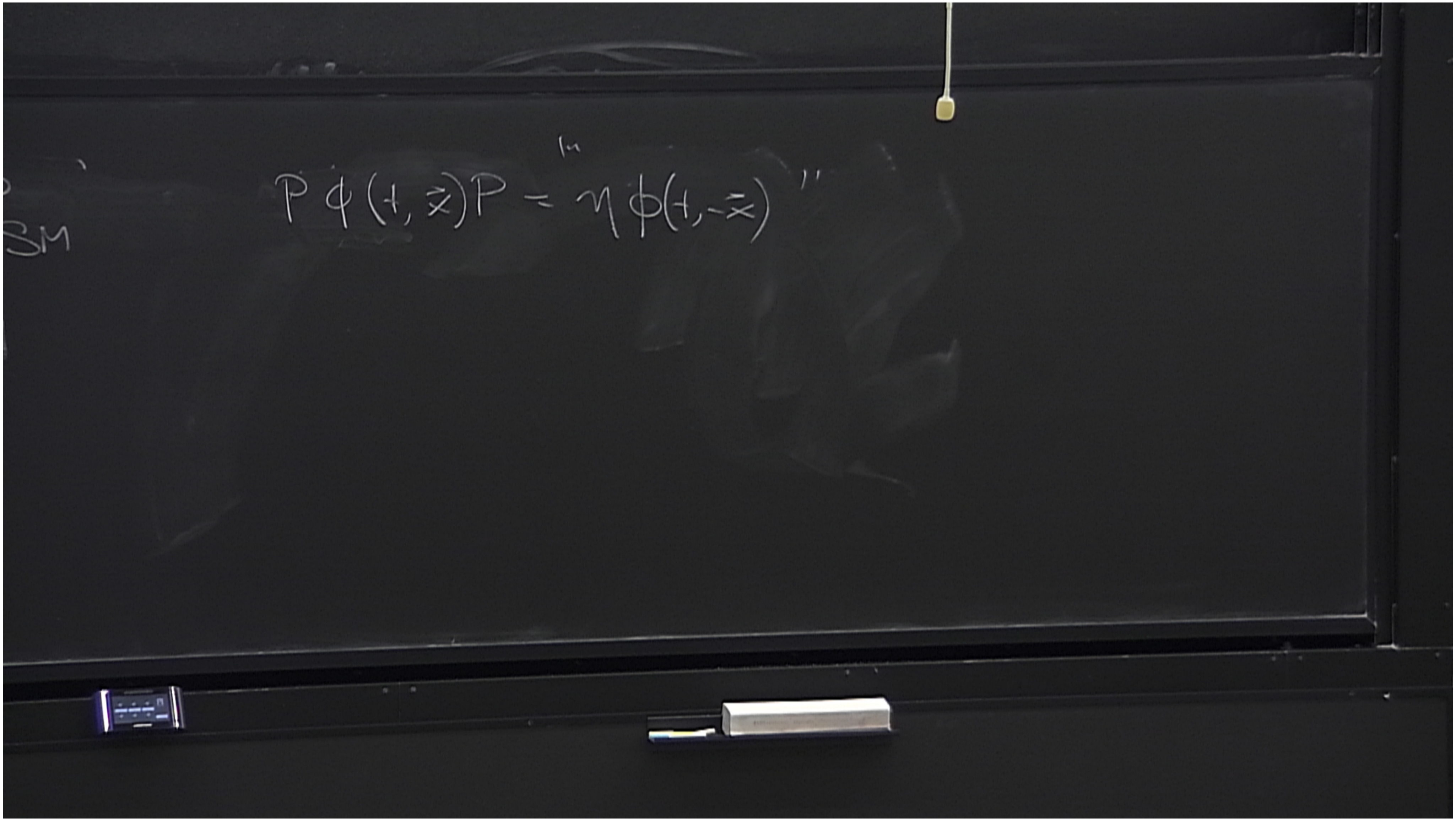
Date: Jan 25, 2013 09:00 AM

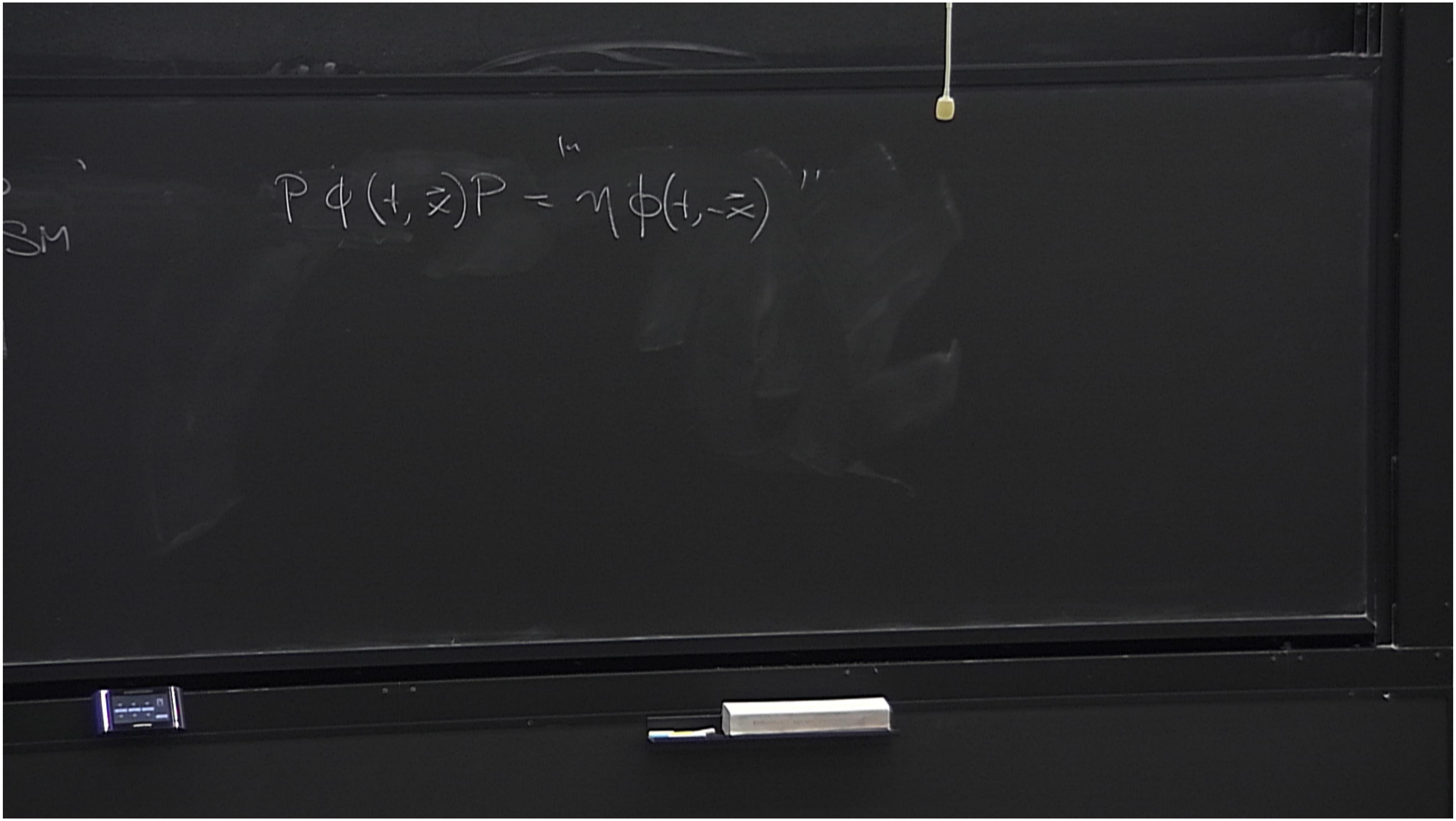
URL: http://pirsa.org/13010042

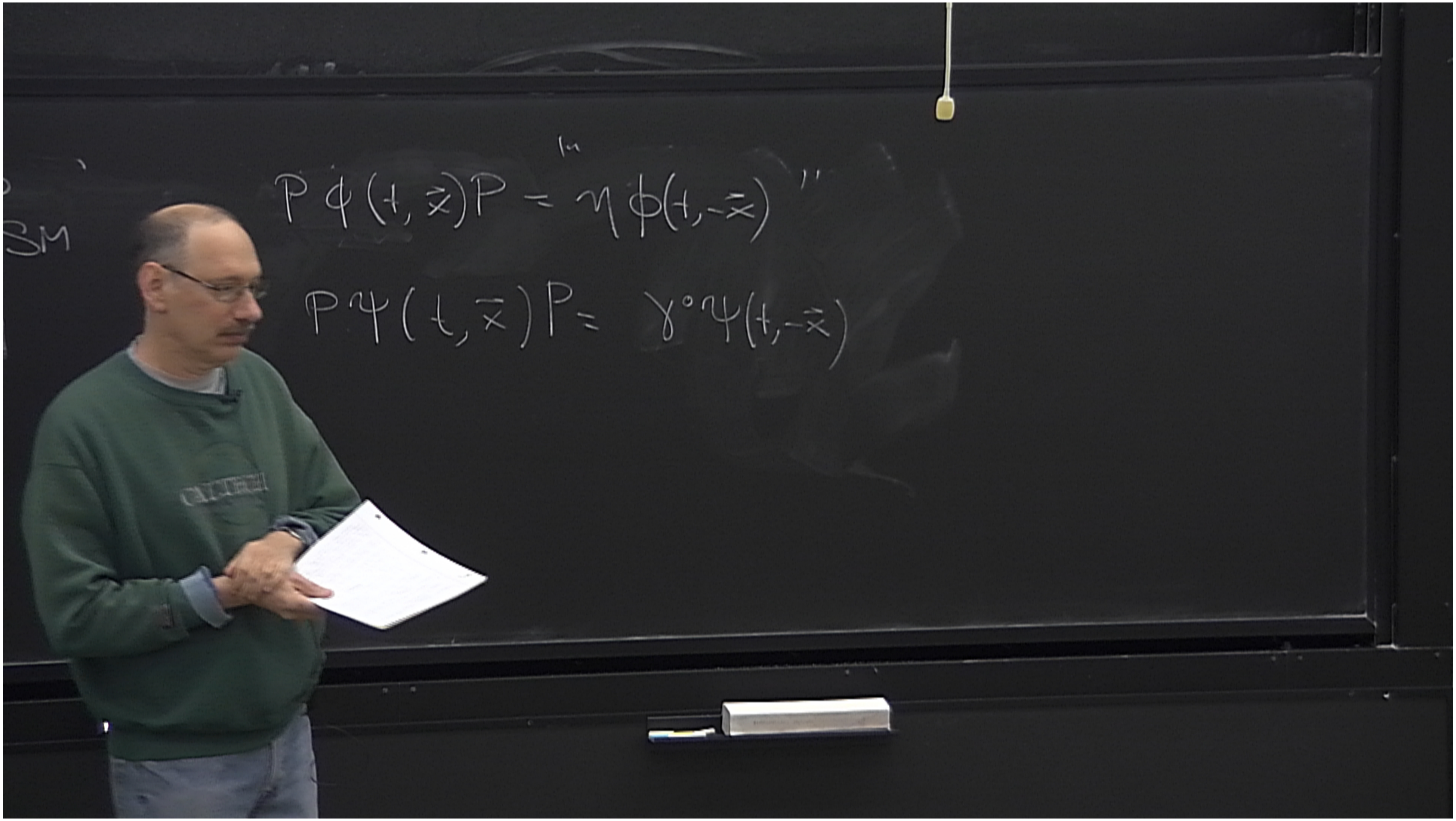
Abstract:

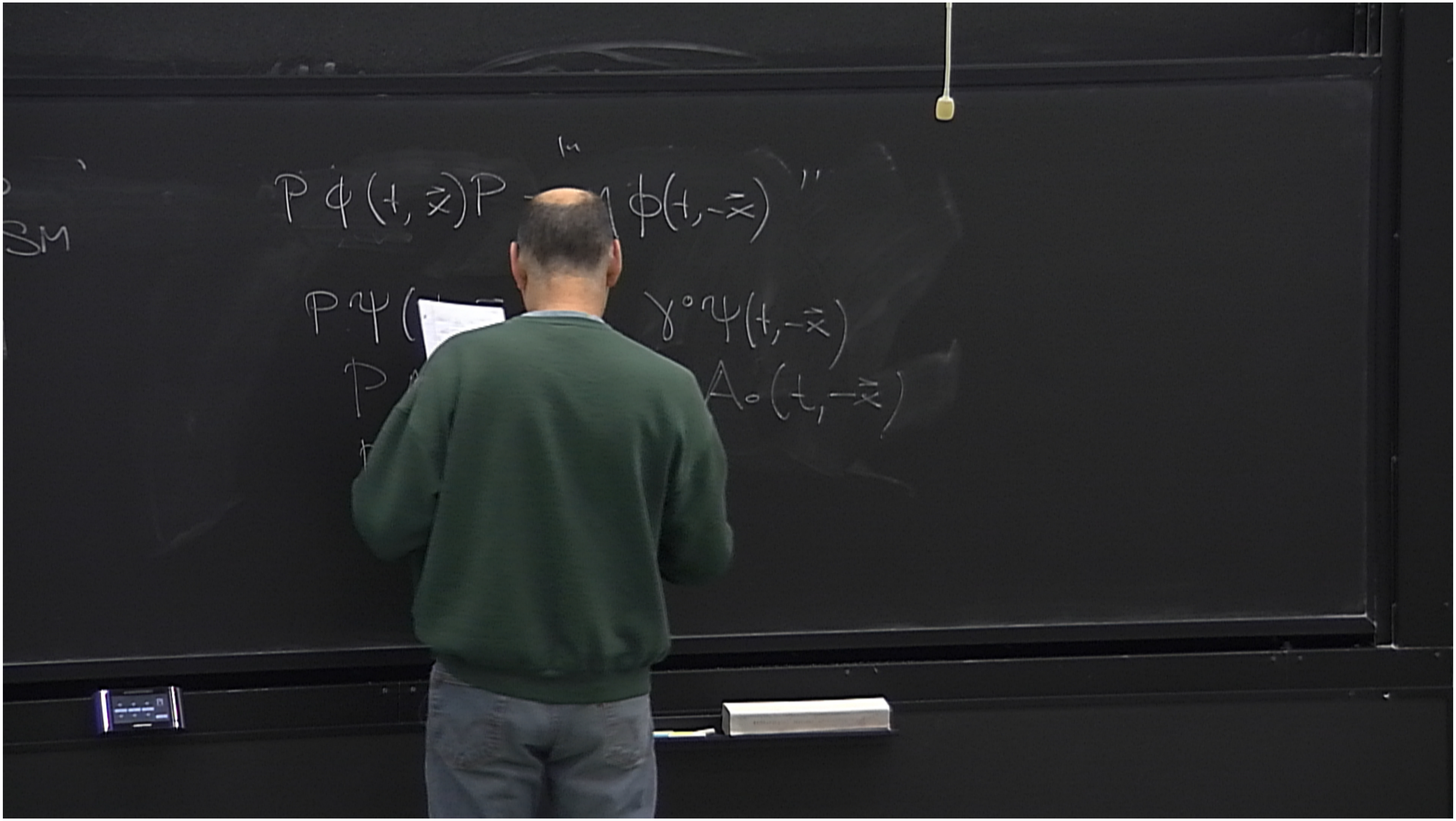

Discrete Symmetries
CP Violation in the SM

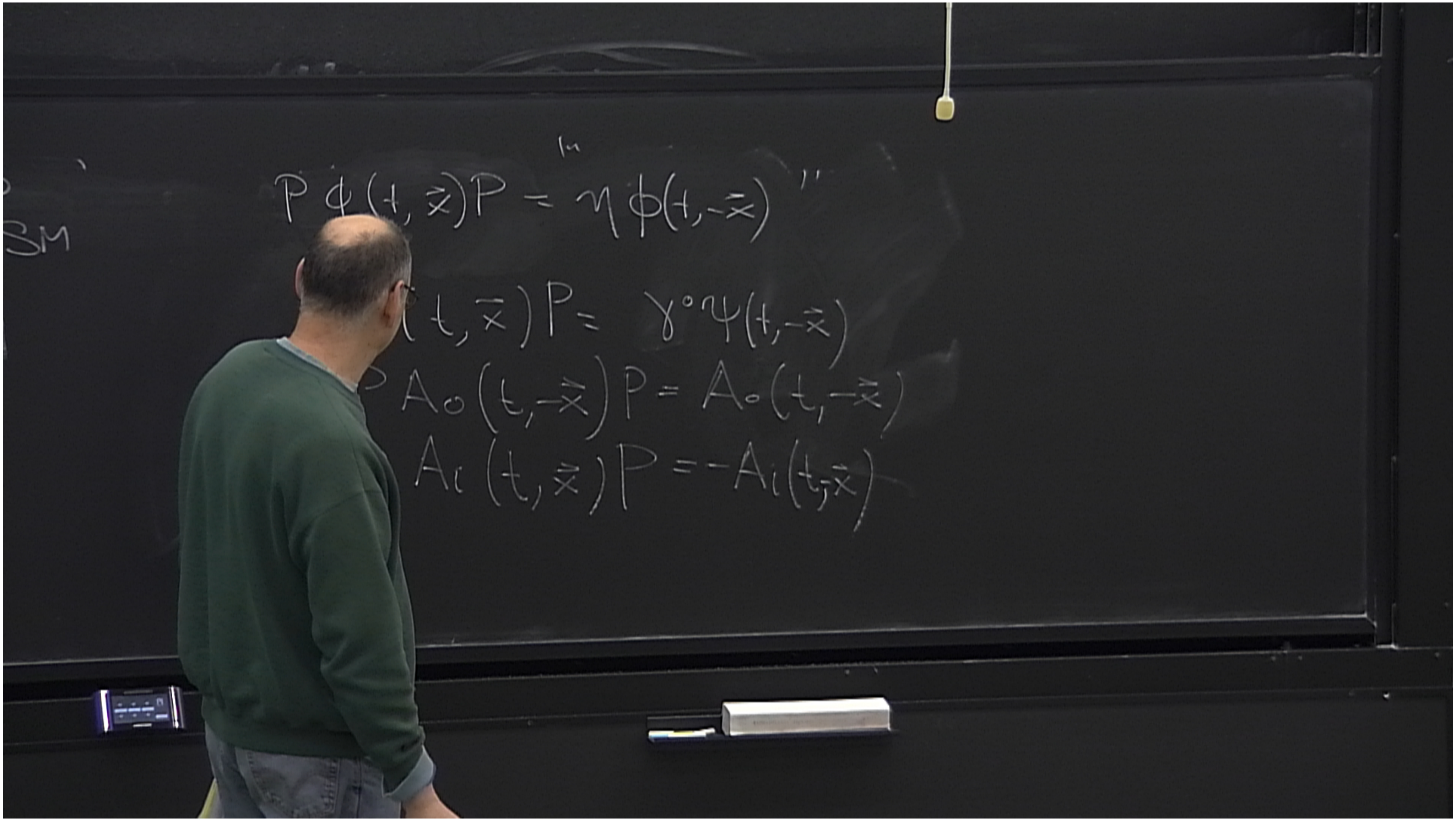

Discrete Symmetries
φ(t, x⃗)
CP Violation in the SM
P|p⃗⟩ part antipart = η|−p⃗⟩ part ant
η² = 1
P

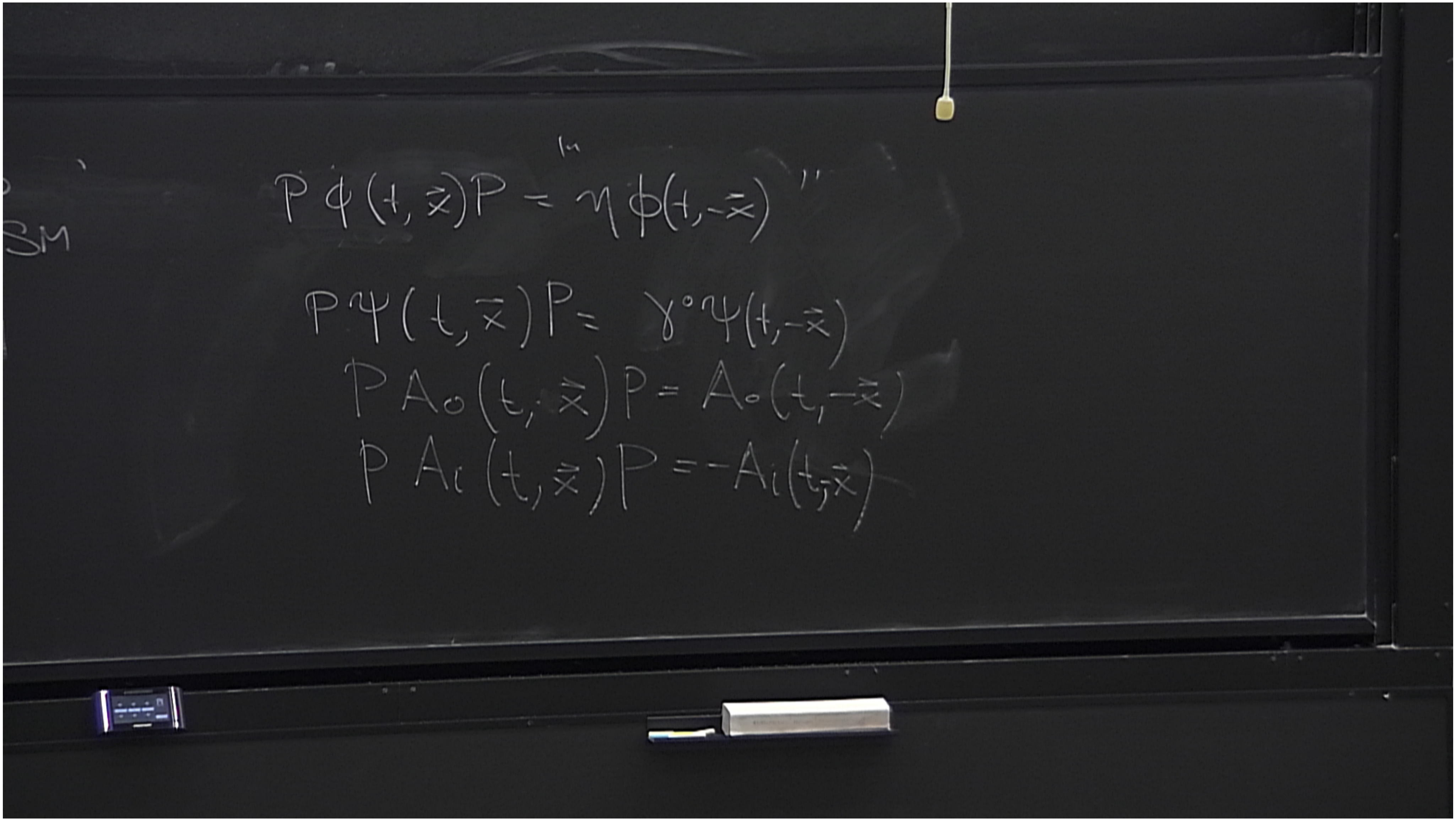

SM
P φ(t, x⃗) P = "η φ(t, −x⃗)"

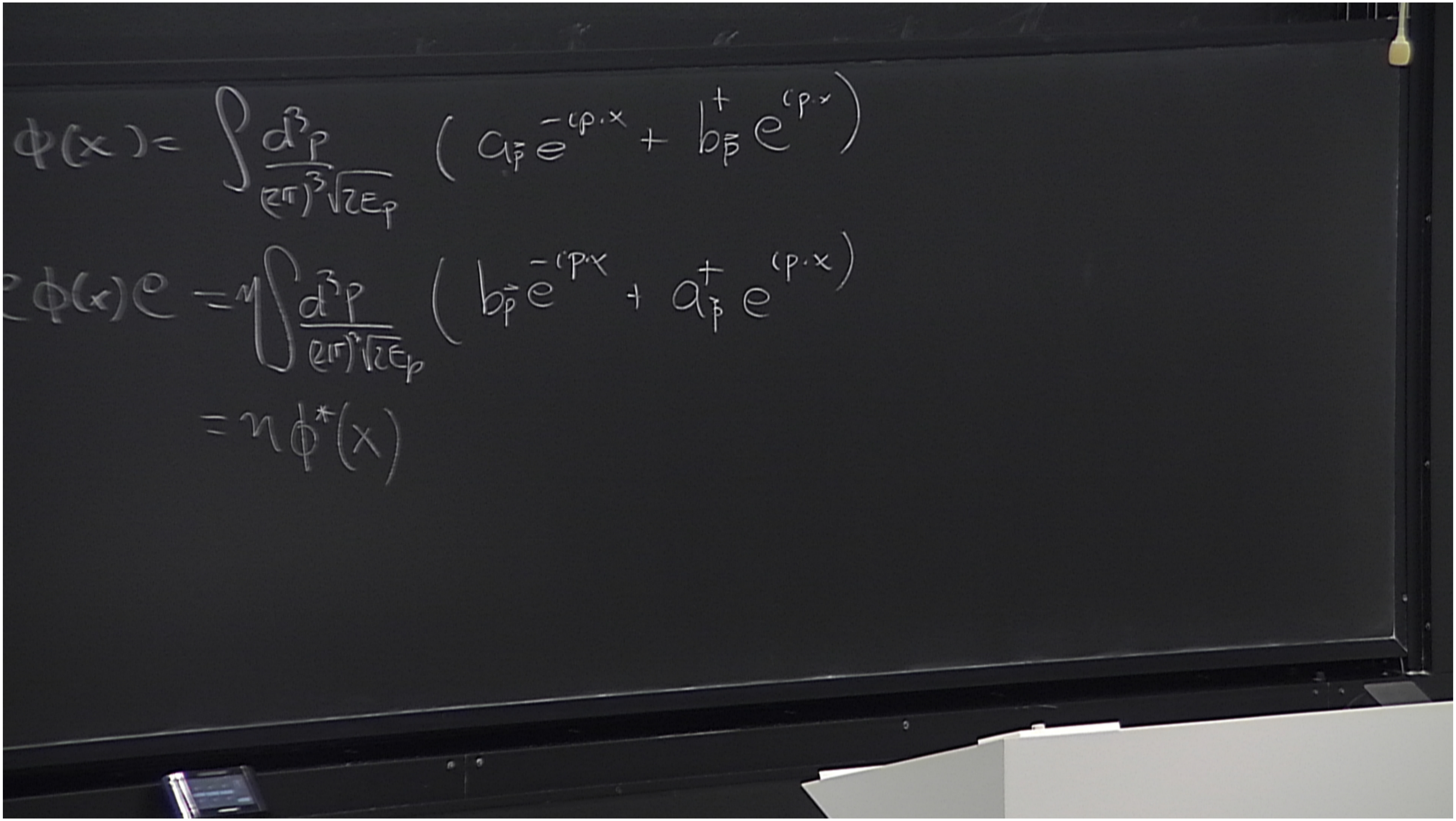

SM
Pφ(t, x⃗)P = "η φ(t, −x⃗)"


SM
$P\phi(t,\vec{x})P = $ "$\eta\,\phi(t,-\vec{x})$"
$P\psi(t,\vec{x})P = \gamma^0\psi(t,-\vec{x})$

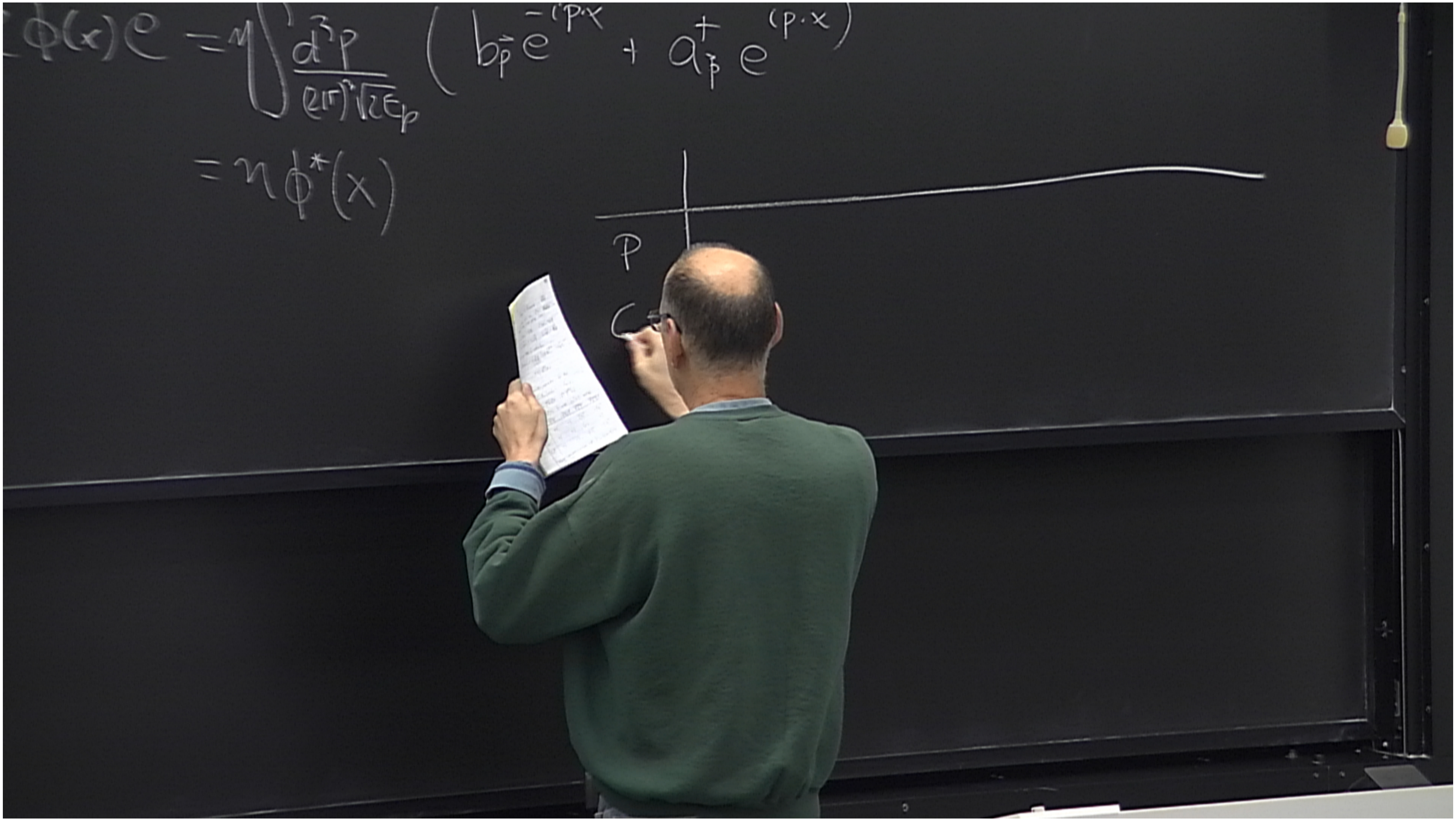

SM

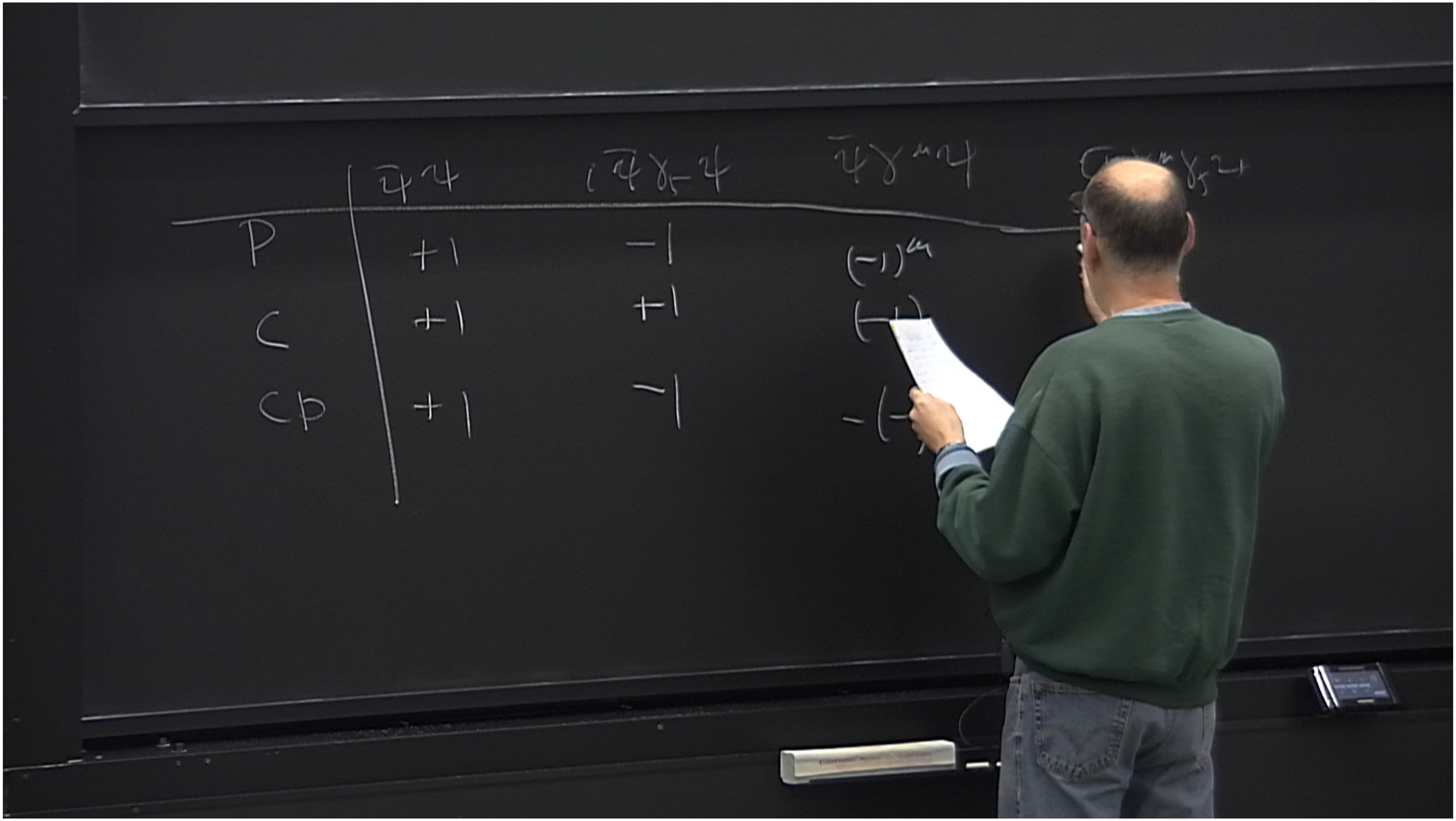

SM
$P \phi(t, \vec{x}) P = \text{“}\eta \phi(t, -\vec{x})\text{”}$
$(t, \vec{x}) P = \gamma^0 \psi(t, -\vec{x})$
$A_0(t, -\vec{x}) P = A_0(t, -\vec{x})$
$A_i(t, \vec{x}) P = -A_i(t, -\vec{x})$


SM
$P\phi(t,\vec{x})P = $ "$\eta\phi(t,-\vec{x})$"
$P\psi(t,\vec{x})P = \gamma^0\psi(t,-\vec{x})$
$PA_0(t,\vec{x})P = A_0(t,-\vec{x})$
$PA_i(t,\vec{x})P = -A_i(t,-\vec{x})$

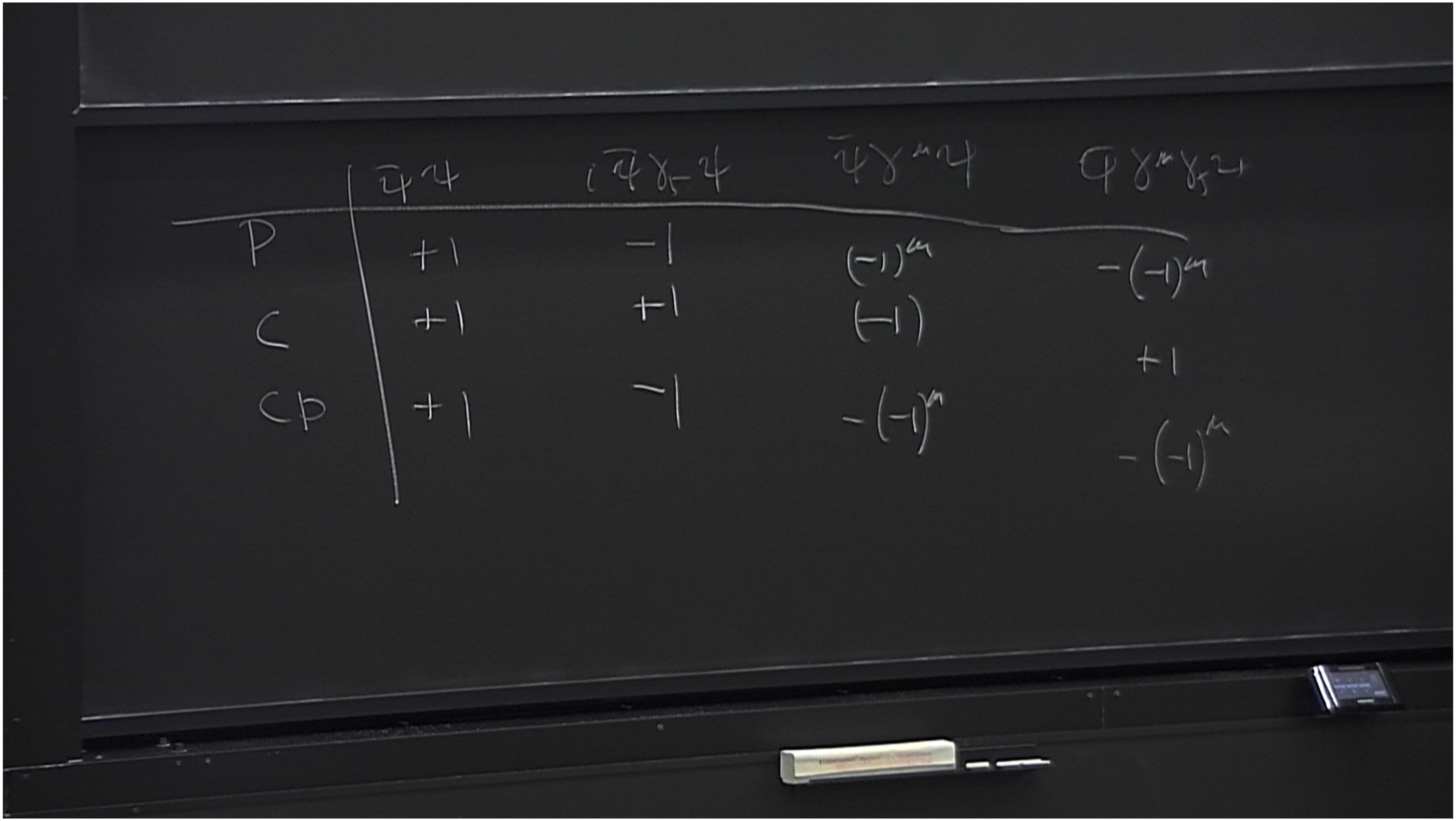


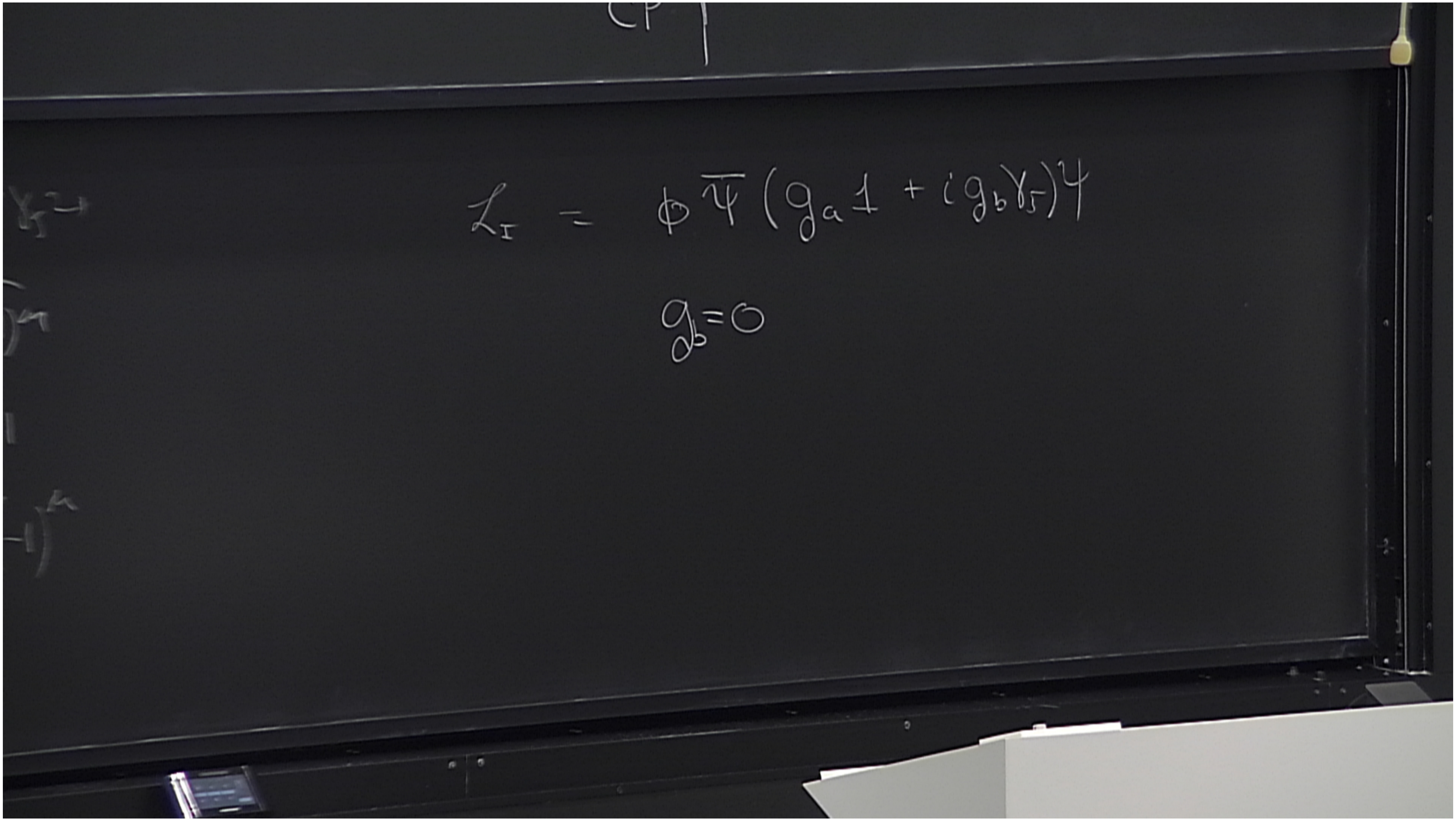
$\phi(x) = \int \frac{d^3p}{(2\pi)^3\sqrt{2E_p}} \left(a_{\vec{p}}\, e^{-ip\cdot x} + b^{\dagger}_{\vec{p}}\, e^{ip\cdot x} \right)$
$C\phi(x)C = \eta \int \frac{d^3p}{(2\pi)^3\sqrt{2E_p}} \left(b_{\vec{p}}\, e^{-ip\cdot x} + a^{\dagger}_{\vec{p}}\, e^{ip\cdot x} \right)$
$= \eta\, \phi^*(x)$

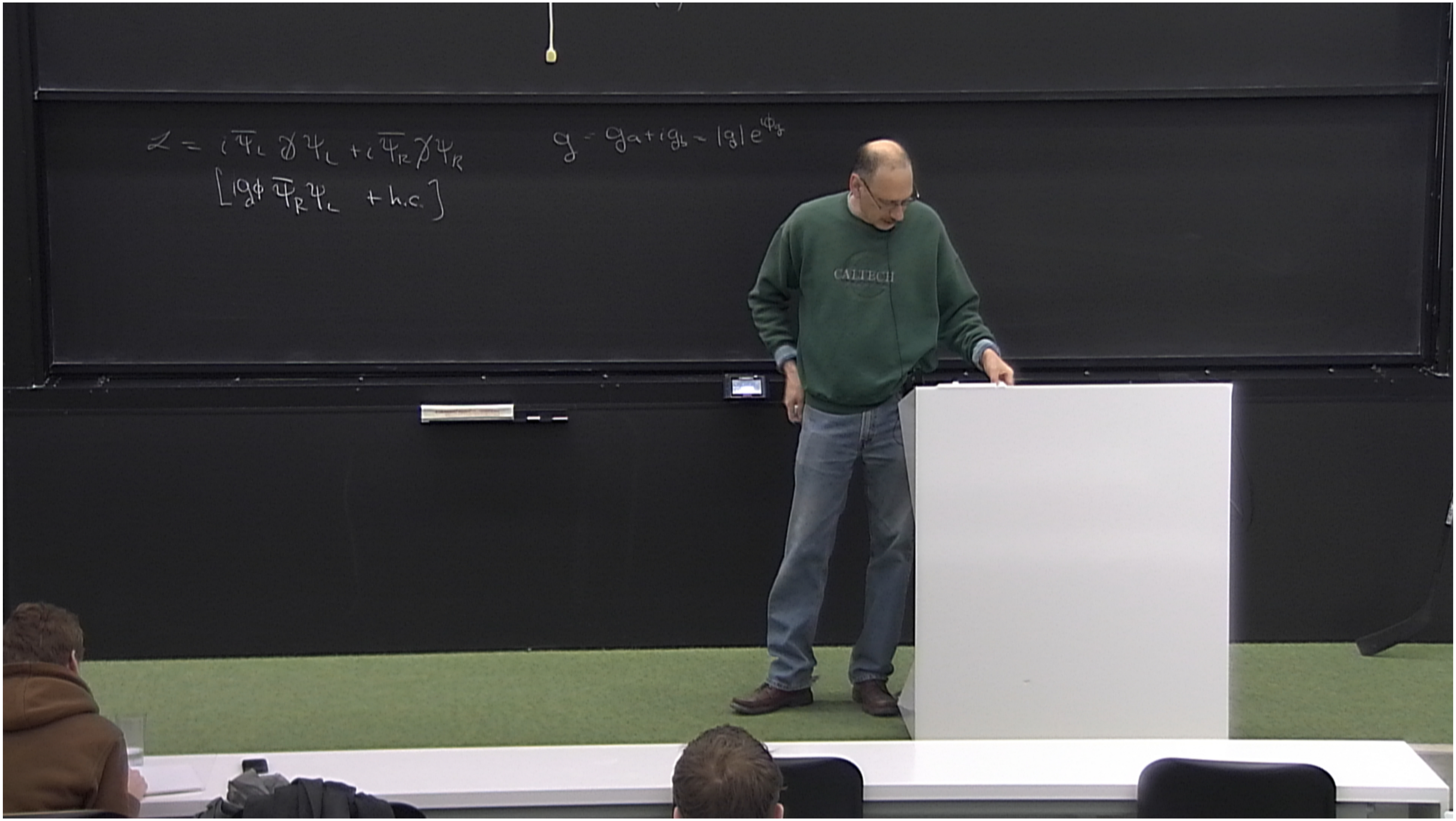

P
C

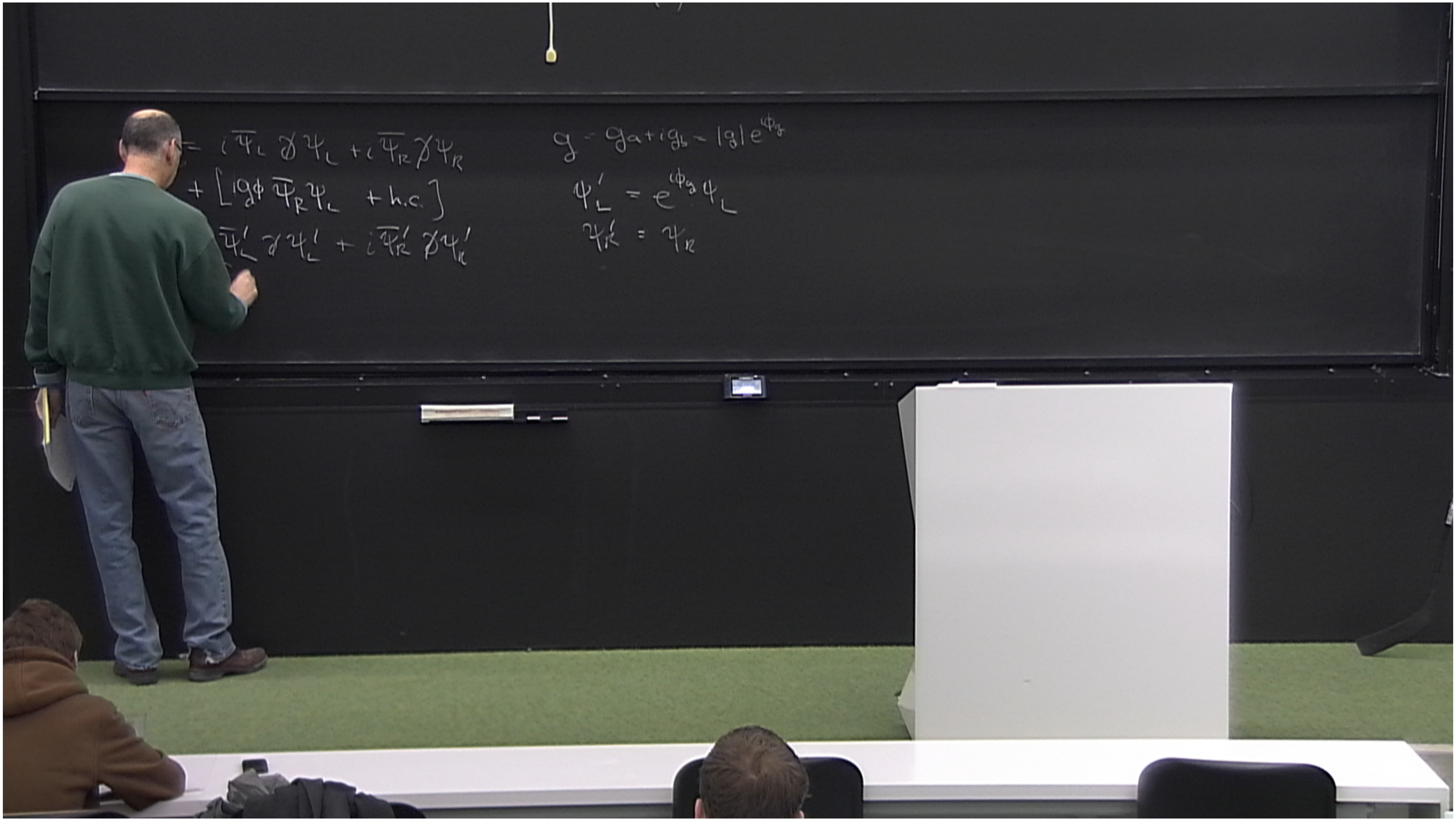


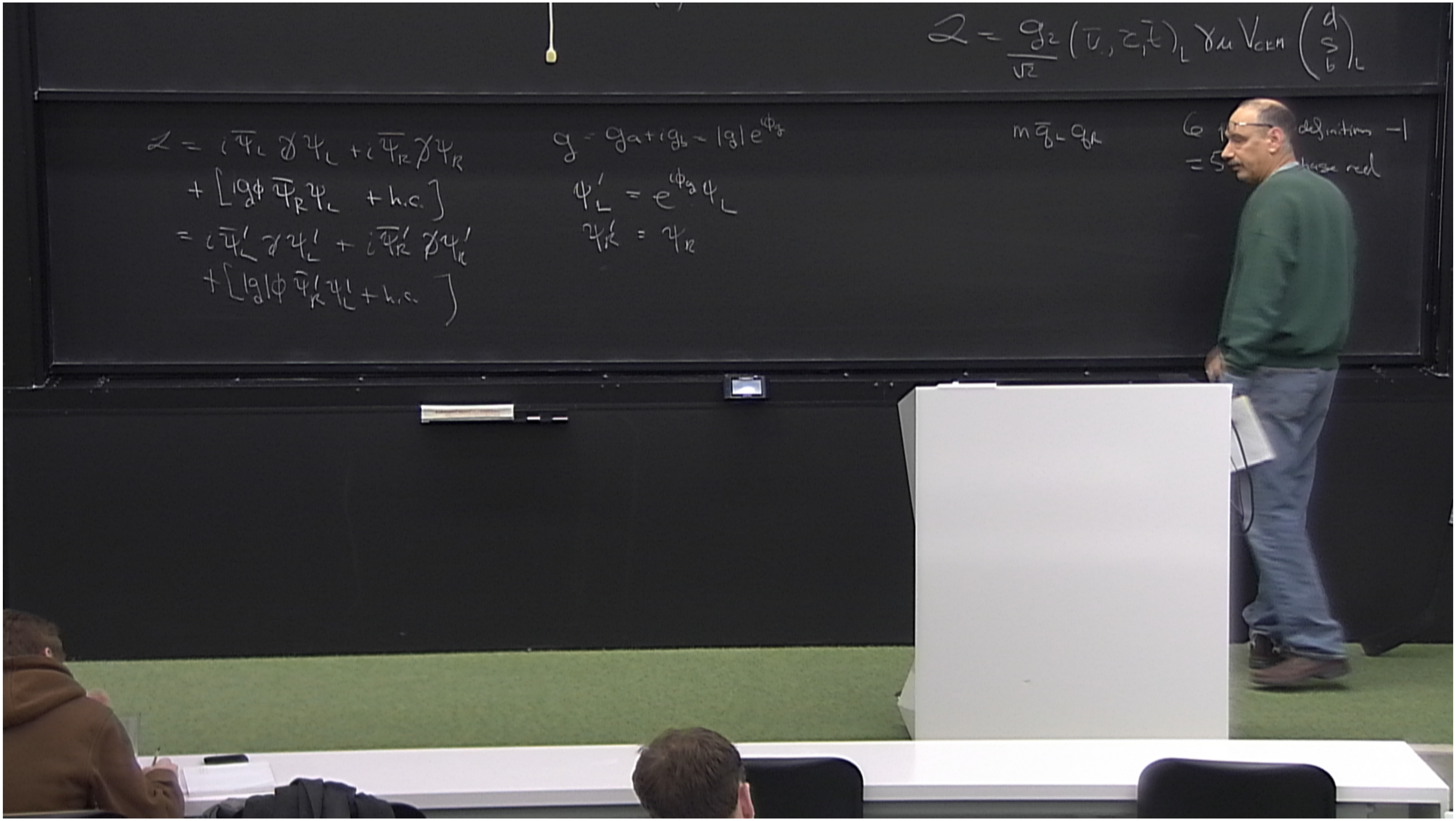
$\bar\psi\psi$
$i\bar\psi\gamma_5\psi$
$\bar\psi\gamma^\mu\psi$
P
+1
−1
$(-1)^\mu$
C
+1
+1
CP
+1
−1

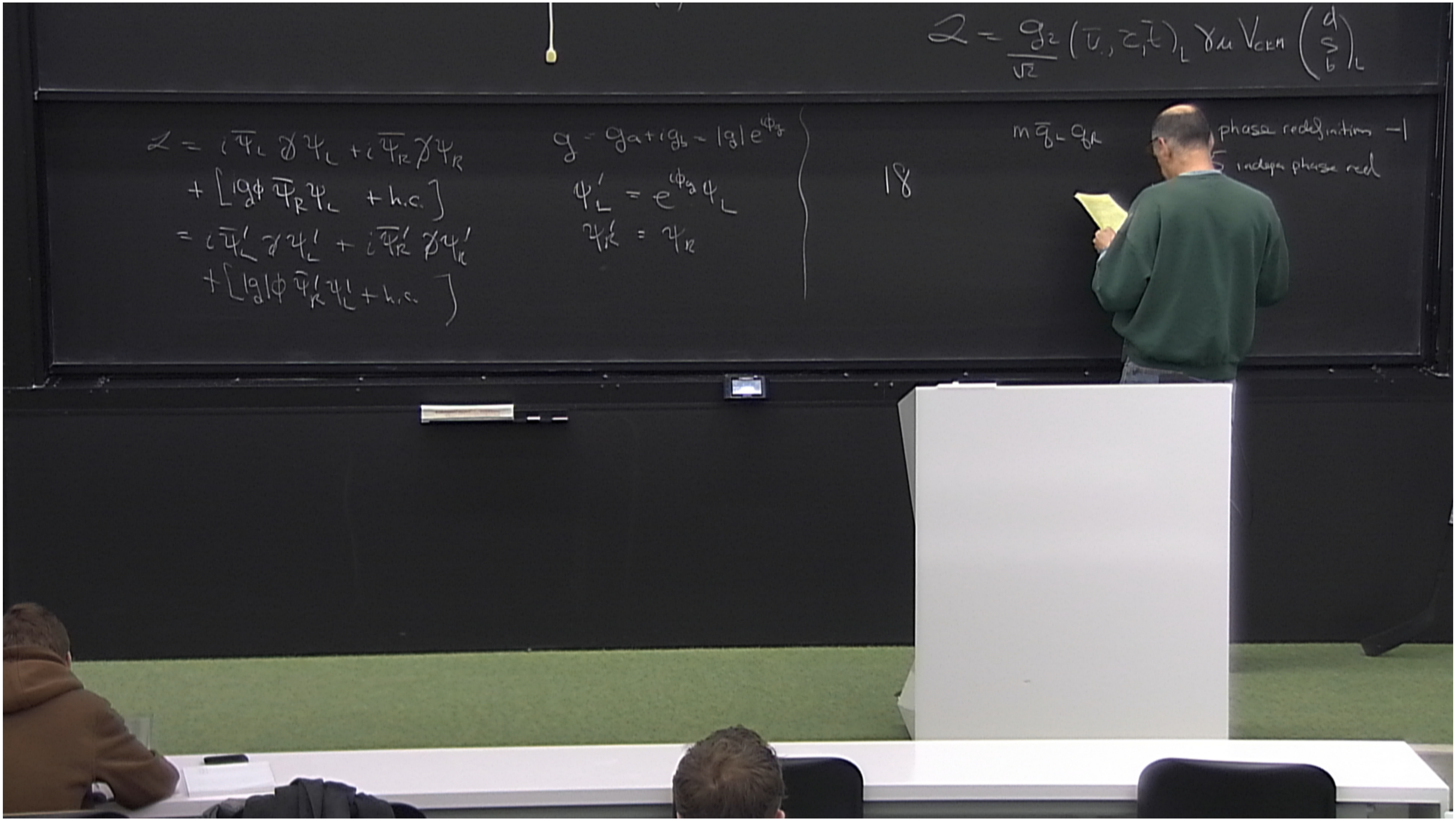

ψ̄ψ   iψ̄γ5ψ   ψ̄γ^μψ   ψ̄γ^μγ5ψ
P   +1   −1   (−1)^μ   −(−1)^μ
C   +1   +1   (−1)   +1
CP   +1   −1   −(−1)^μ   −(−1)^μ

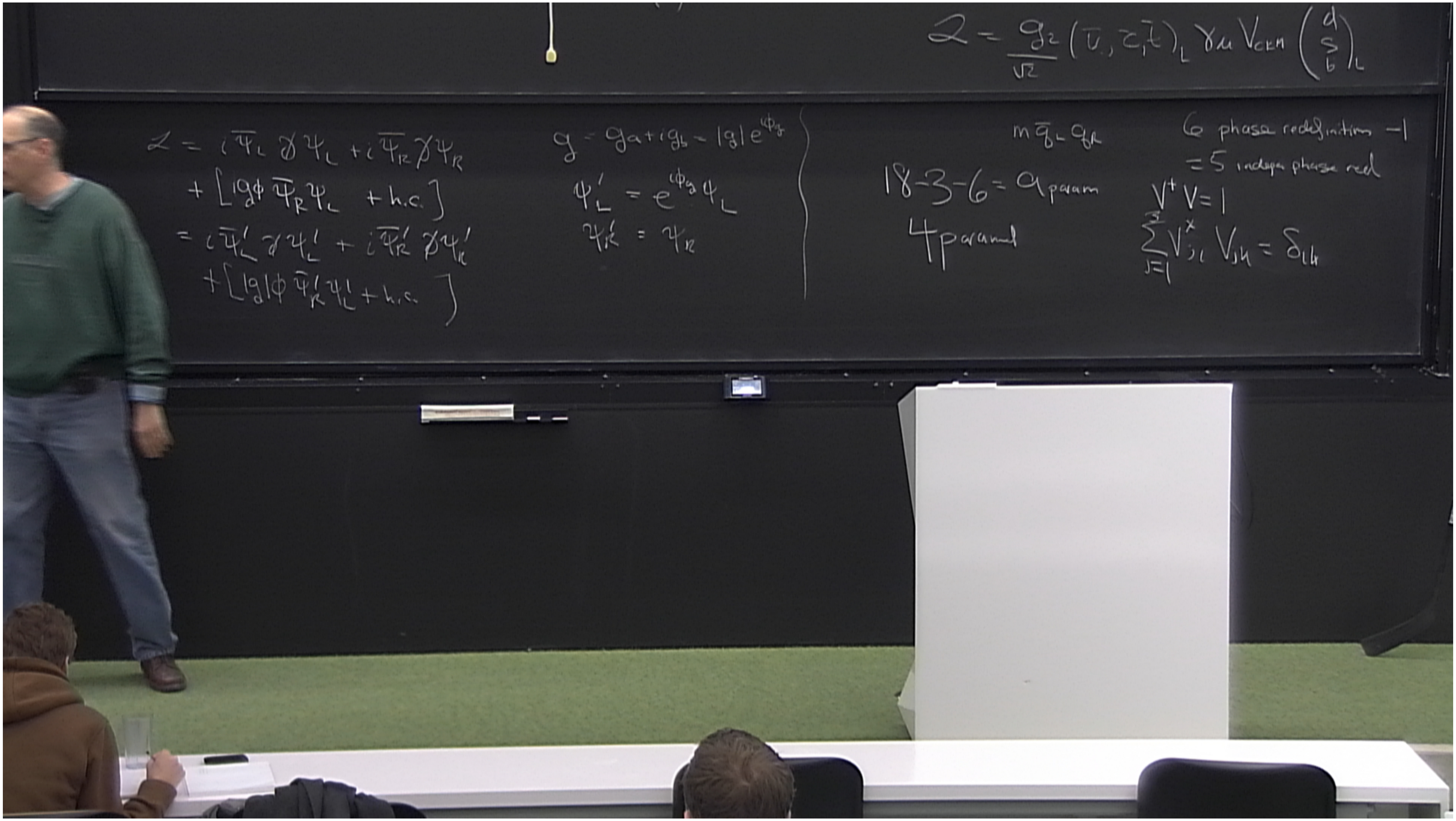

$\mathcal{L}_I = \phi \overline{\Psi} (g_a 1 + i g_b \gamma_5) \Psi$
$g_b = 0$


$\mathcal{L} = i\bar{\Psi}_L \gamma \Psi_L + i\bar{\Psi}_R \gamma \Psi_R$
$[ig\phi \bar{\Psi}_R \Psi_L + h.c.]$
$g = g_a + i g_b = |g| e^{\phi_g}$
CALTECH

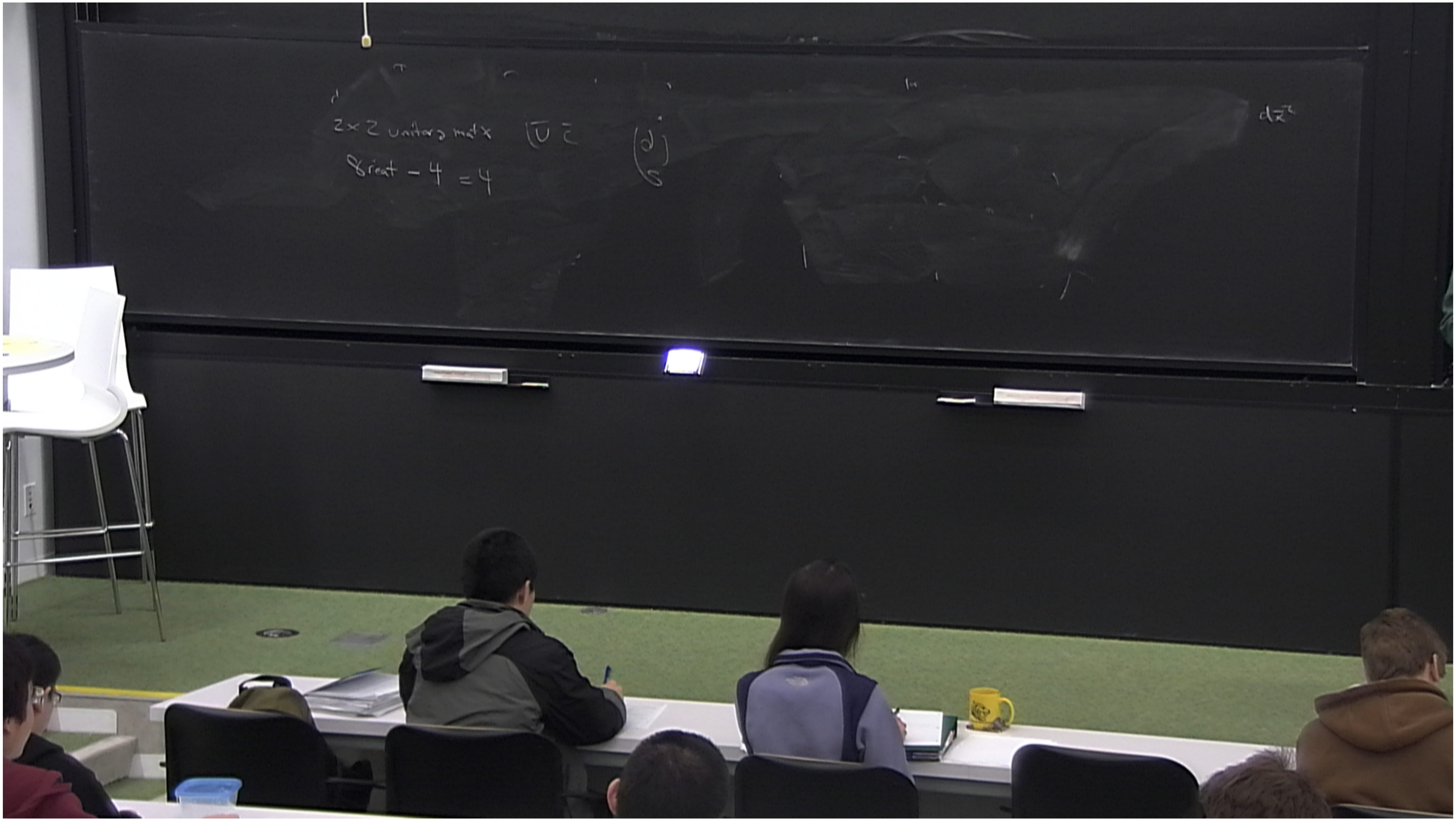

+ [igφ Ψ̄R ΨL + h.c.]
g = ga + igb = |g| e^{iφg}
ψ'L = e^{iφg} ψL
ψ'R = ψR

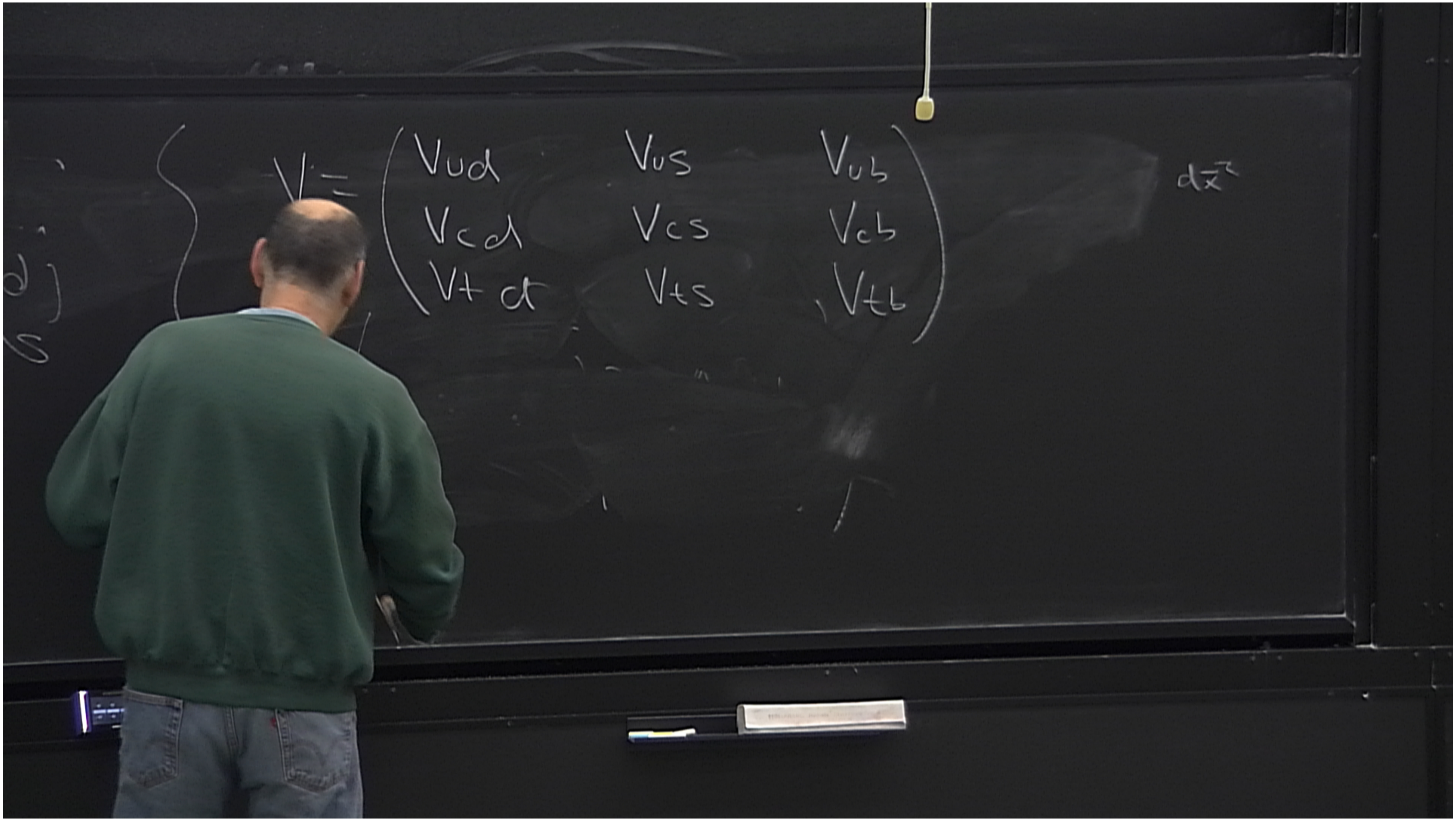

$\mathcal{L} = \frac{g_2}{\sqrt{2}} (\bar{u}, \bar{c}, \bar{t})_L \gamma_\mu V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L$
$\mathcal{L} = i\bar{\Psi}_L \gamma \Psi_L + i\bar{\Psi}_R \gamma \Psi_R$
$+ [ig\phi \bar{\Psi}_R \Psi_L + h.c.]$
$= i\bar{\Psi}'_L \gamma \Psi'_L + i\bar{\Psi}'_R \gamma \Psi'_R$
$+ [|g|\phi \bar{\Psi}'_R \Psi'_L + h.c.]$
$g = g_a + ig_b = |g| e^{i\phi_g}$
$\Psi'_L = e^{i\phi_g} \Psi_L$
$\Psi'_R = \Psi_R$
definitions -1
phase red

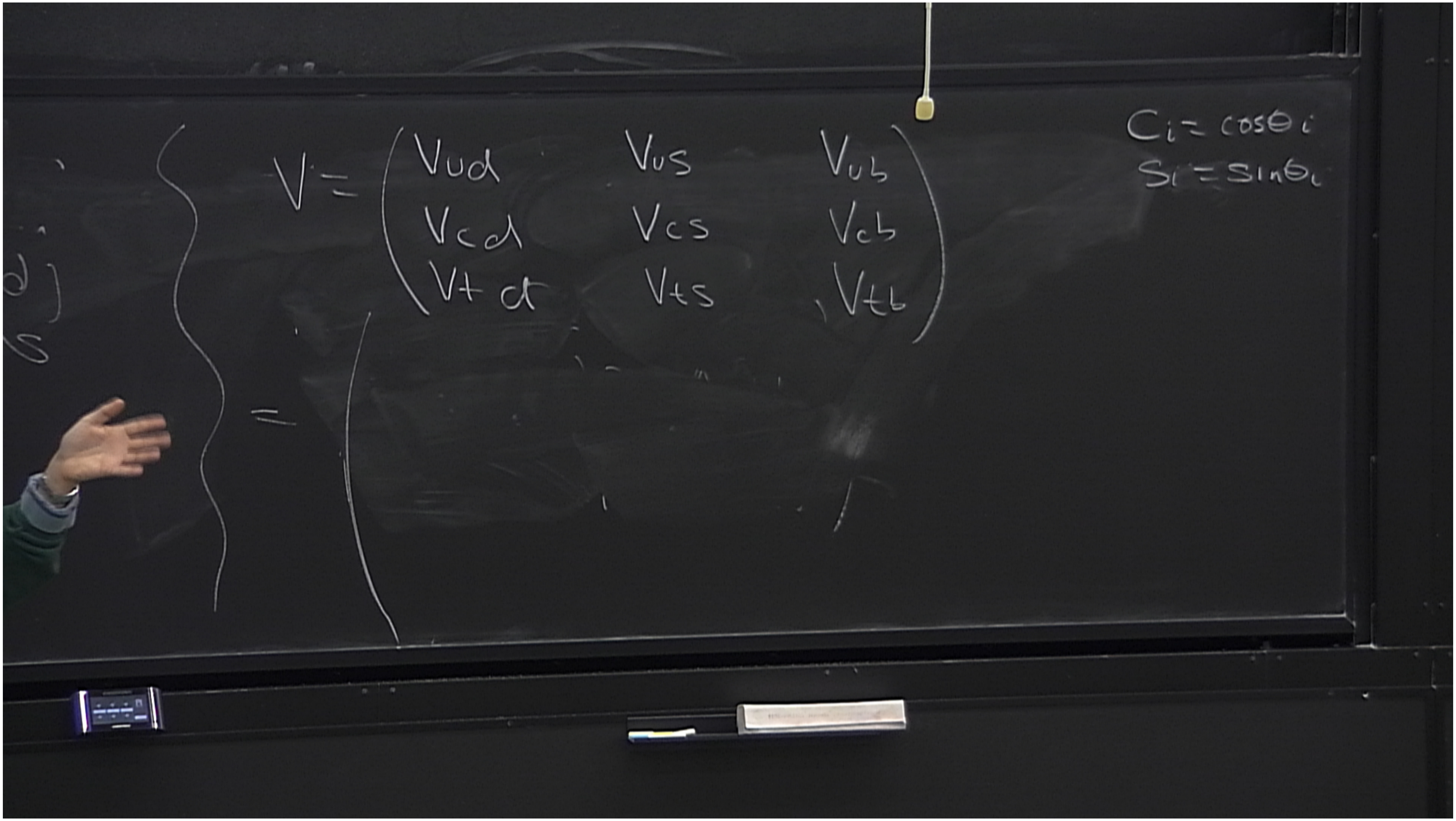

phase redefinitions −1
18
+ h.c.



L = g2/√2 (ū, c̄, t̄)L γμ VCKM (d s b)L
L = i Ψ̄L γ ΨL + i Ψ̄R γ ΨR
+ [g φ Ψ̄R ΨL + h.c.]
= i Ψ̄'L γ Ψ'L + i Ψ̄'R γ Ψ'R
+ [|g| φ Ψ̄'R Ψ'L + h.c.]
g = ga + i gb = |g| e^{iφg}
Ψ'L = e^{iφg} ΨL
Ψ'R = ΨR
m q̄L qR
18-3-6 = 9 param
4 param
6 phase redefinitions -1
= 5 indep phase red
V† V = 1
Σ V*ji Vjk = δik


2×2 unitary matx
8 real − 4 = 4


V =
Vud Vus Vub
Vcd Vcs Vcb
Vtd Vts Vtb


V = (Vud Vus Vub
Vcd Vcs Vcb
Vtd Vts Vtb)
Ci = cosθi
Si = sinθi

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{23}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

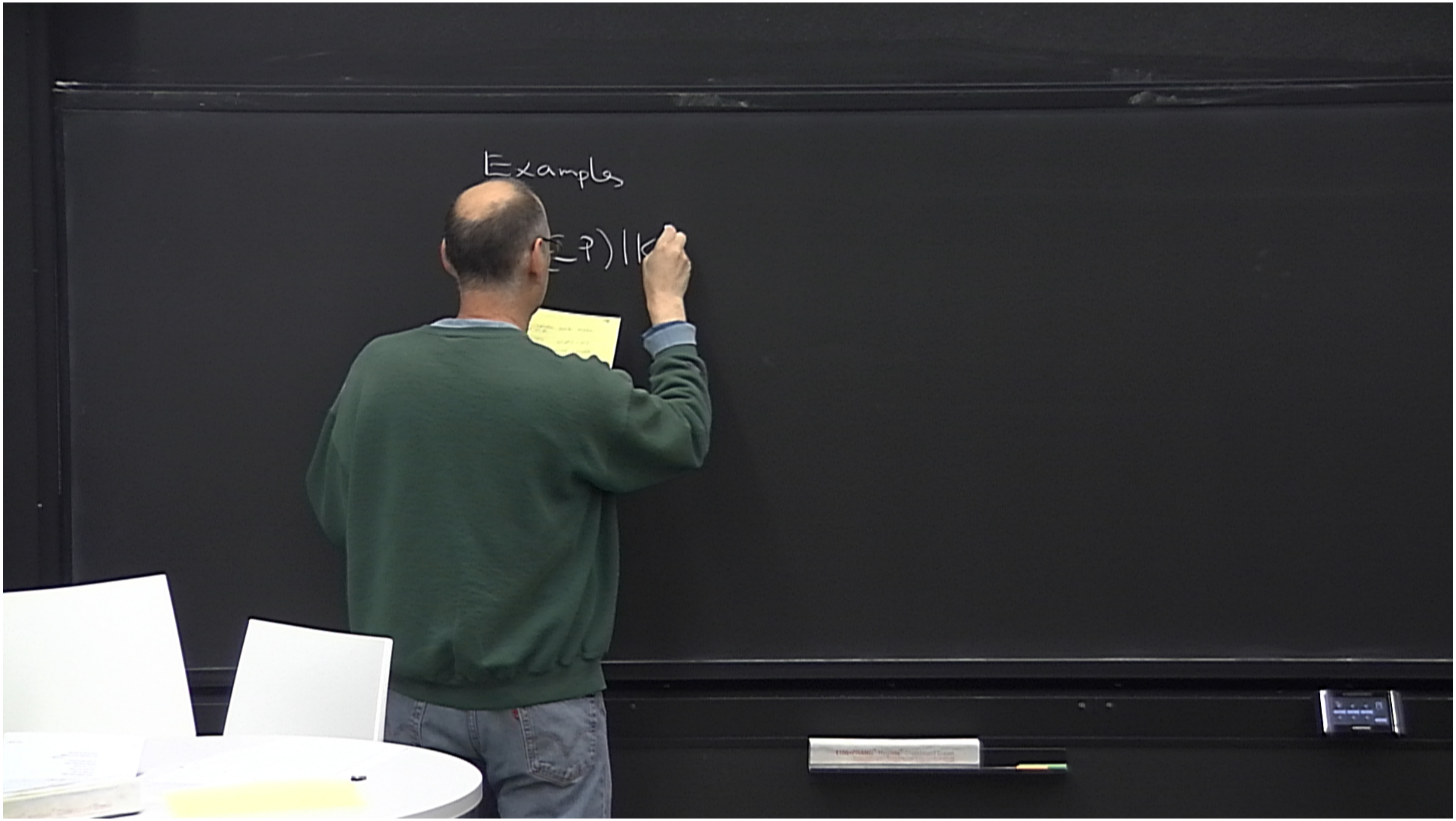
$c_i = \cos\theta_i$

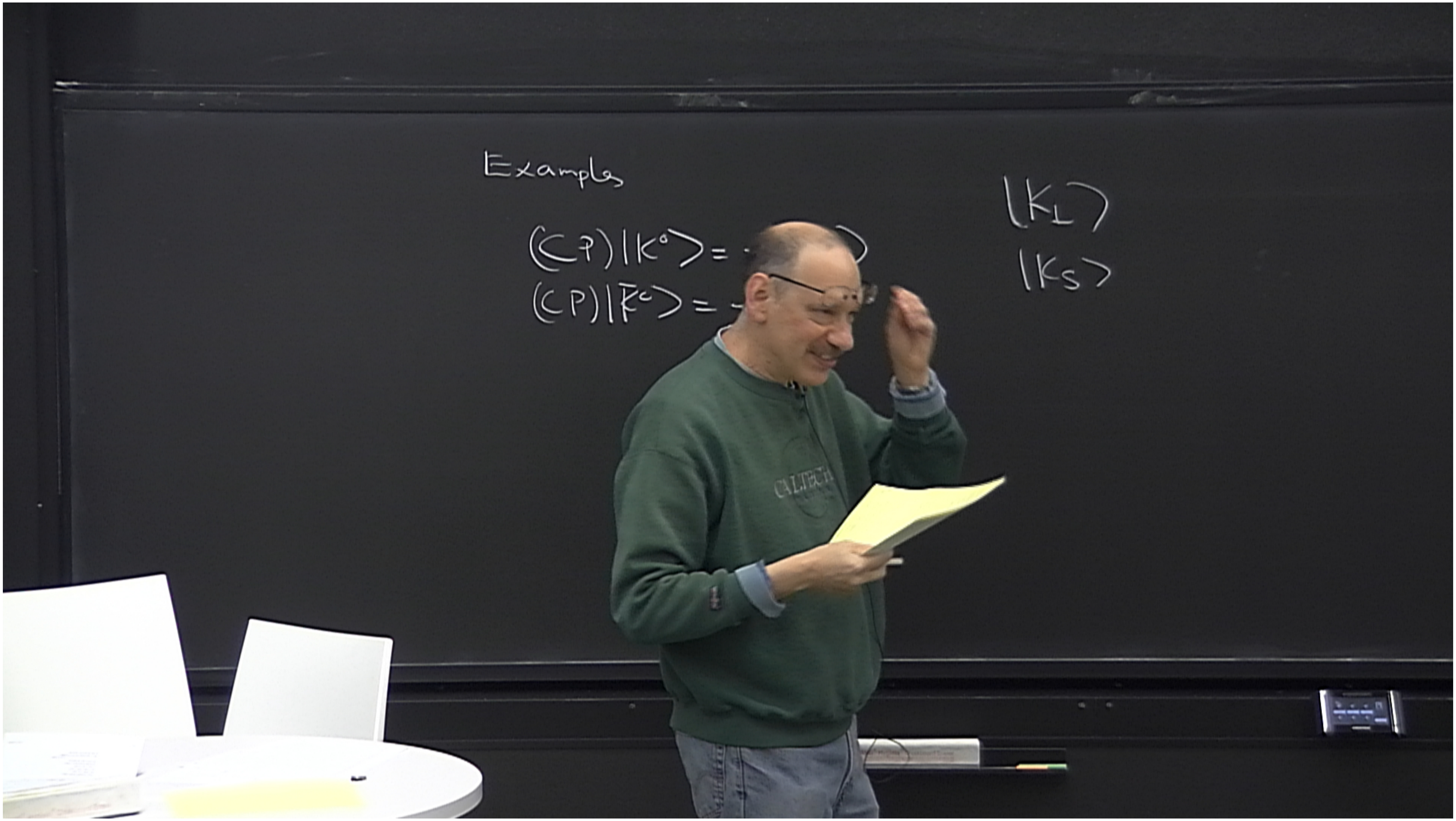
$s_i = \sin\theta_i$

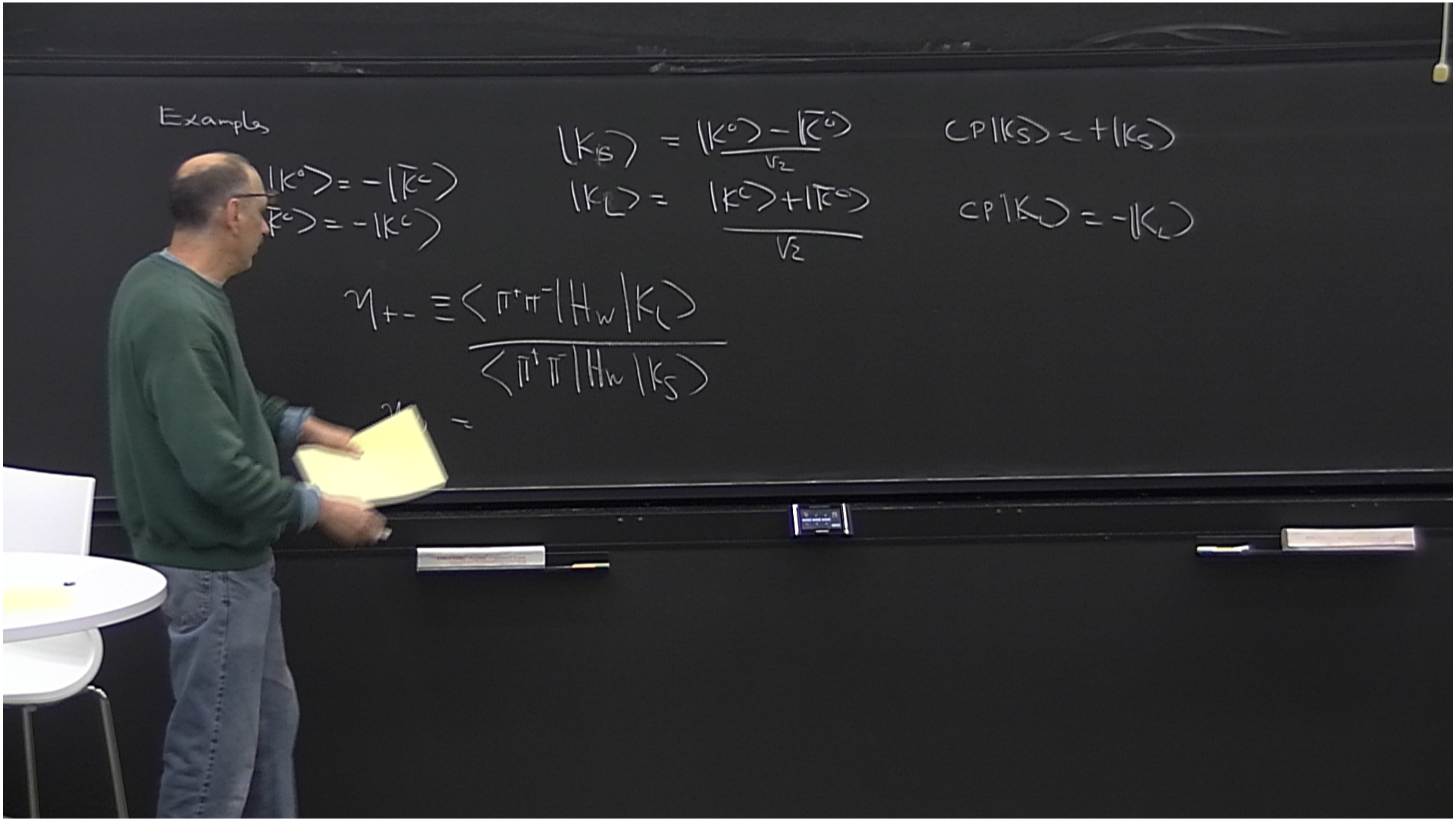
θ_{12}

θ_{13}

θ_{23}


Examples


Example
(CP)|K°> =
(CP)|K̄°> =
|K_L>
|K_S>


Examples
|K_S⟩ = (|K°⟩ − |K̄°⟩)/√2
CP|K_S⟩ = +|K_S⟩
|K_L⟩ = (|K°⟩ + |K̄°⟩)/√2
CP|K_L⟩ = −|K_L⟩
η+− ≡ ⟨π⁺π⁻|H_W|K_L⟩ / ⟨π⁺π⁻|H_W|K_S⟩

Examples

$$(CP)|K^0\rangle = -|\bar{K}^0\rangle$$

$$(CP)|\bar{K}^0\rangle = -|K^0\rangle$$

$$|K_S\rangle = \frac{|K^0\rangle - |\bar{K}^0\rangle}{\sqrt{2}}$$

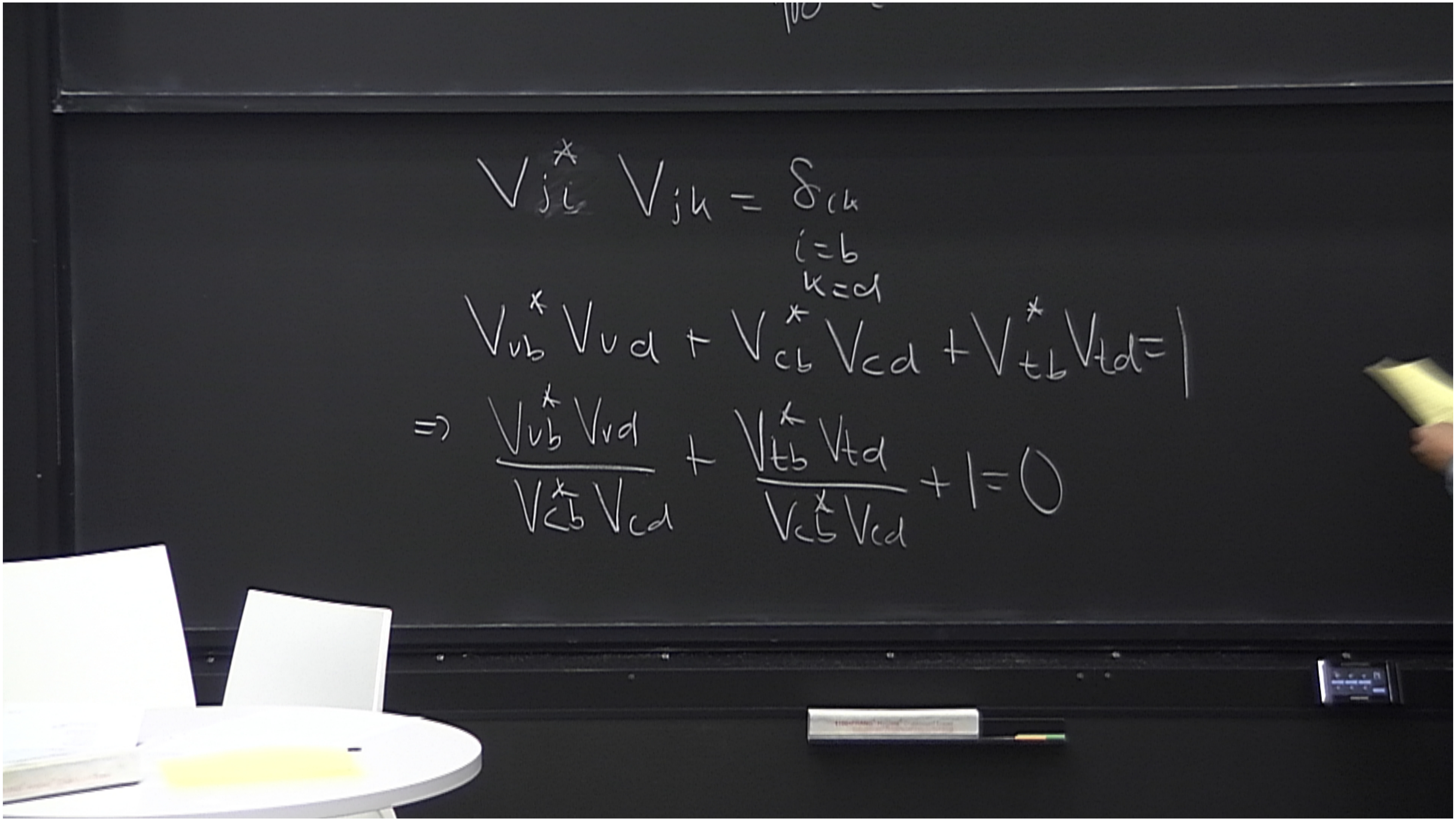
$$|K_L\rangle = \frac{|K^0\rangle + |\bar{K}^0\rangle}{\sqrt{2}}$$

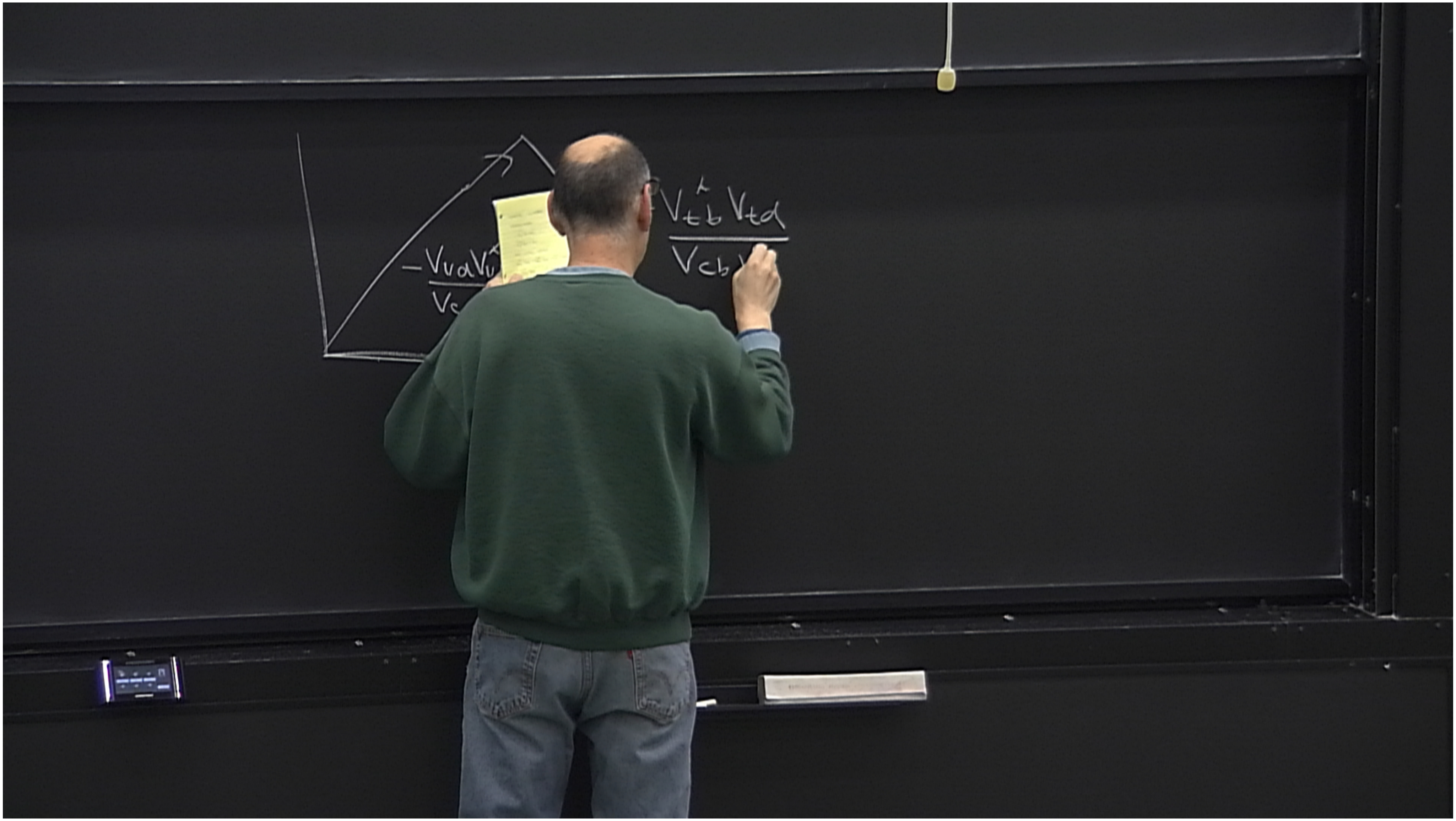
$$CP|K_S\rangle = +|K_S\rangle$$

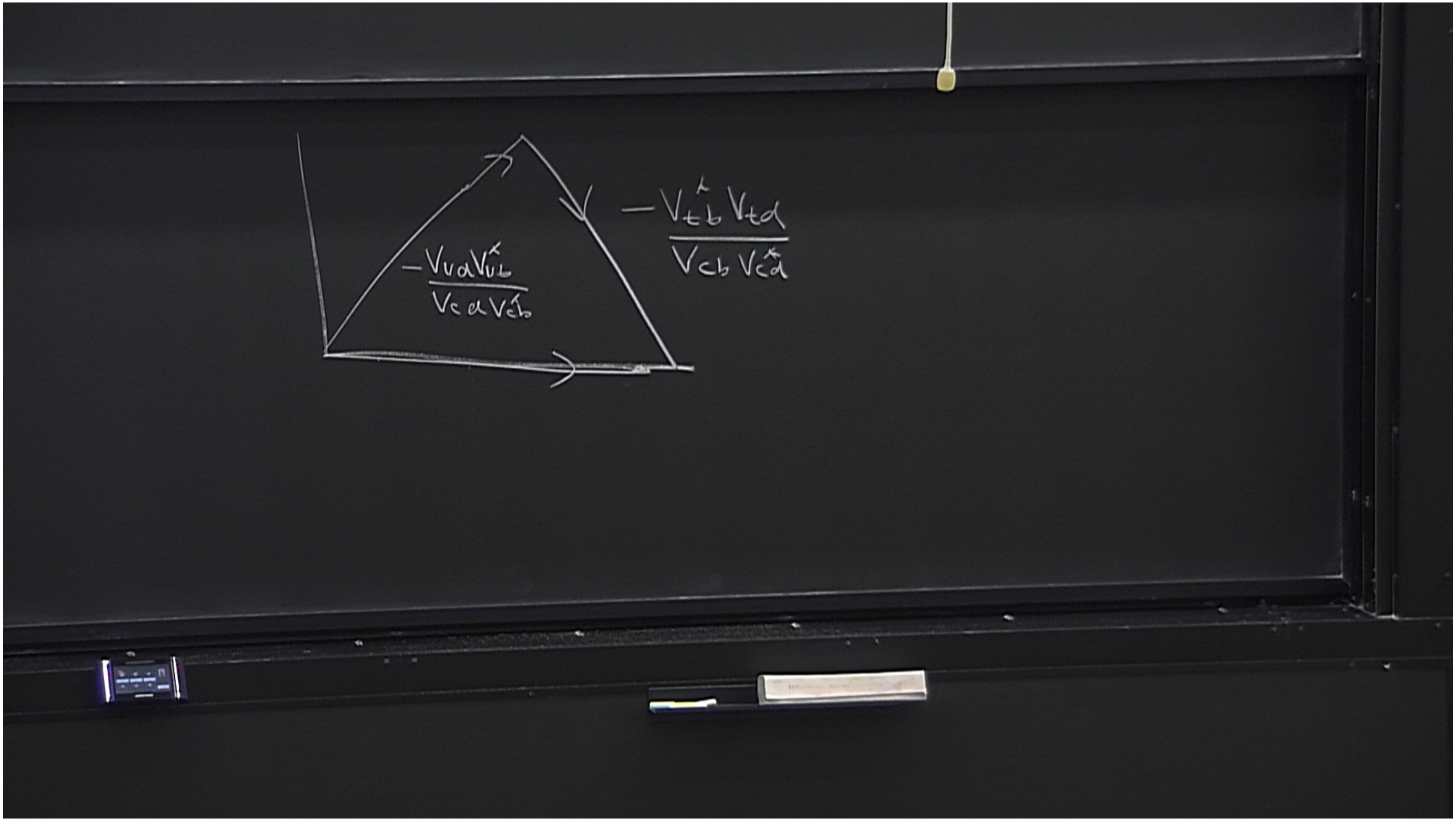
$$CP|K_L\rangle = -|K_L\rangle$$

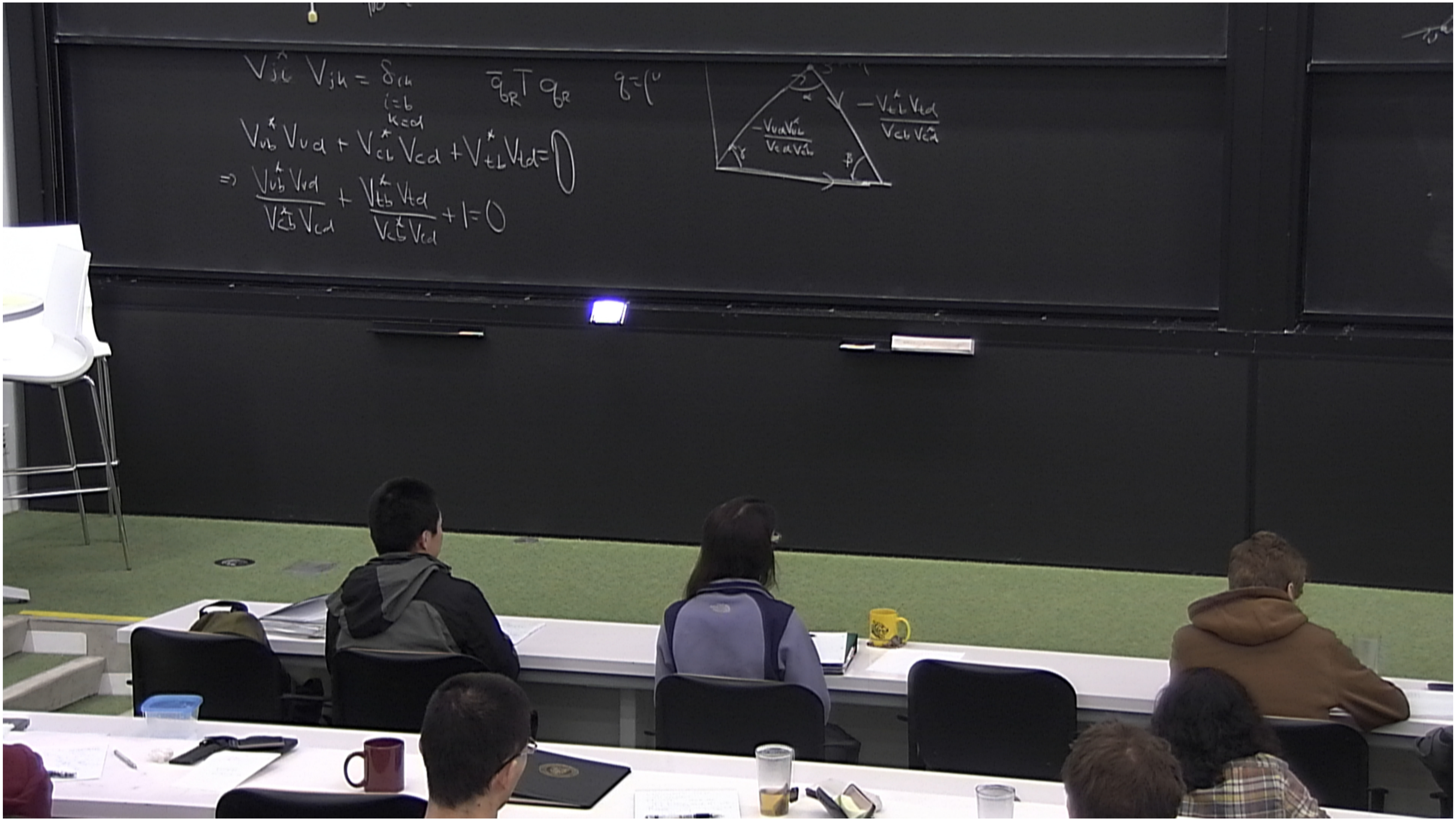
$$\eta_{+-} \equiv \frac{\langle \pi^+\pi^- | H_W | K_L\rangle}{\langle \pi^+\pi^- | H_W | K_S\rangle} = 0 \quad \leftarrow \text{CP conserved}$$

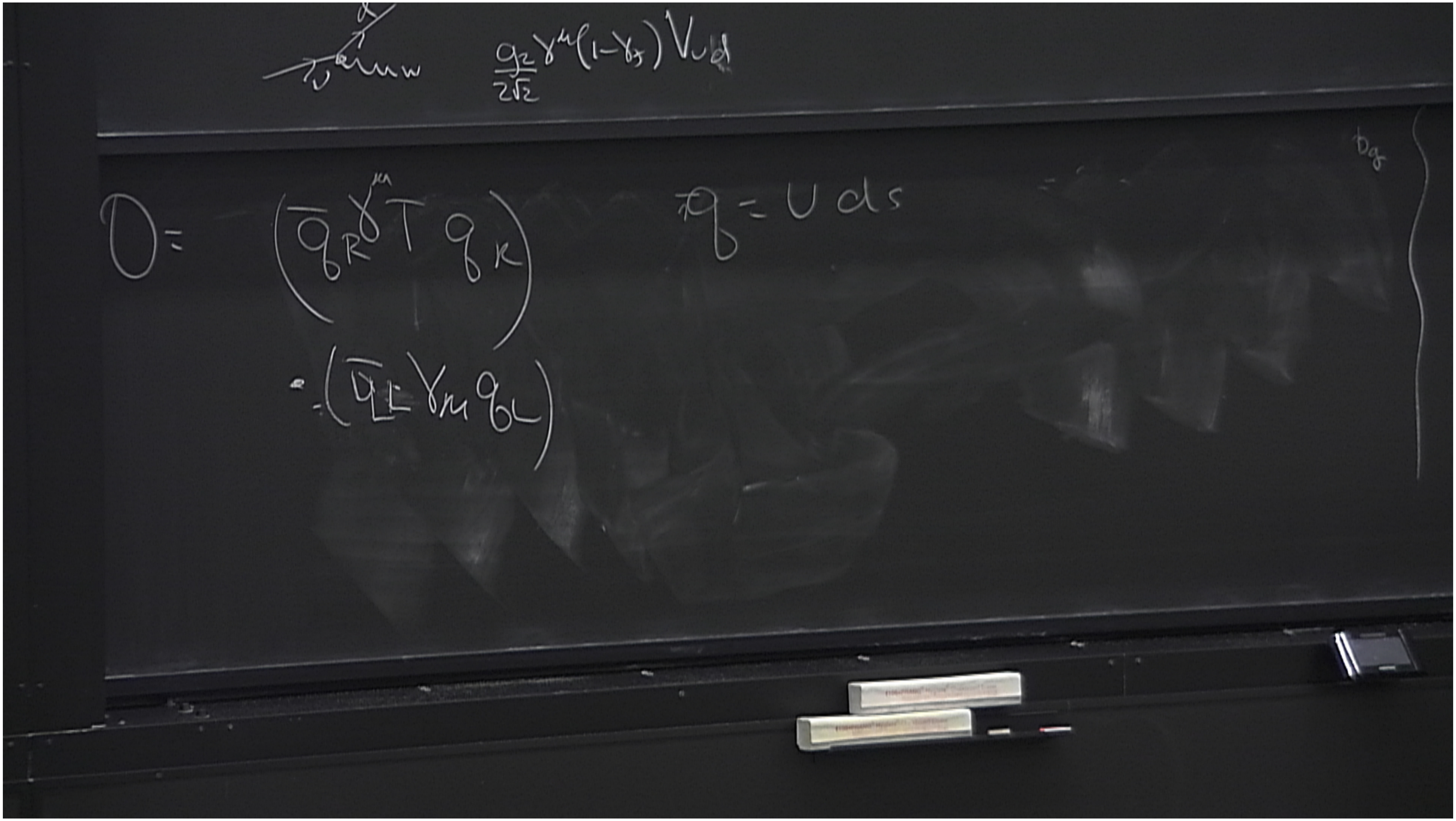
$$\eta_{00} =$$

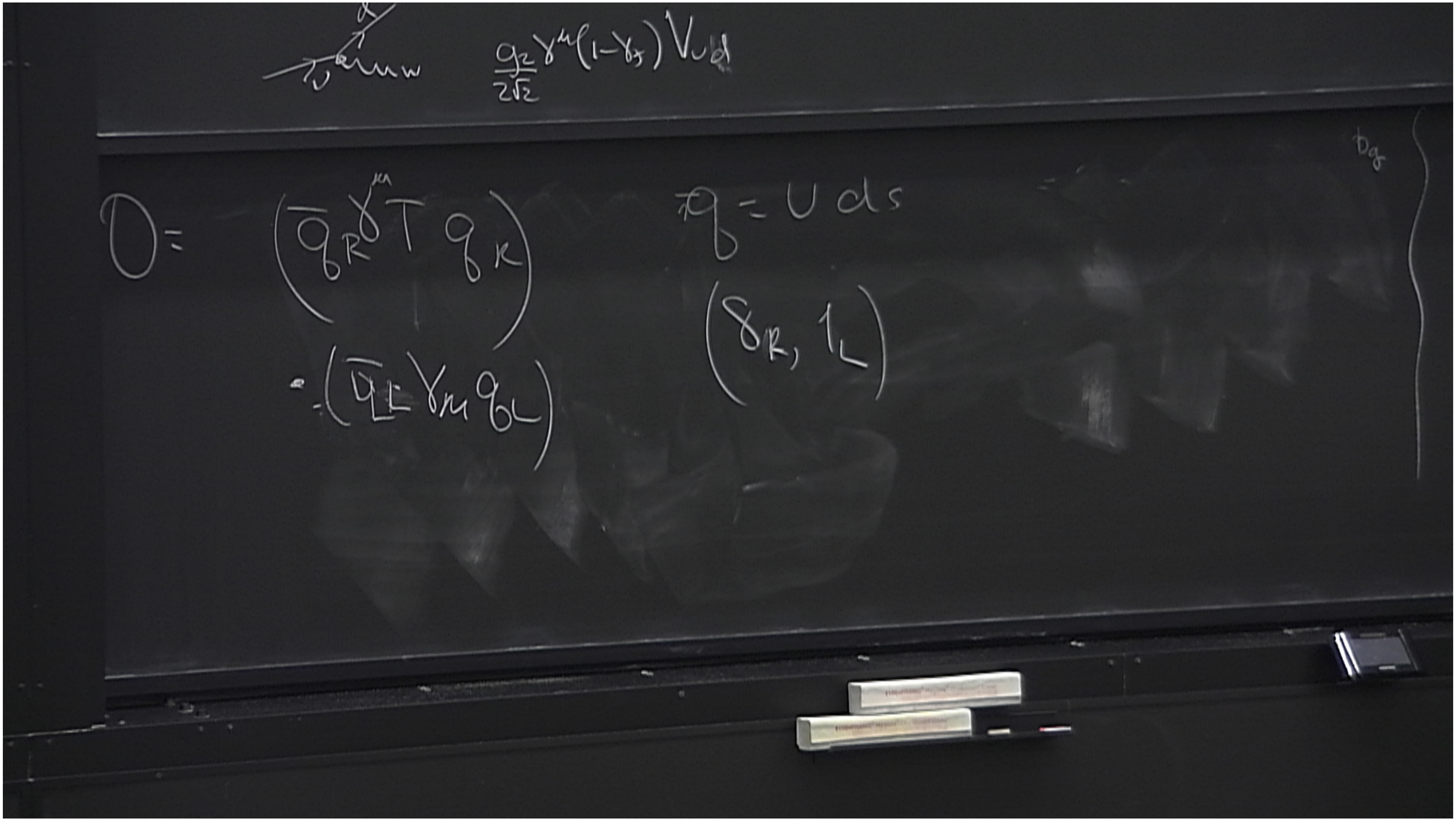

$V^*_{ji} V_{jk} = \delta_{ik}$
$i=b$
$k=d$
$V^*_{ub} V_{ud} + V^*_{cb} V_{cd} + V^*_{tb} V_{td} = 1$
$\Rightarrow \frac{V^*_{ub} V_{ud}}{V^*_{cb} V_{cd}} + \frac{V^*_{tb} V_{td}}{V^*_{cb} V_{cd}} + 1 = 0$

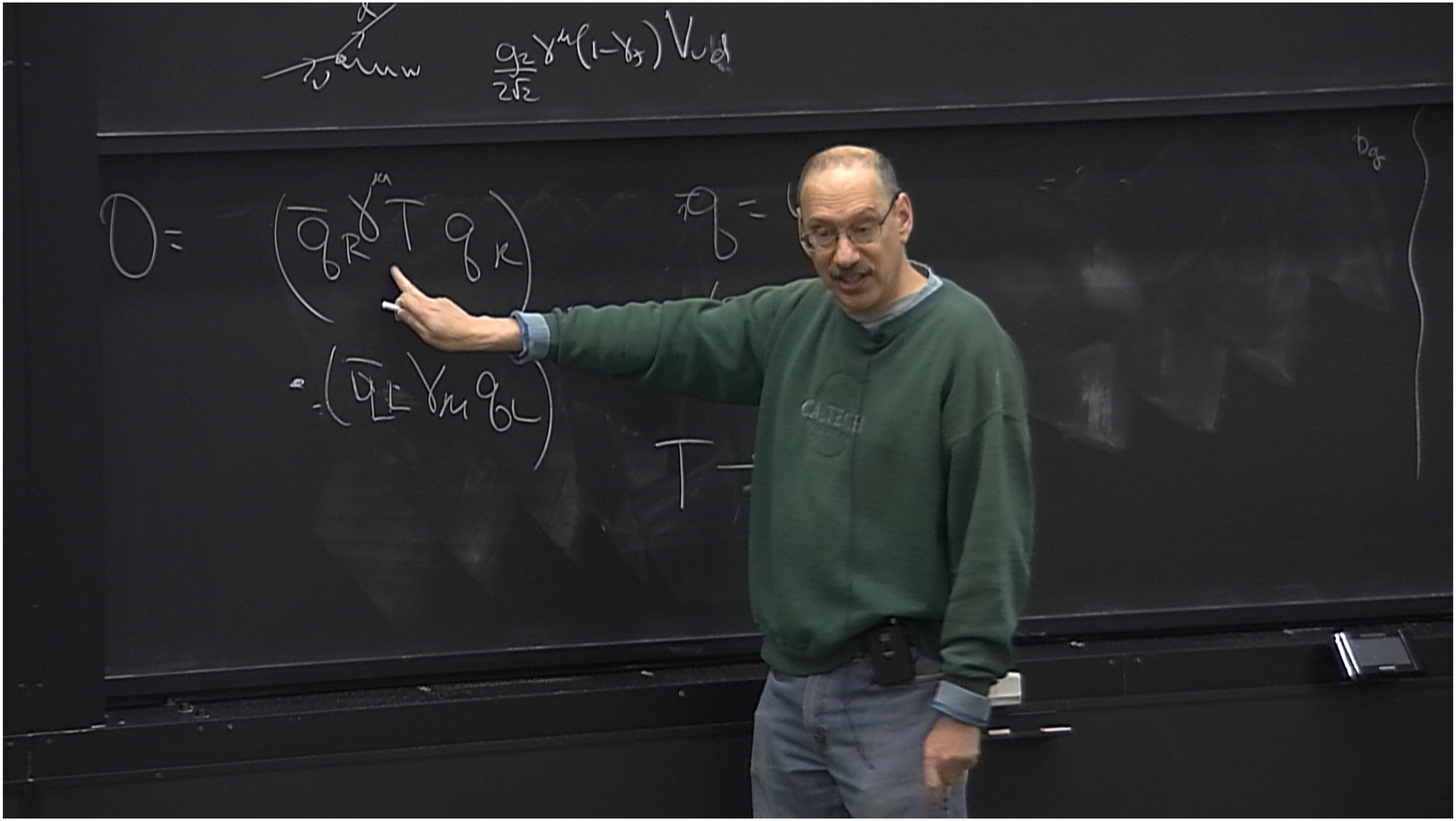

Vtb Vtd
Vcb


−VudVub* / VcdVcb*
−Vtb*Vtd / VcbVcd*


V_ji* V_jk = δ_ik
i=b
k=d
V_ub* V_ud + V_cb* V_cd + V_tb* V_td = 0
=> V_ub* V_ud / V_cb* V_cd + V_tb* V_td / V_cb* V_cd + 1 = 0
−V_tb* V_td / V_cb V_cd*
−V_ud V_ub* / V_cd V_cb*


q = u d s


g2/2√2 γ^μ(1−γ5) Vud
O = (q̄R γ^μ T qR)(q̄L γμ qL)
q = u d s
(8R, 1L)


$\frac{g_2}{2\sqrt{2}}\gamma^\mu(1-\gamma_5)V_{ud}$
$D = (\bar{q}_R \gamma^\mu T q_R) \cdot (\bar{q}_L \gamma_\mu q_L)$