Title: PSI 2019/2020 - Standard Model and Beyond - Part 1 - Lecture 6

Speakers: Latham Boyle

Collection: PSI 2019/2020 - Standard Model and Beyond - Part 1

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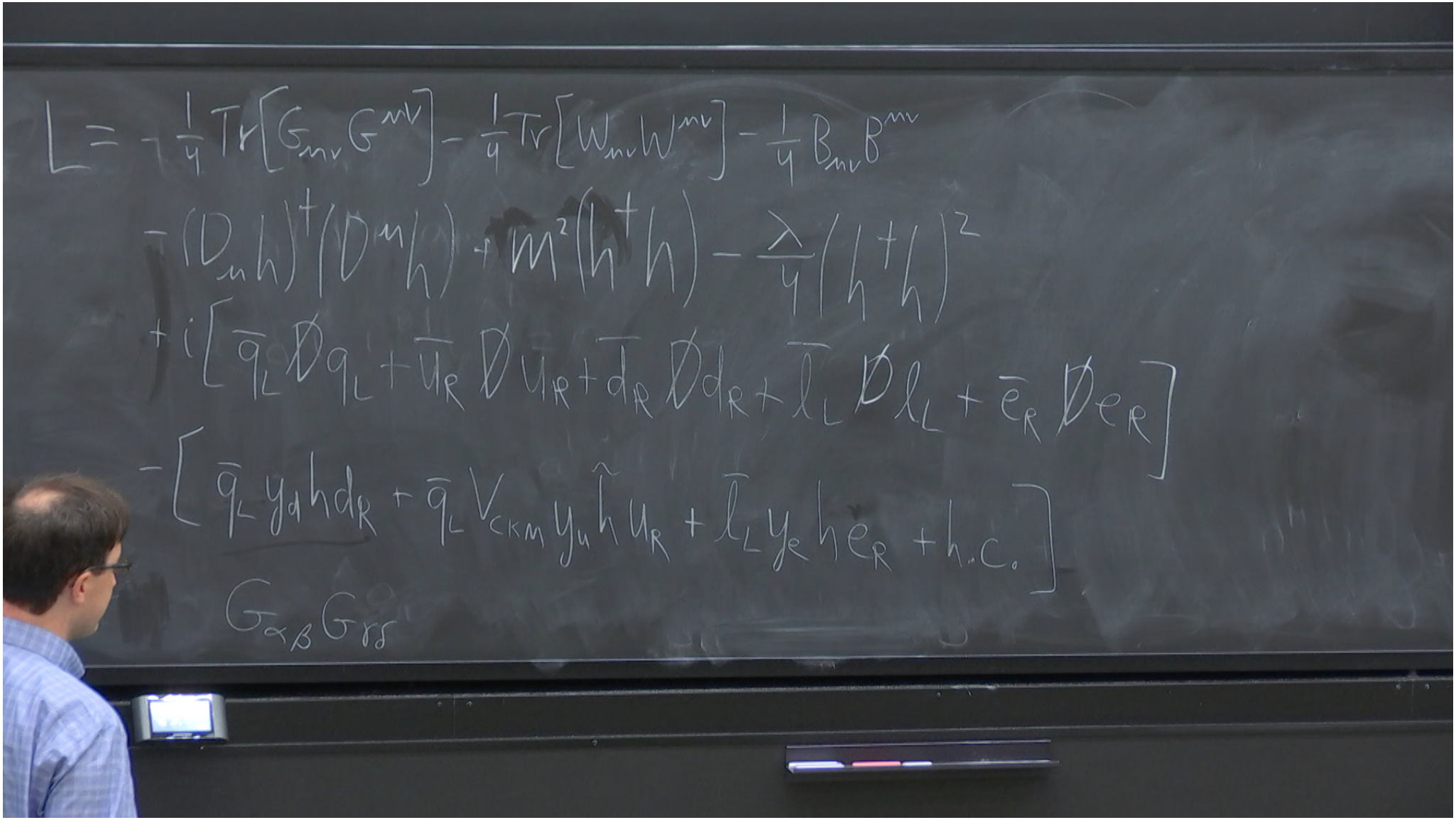
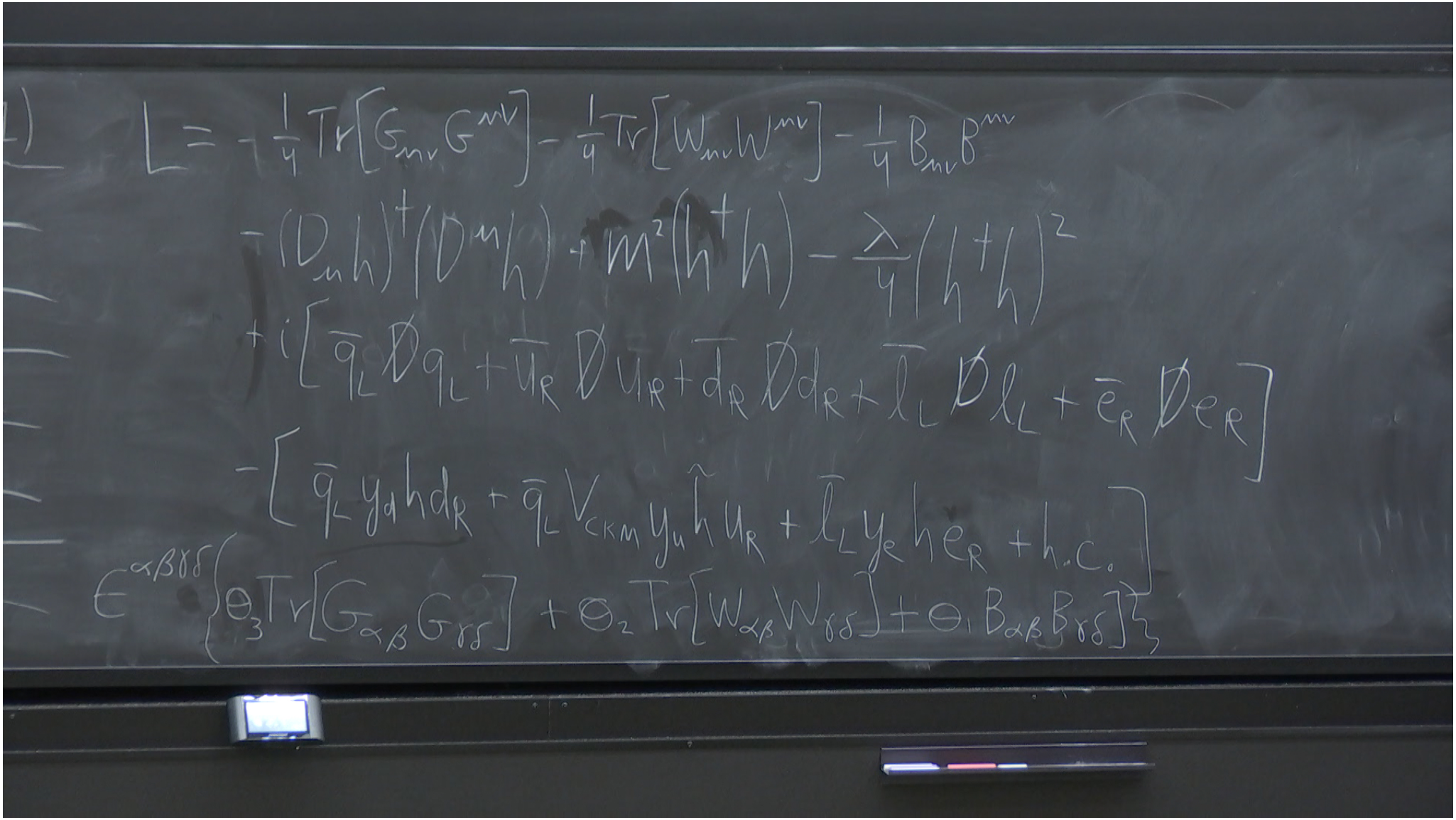
# Lecture 6:

| | SU(3) | SU(2) | U(1) |
|---|---|---|---|
| $q_L$ | 3 | 2 | 1/6 |
| $u_R$ | 3 | 1 | 2/3 |
| $d_R$ | 3 | 1 | $-1/3$ |
| $l_L$ | 1 | 2 | $-1/2$ |
| $\nu_R$ | 1 | 1 | 0 |
| $e_R$ | 1 | 1 | $-1$ |
| $h$ | 1 | 2 | 1/2 |
| $\tilde{h} = i\sigma^2 h^*$ | 1 | 2 | $-1/2$ |

$L =$


$\mathcal{L} = -\frac{1}{4}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}\mathrm{Tr}[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$
$-(D_\mu h)^\dagger (D^\mu h) + m^2(h^\dagger h) - \frac{\lambda}{4}(h^\dagger h)^2$
$+ i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R]$
$-[\bar{q}_L y_d h d_R + \bar{q}_L V_{CKM} y_u \tilde{h} u_R + \bar{l}_L y_e h e_R + h.c.]$
$G_{\alpha\beta} G_{\gamma\delta}$


L) $L = -\frac{1}{4}Tr[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}Tr[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$
$-(D_\mu h)^\dagger (D^\mu h) + m^2(h^\dagger h) - \frac{\lambda}{4}(h^\dagger h)^2$
$+ i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R]$
$-[\bar{q}_L y_d h d_R + \bar{q}_L V_{CKM} y_u \tilde{h} u_R + \bar{l}_L y_e h e_R + h.c.]$
$\epsilon^{\alpha\beta\gamma\delta}\{\theta_3 Tr[G_{\alpha\beta}G_{\gamma\delta}] + \theta_2 Tr[W_{\alpha\beta}W_{\gamma\delta}] + \theta_1 B_{\alpha\beta}B_{\gamma\delta}]\}$

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| $h$ | 1 | 2 | 1/2 |
| $\tilde{h} = i\sigma^2 h^*$ | 1 | 2 | -1/2 |

$$\mathcal{L} = -\frac{1}{4}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}\mathrm{Tr}[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

$$-(D_\mu h)^\dagger (D^\mu h) + m^2(h^\dagger h) - \frac{\lambda}{4}(h^\dagger h)^2$$

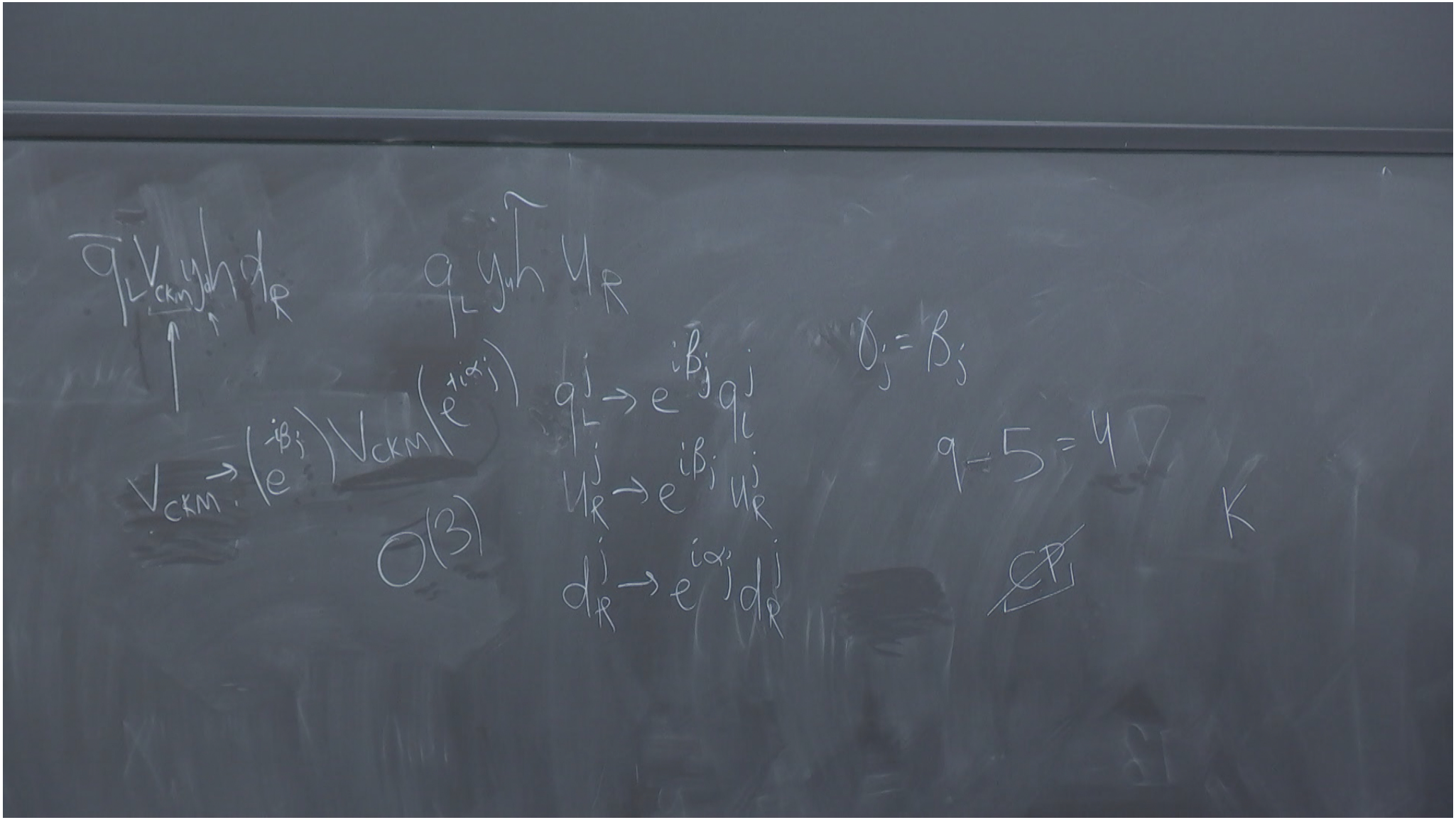
$$+ i\left[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R\right]$$

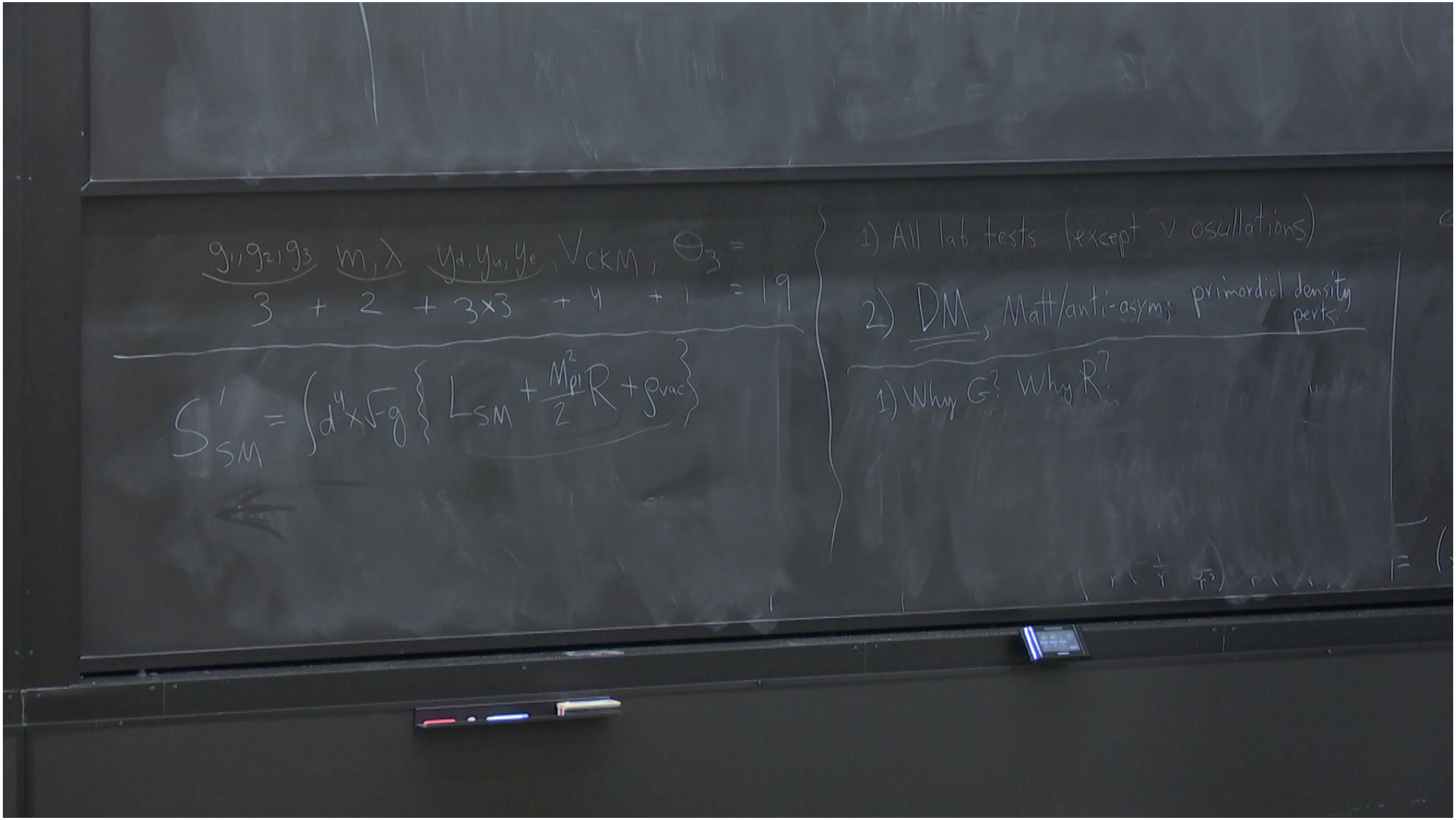
$$-\left[\bar{q}_L V_{CKM} y_d h d_R + \bar{q}_L \hat{y}_u \hat{h} u_R + \bar{l}_L y_e h e_R + \text{h.c.}\right]$$

$$\epsilon^{\alpha\beta\delta\delta}\left\{\Theta_3 \mathrm{Tr}[G_{\alpha\beta}G_{\delta\delta}] + \Theta_2 \mathrm{Tr}[W_{\alpha\beta}W_{\delta\delta}] + \Theta_1 B_{\alpha\beta}B_{\delta\delta}\right\}$$

$$S = \int d^4x \mathcal{L}$$

$$\frac{\delta S}{\delta \Lambda} = 0$$


$\bar{q}_L V_{CKM} y_u h d_R$
$q_L y_u \tilde{h} u_R$
$V_{CKM} \to (e^{-i\beta_j}) V_{CKM} (e^{+i\alpha_j})$
$O(3)$
$q_L^j \to e^{i\beta_j} q_L^j$
$u_R^j \to e^{i\beta_j} u_R^j$
$d_R^j \to e^{i\alpha_j} d_R^j$
$\gamma_j = \beta_j$
$9 - 5 = 4$
K
CP


$g_1, g_2, g_3$ $m, \lambda$ $y_d, y_u, y_e$, $V_{CKM}$, $\theta_3$ =
3 + 2 + 3×3 + 4 + 1 = 19
$S'_{SM} = \int d^4x \sqrt{-g} \left\{ L_{SM} + \frac{M_{Pl}^2}{2} R + \rho_{vac} \right\}$
1) All lab tests (except ν osallations)
2) DM, Matt/anti-asym; primordial density perts.
1) Why G? Why R?

ture 6:

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$$\mathcal{L} = -\frac{1}{4}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}\mathrm{Tr}[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

$$-(D_\mu h)^\dagger (D^\mu h) + m^2(h^\dagger h) - \frac{\lambda}{4}(h^\dagger h)^2$$

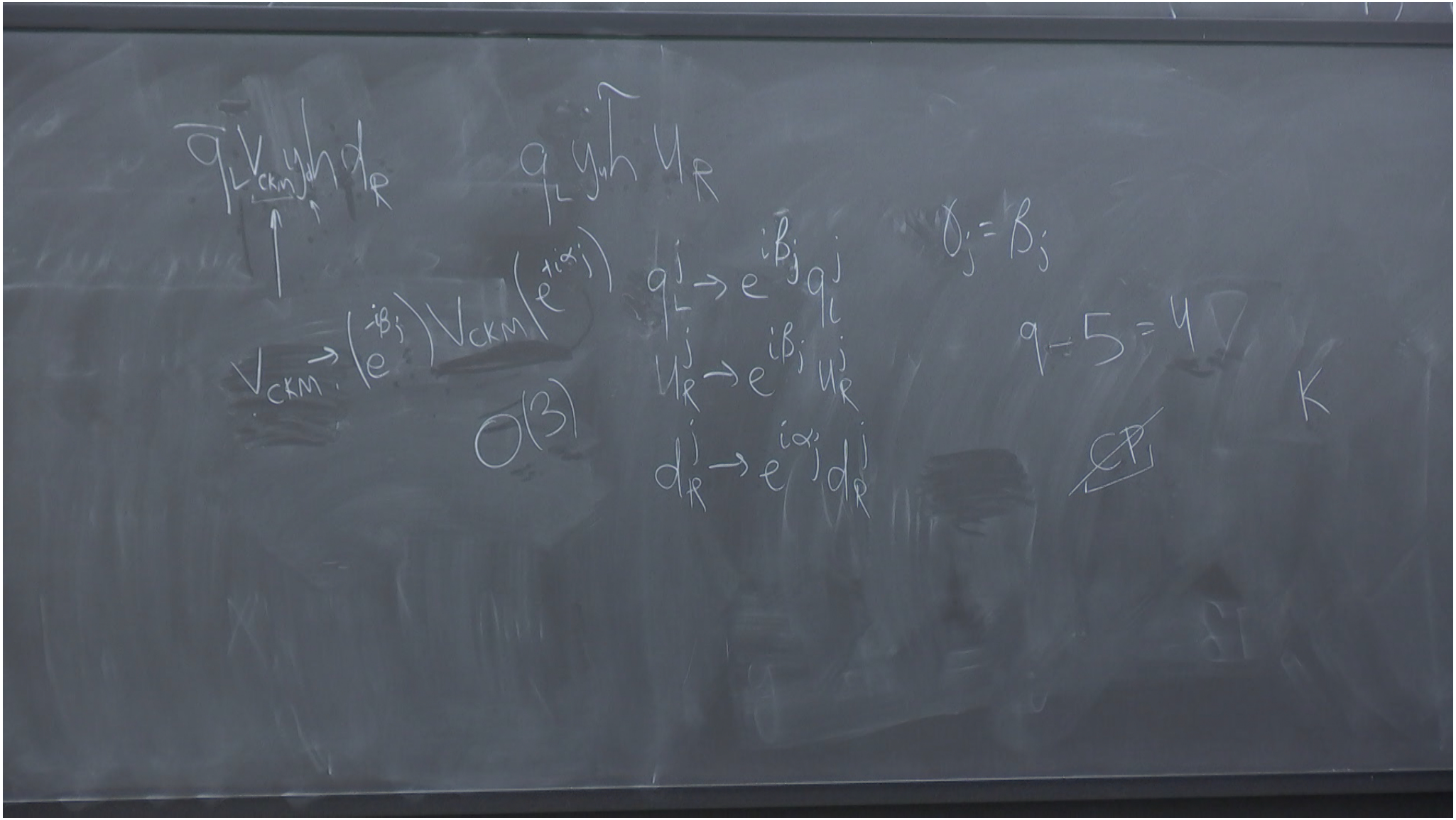
$$+ i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + \bar{e}_R \not{D} e_R]$$

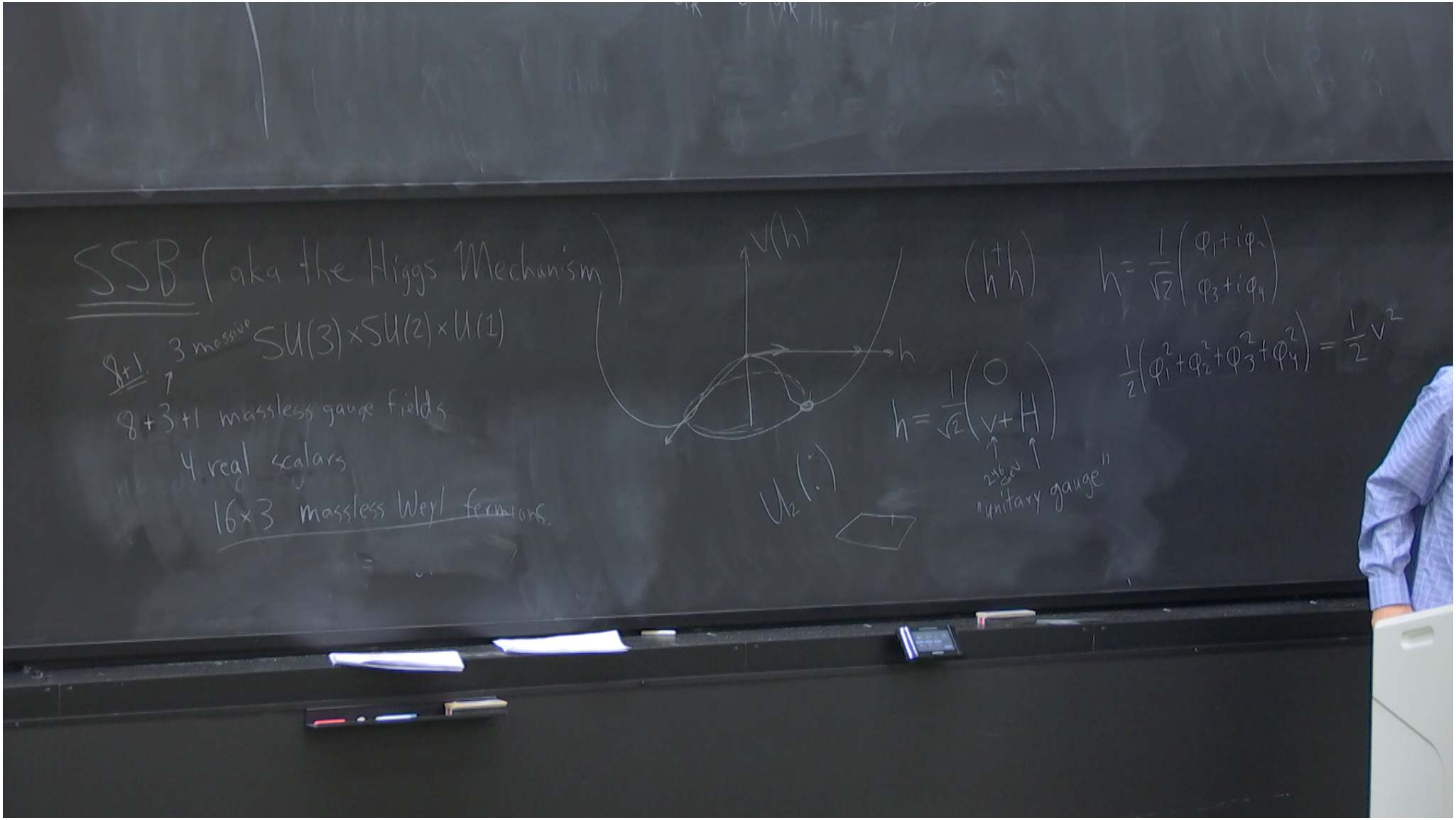
$$- [\bar{q}_L V_{CKM} y_d h d_R + \bar{q}_L \, y_u \tilde{h} u_R + \bar{l}_L y_e h e_R + \text{h.c.}]$$

$$\epsilon^{\alpha\beta\gamma\delta}\{\theta_3 \mathrm{Tr}[G_{\alpha\beta}G_{\gamma\delta}] + \theta_2 \mathrm{Tr}[W_{\alpha\beta}W_{\gamma\delta}] + \theta_1 B_{\alpha\beta}B_{\gamma\delta}\}$$

$S =$

$\frac{\delta S}{\delta A}$


$\bar{q}_L V_{CKM} y_{ud} h d_R$
$q_L y_{un} \tilde{h} u_R$
$V_{CKM} \to (e^{-i\beta_j}) V_{CKM} (e^{+i\alpha_j})$
$q_L^j \to e^{i\beta_j} q_L^j$
$u_R^j \to e^{i\beta_j} u_R^j$
$d_R^j \to e^{i\alpha_j} d_R^j$
$\alpha_j = \beta_j$
$9 - 5 = 4$
$O(3)$
K
CP


SSB (aka the Higgs Mechanism)
8+1 → 3 massive
SU(3)×SU(2)×U(1)
8+3+1 massless gauge fields
4 real scalars
16×3 massless Weyl fermions.
V(h)
h
$U_2(\cdot)$
$(h^\dagger h)$
$h = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix}$
$\frac{1}{2}(\phi_1^2+\phi_2^2+\phi_3^2+\phi_4^2) = \frac{1}{2}v^2$
$h = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+H \end{pmatrix}$
246 GeV
"unitary gauge"