Title: PSI 2019/2020 - Standard Model and Beyond - Part 1 - Lecture 5

Speakers: Latham Boyle

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

Date: January 14, 2020 - 11:30 AM

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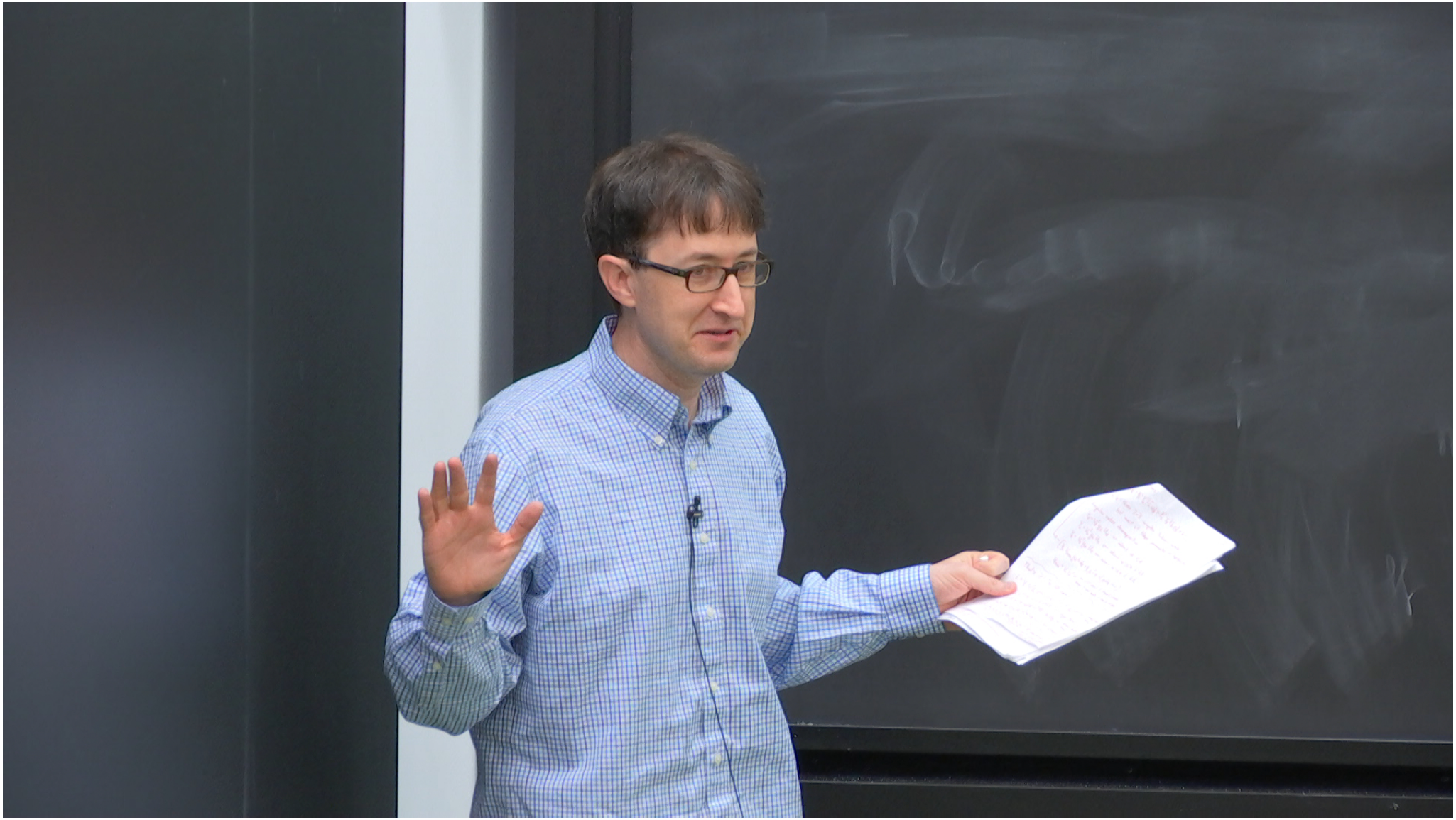
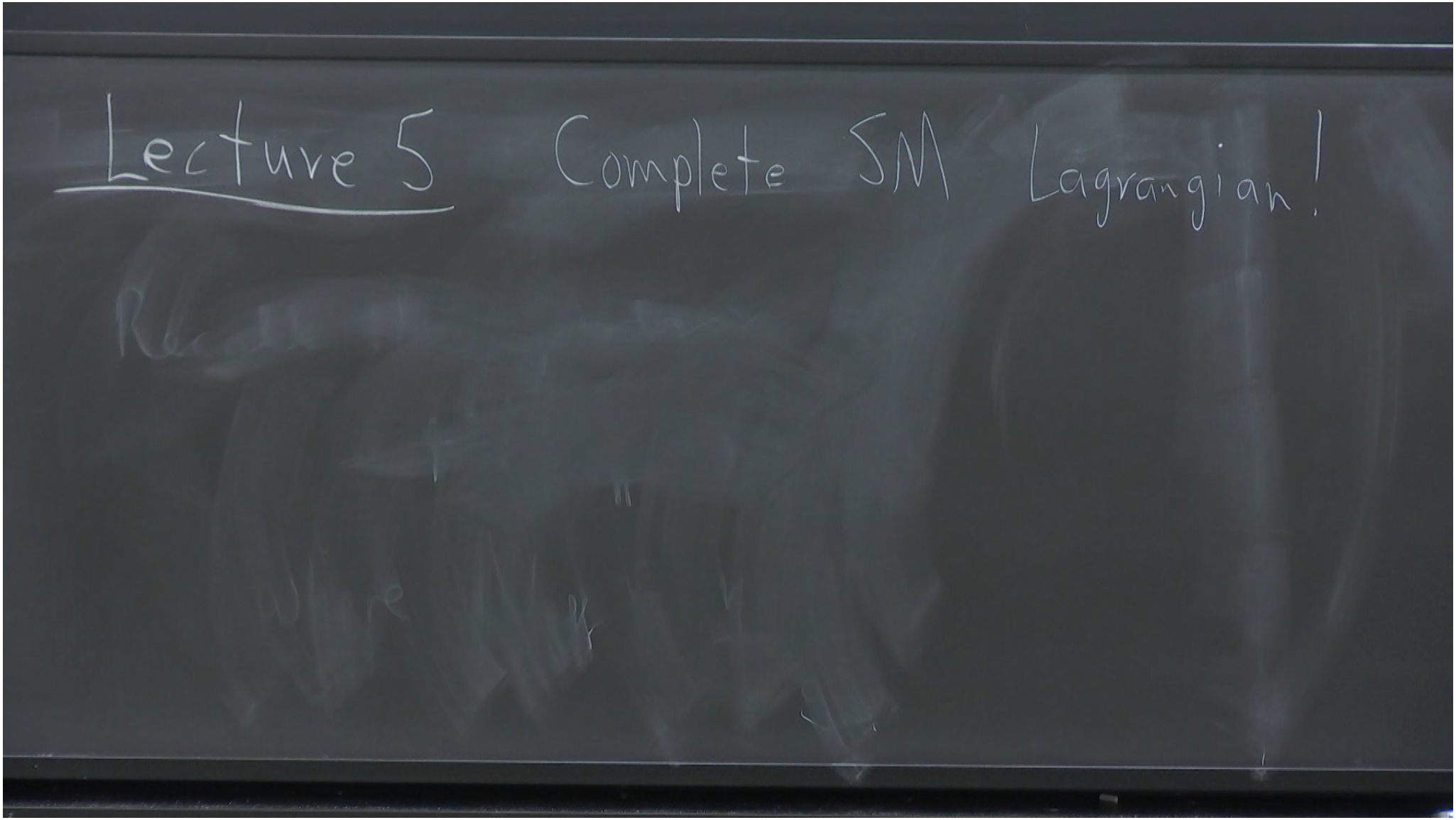


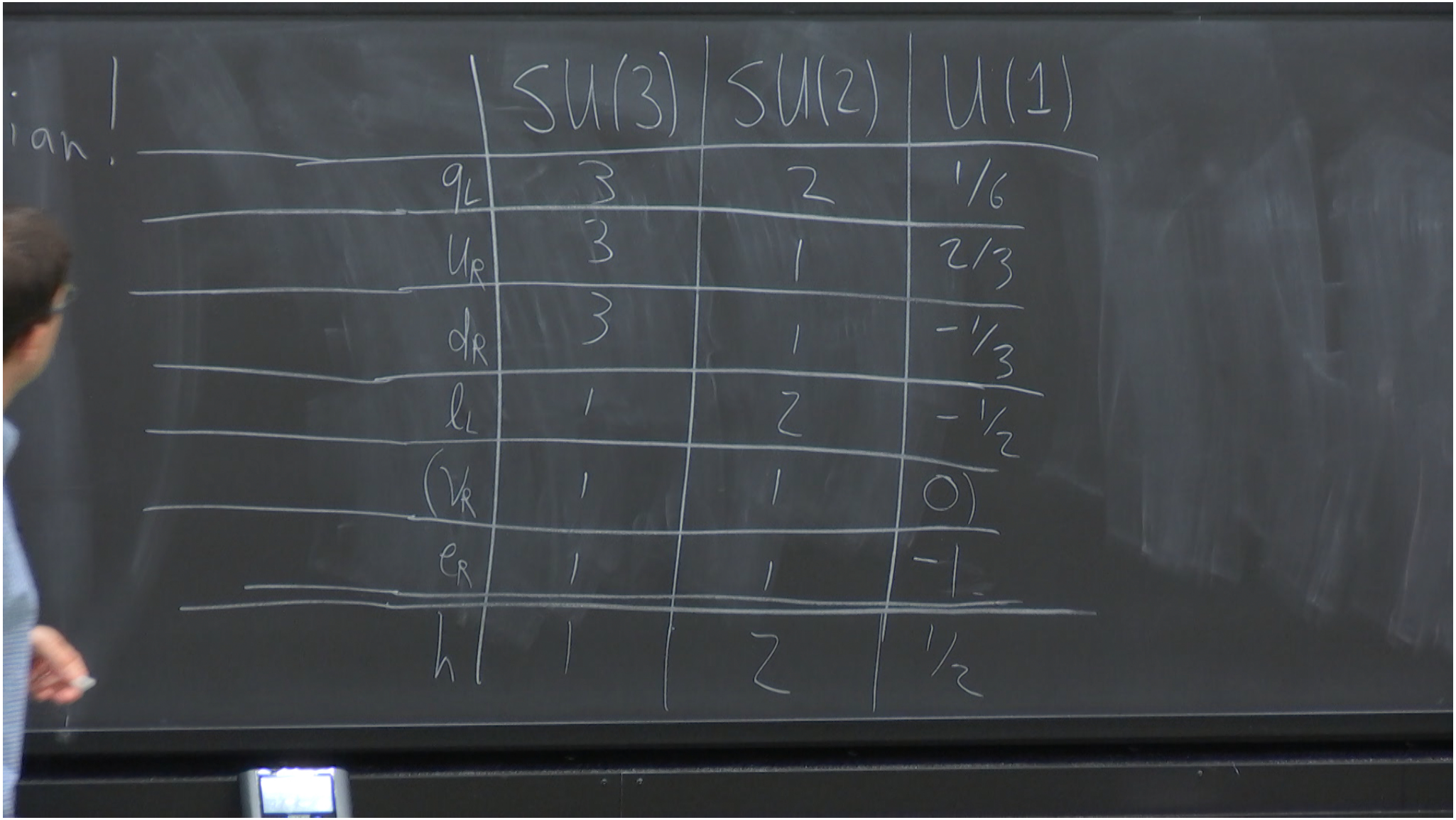

Lecture 5 Complete SM Lagrangian!

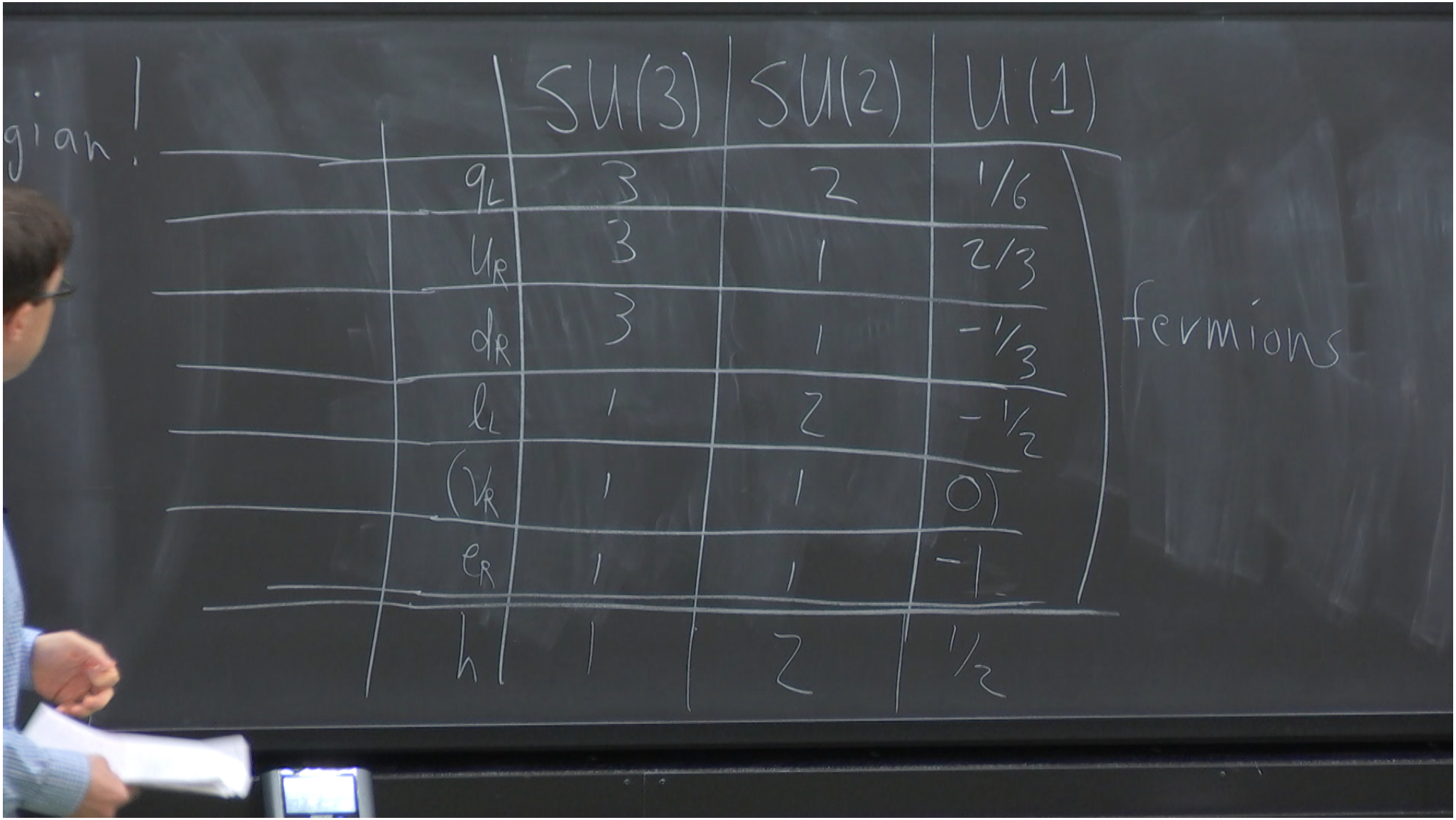
ian!

	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	1/2
h	1	2	1/2

ian!

	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


ian!
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


gian!
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
fermions

gian.

		SU(3)	SU(2)	U(1)
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	q_L	3	2	1/6
(u_R^b, u_R^g, u_R^r)	u_R	3	1	2/3
(d_R^b, d_R^g, d_R^r)	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

fermions

gian.

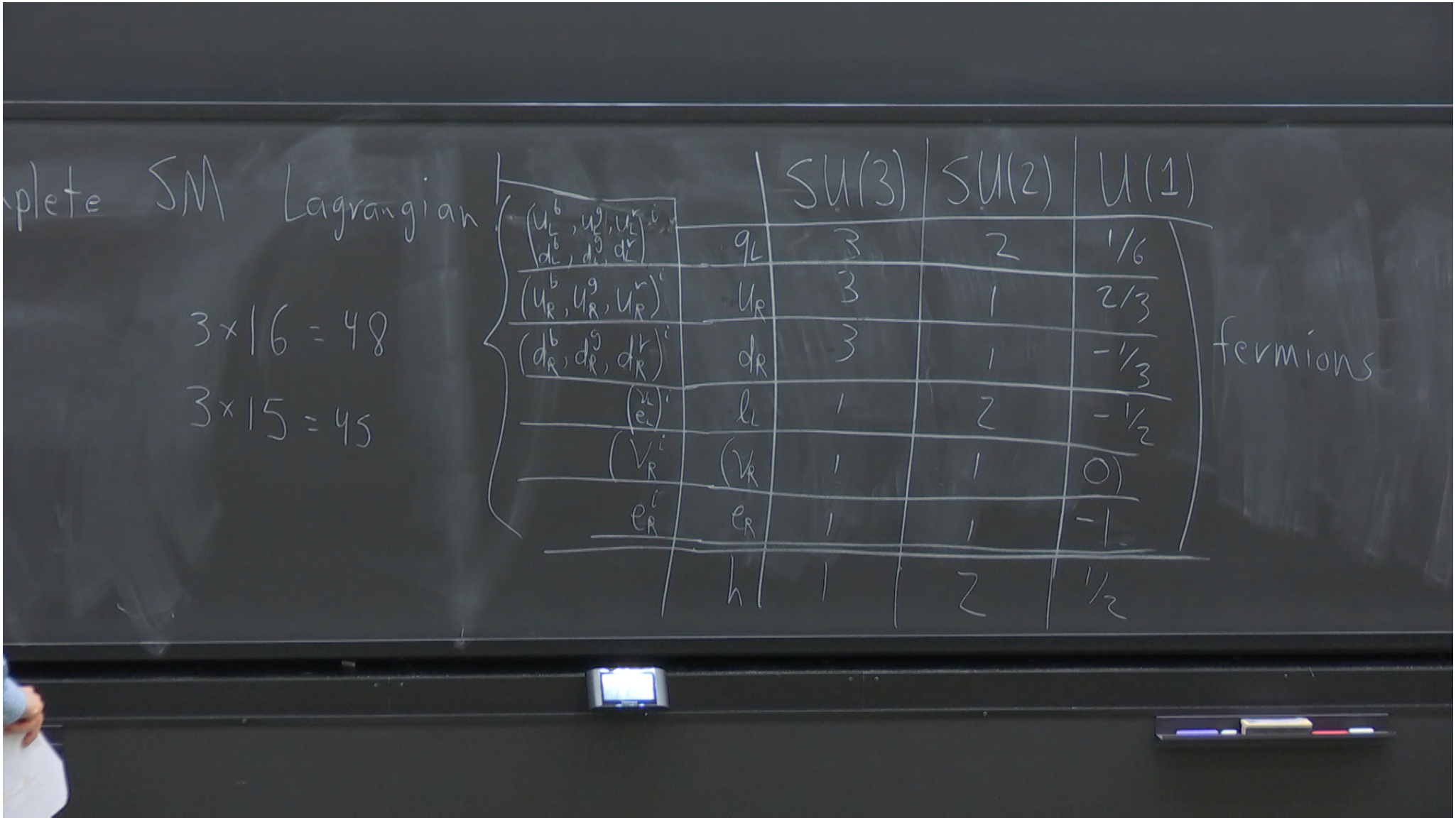
		SU(3)	SU(2)	U(1)
$\begin{pmatrix} u_L^b, u_L^g, u_L^r \\ d_L^b, d_L^g, d_L^r \end{pmatrix}$	q_L	3	2	1/6
(u_R^b, u_R^g, u_R^r)	u_R	3	1	2/3
(d_R^b, d_R^g, d_R^r)	d_R	3	1	−1/3
	l_L	1	2	−1/2
	$(\nu_R$	1	1	0)
	e_R	1	1	−1
	h	1	2	1/2

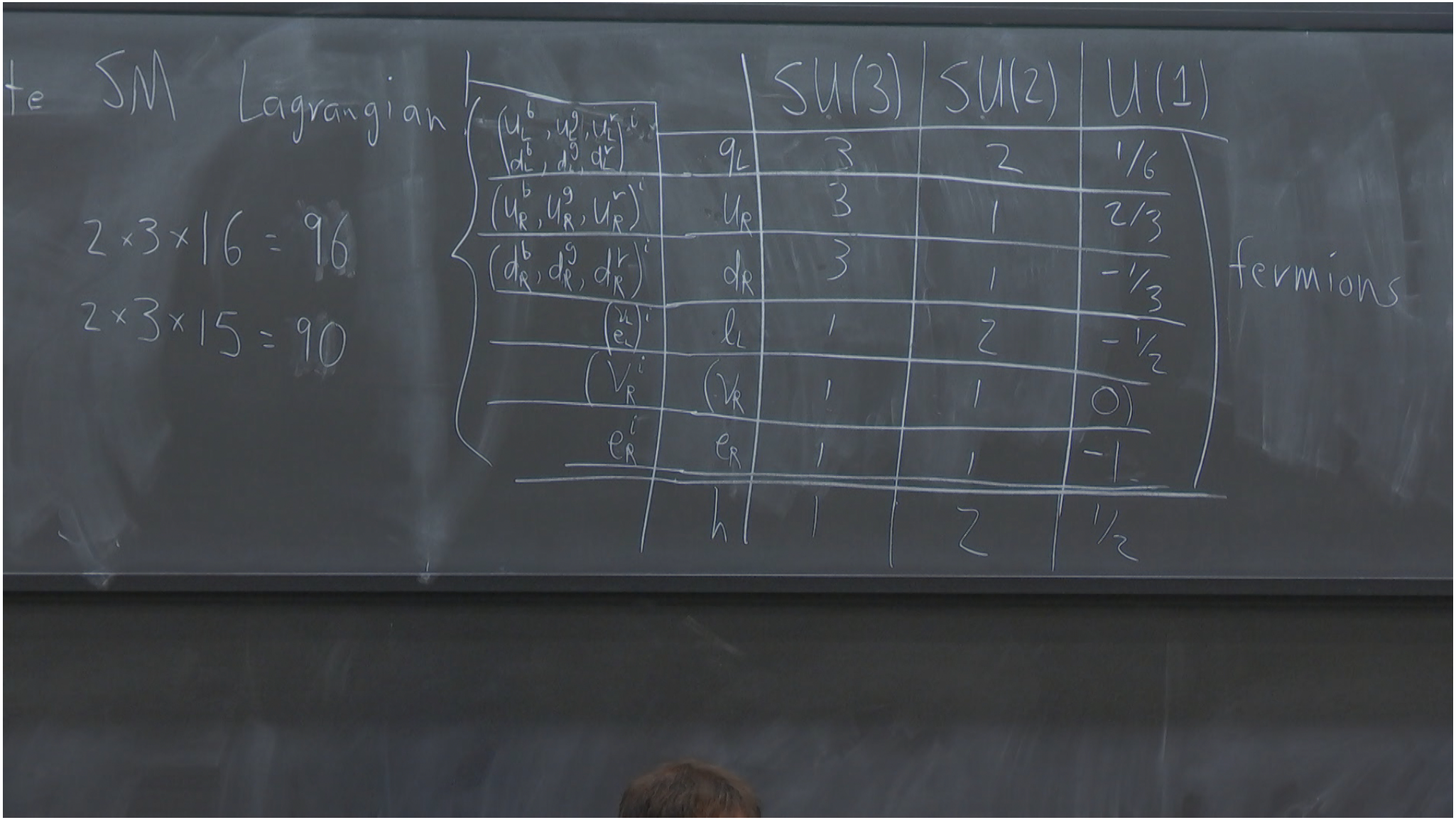
fermions

gian.

		SU(3)	SU(2)	U(1)
$\begin{pmatrix} u_L^b, u_L^g, u_L^r \\ d_L^b, d_L^g, d_L^r \end{pmatrix}$	q_L	3	2	1/6
(u_R^b, u_R^g, u_R^r)	u_R	3	1	2/3
(d_R^b, d_R^g, d_R^r)	d_R	3	1	-1/3
$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	l_L	1	2	-1/2
ν_R	$(\nu_R$	1	1	0)
e_R	e_R	1	1	-1
	h	1	2	1/2

fermions


plete SM Lagrangian
3×16 = 48
3×15 = 45
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
ν_R 1 1 0
e_R 1 1 -1
h 1 2 1/2
fermions


te SM Lagrangian
2×3×16 = 96
2×3×15 = 90
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
ν_R 1 1 0
e_R 1 1 −1
h 1 2 1/2
fermions

		SU(3)	SU(2)	U(1)
$(u_L^b, u_L^g, u_L^r)^i$, $(d_L^b, d_L^g, d_L^r)^i$	q_L	3	2	1/6
$(u_R^b, u_R^g, u_R^r)^i$	u_R	3	1	2/3
$(d_R^b, d_R^g, d_R^r)^i$	d_R	3	1	−1/3
$\begin{pmatrix}\nu_L \\ e_L\end{pmatrix}^i$	l_L	1	2	−1/2
$(\nu_R^i$	$(\nu_R$	1	1	0)
e_R^i	e_R	1	1	−1
	h	1	2	1/2

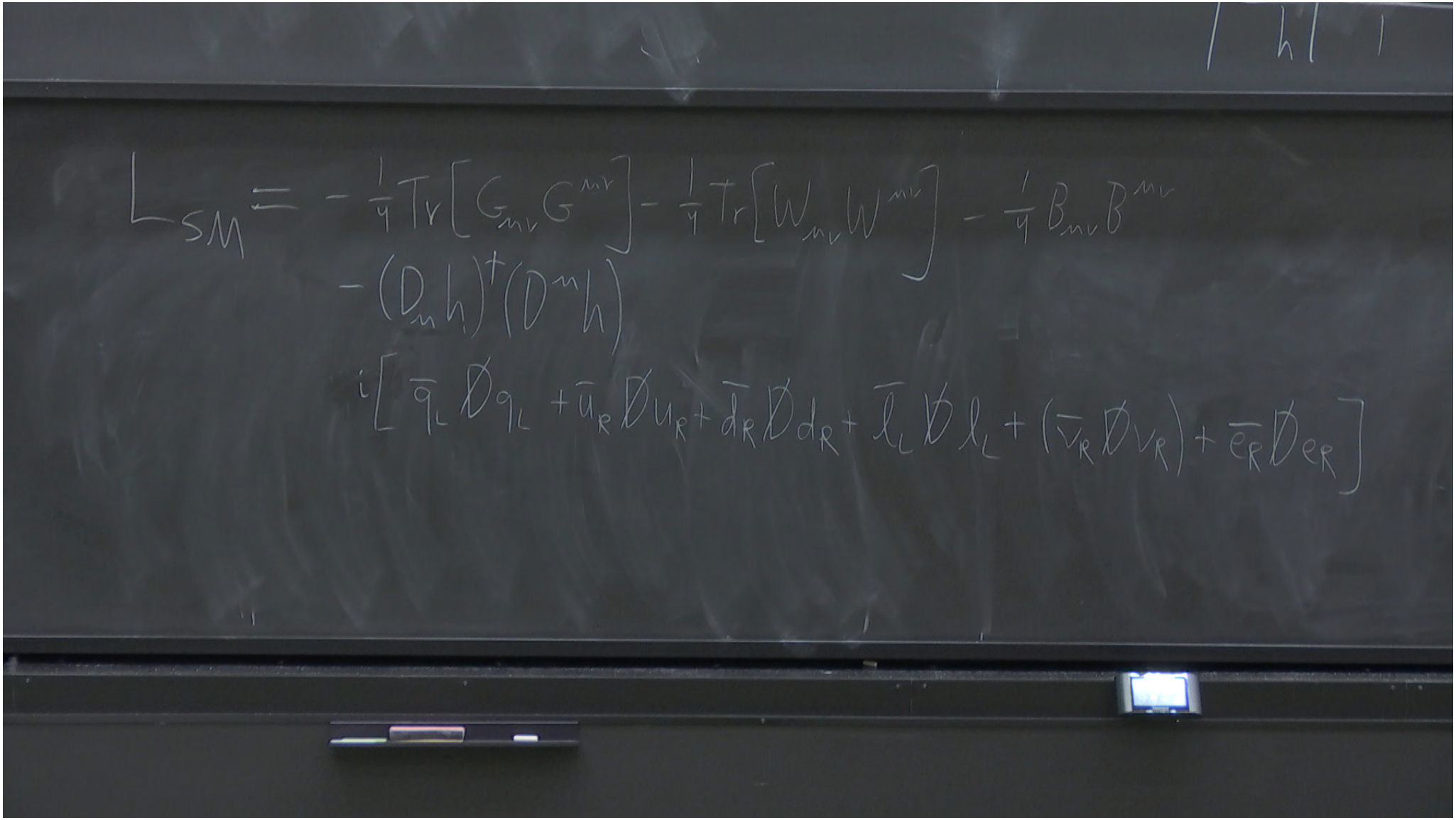
fermions

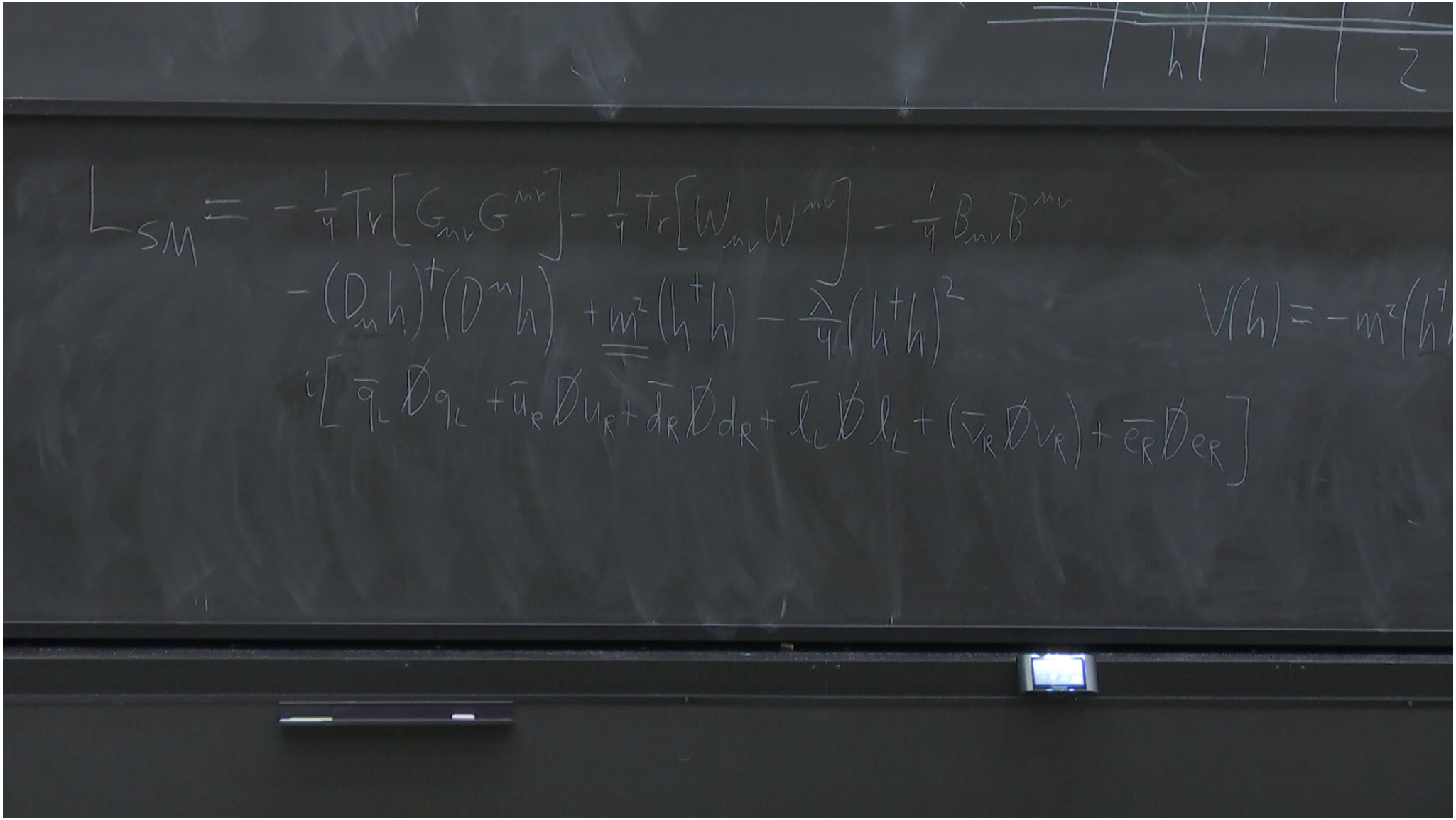
$u^i = \{u, c, t\}$

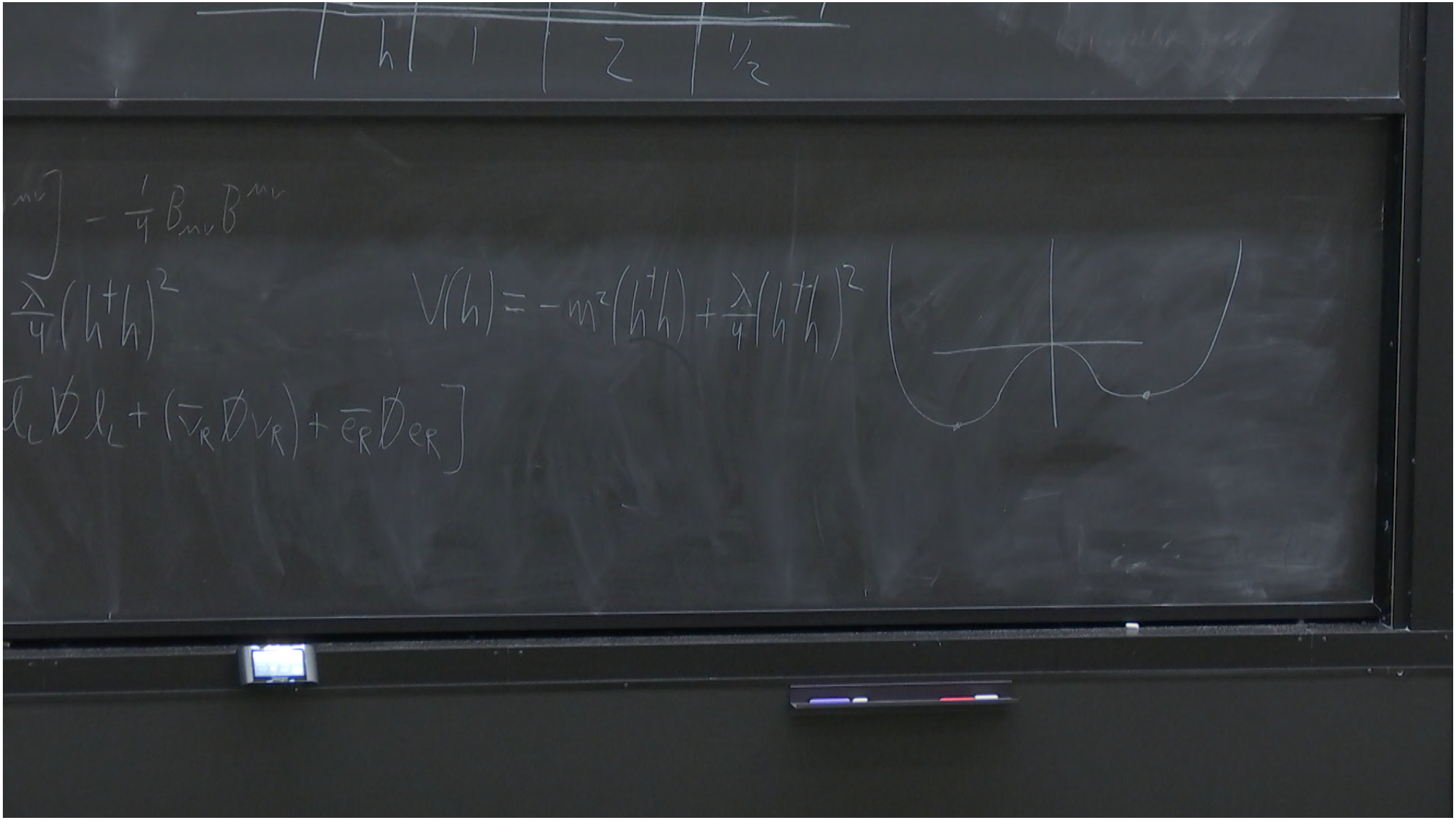
$d^i = \{d, s, b\}$

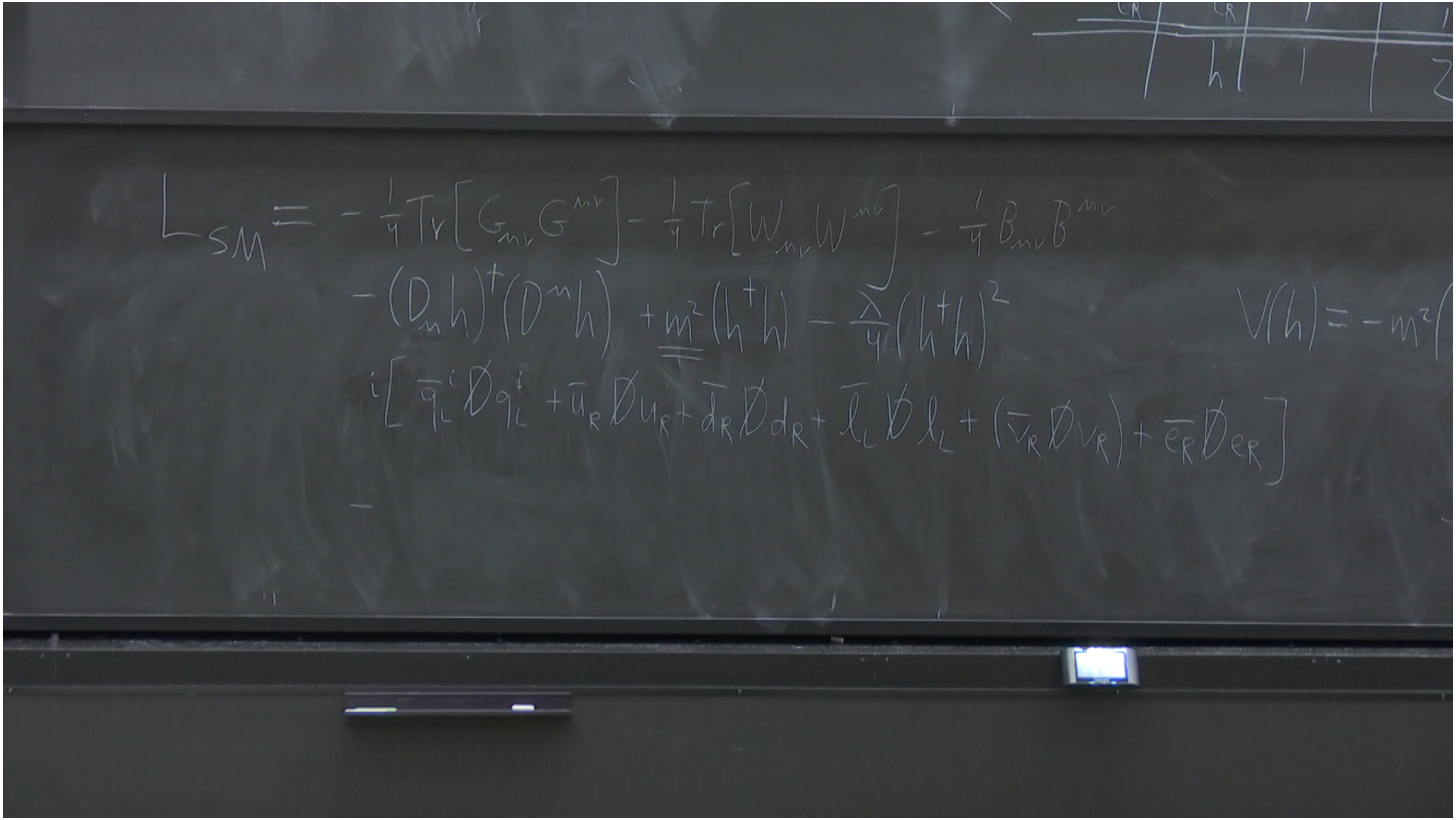
$\nu^i = \{\nu_e, \nu_\mu, \nu_\tau\}$

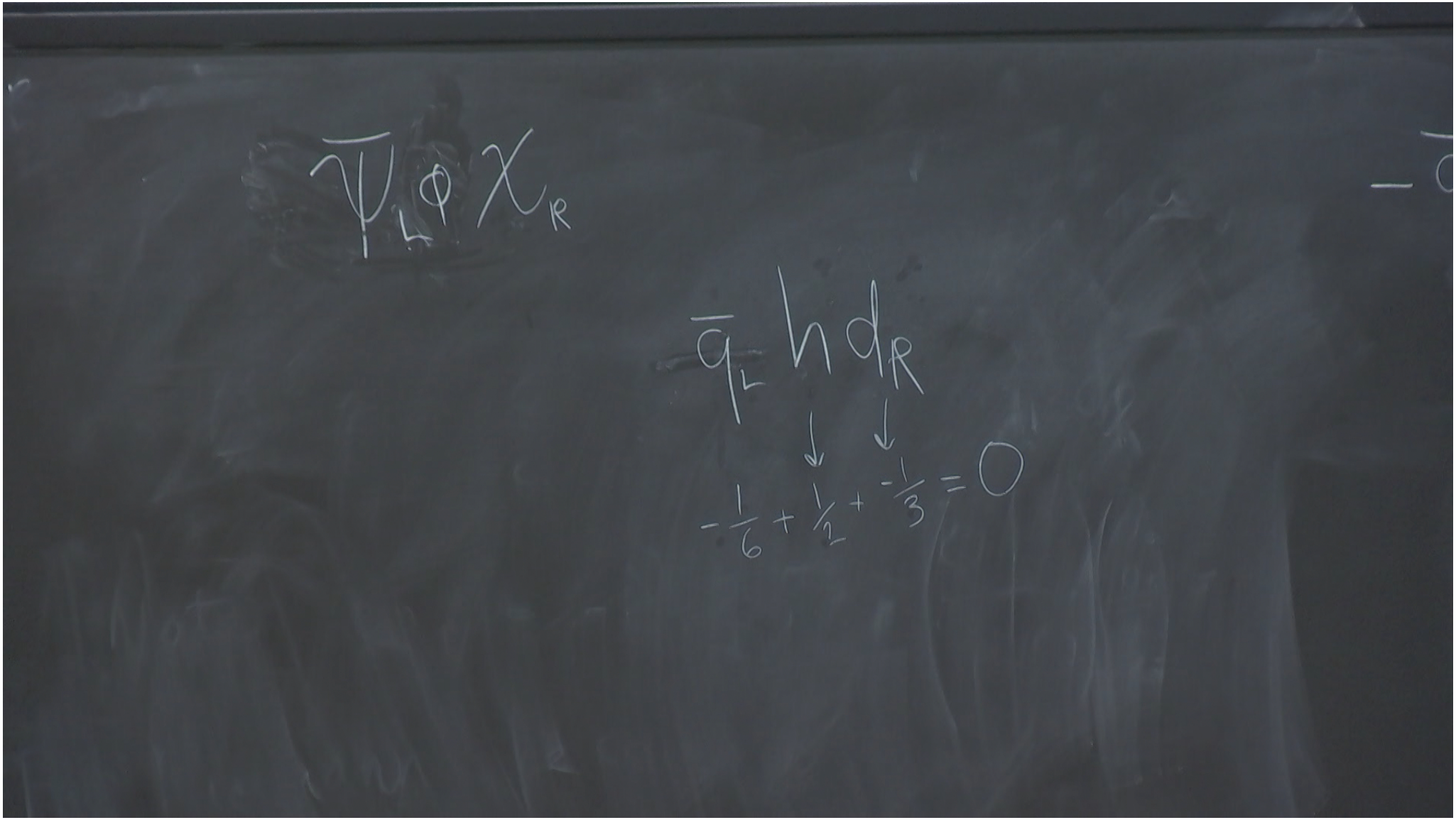
$e^i = \{e, \mu, \tau\}$

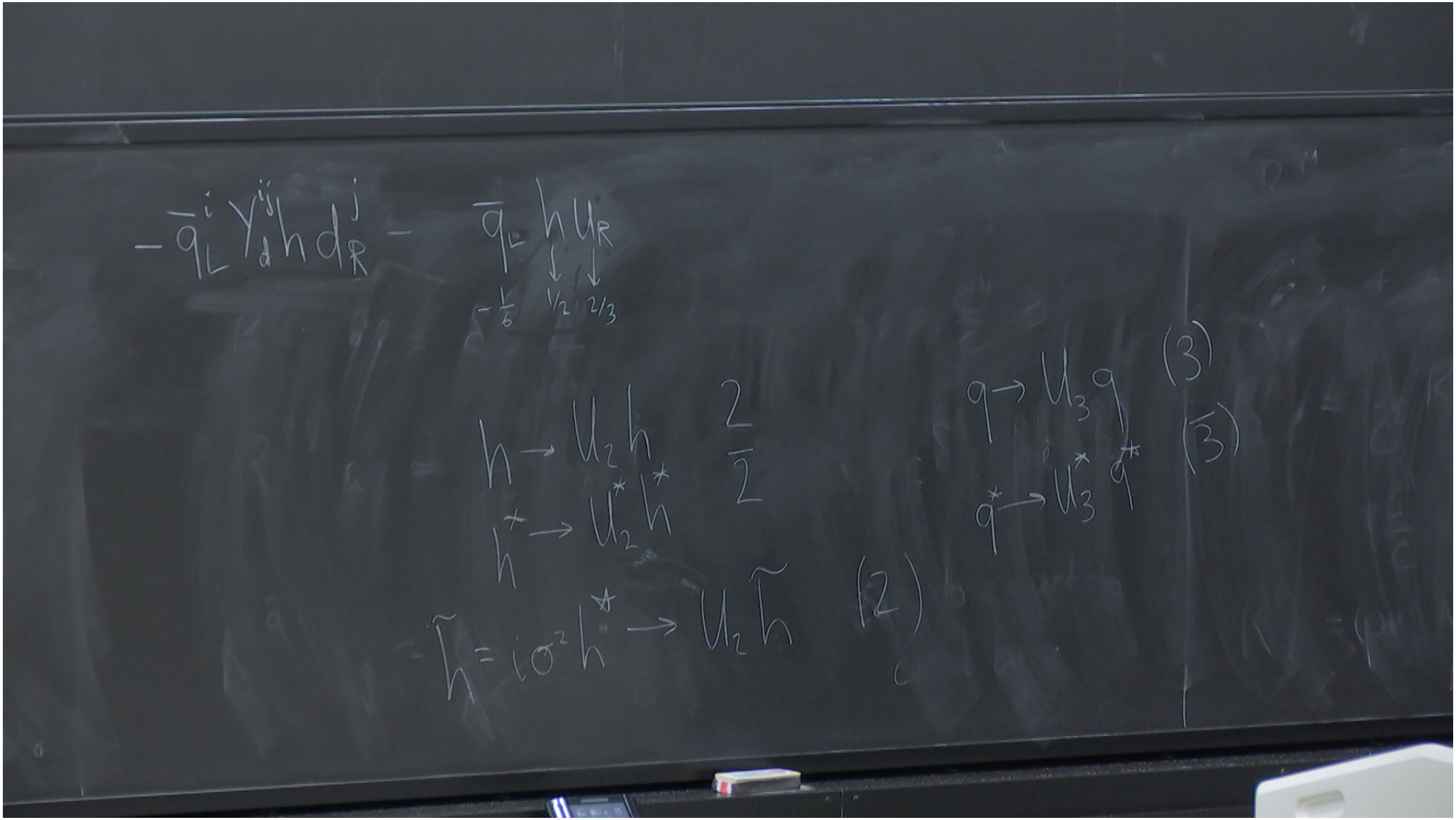

$\mathcal{L}_{SM} = -\frac{1}{4}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}\mathrm{Tr}[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$
$-(D_\mu h)^\dagger (D^\mu h)$
$i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + (\bar{\nu}_R \not{D} \nu_R) + \bar{e}_R \not{D} e_R]$

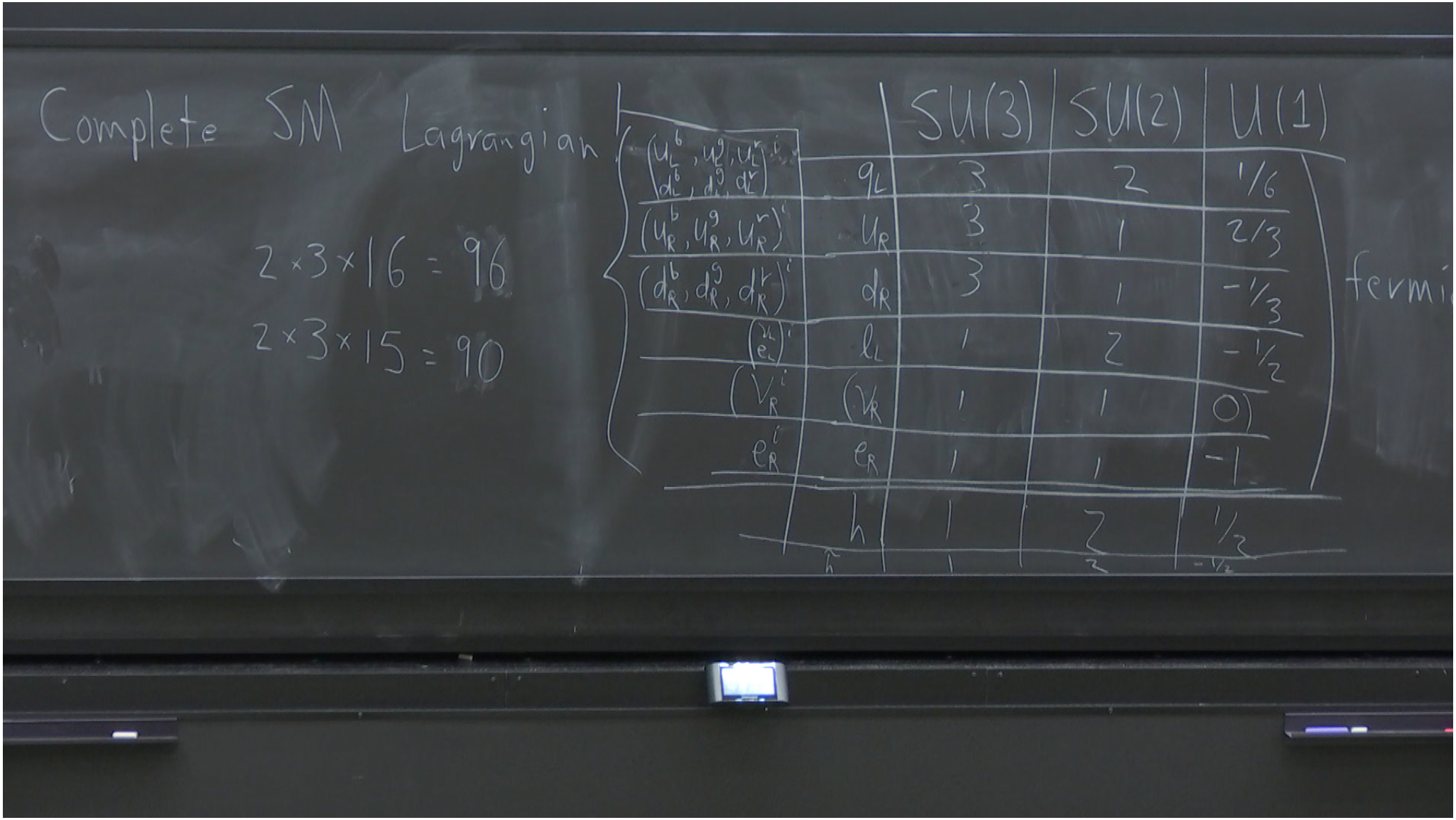

$\mathcal{L}_{SM} = -\frac{1}{4}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}\mathrm{Tr}[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$
$-(D_\mu h)^\dagger (D^\mu h) + m^2(h^\dagger h) - \frac{\lambda}{4}(h^\dagger h)^2$
$V(h) = -m^2(h^\dagger$
$i[\bar{q}_L \not{D} q_L + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + (\bar{\nu}_R \not{D} \nu_R) + \bar{e}_R \not{D} e_R]$

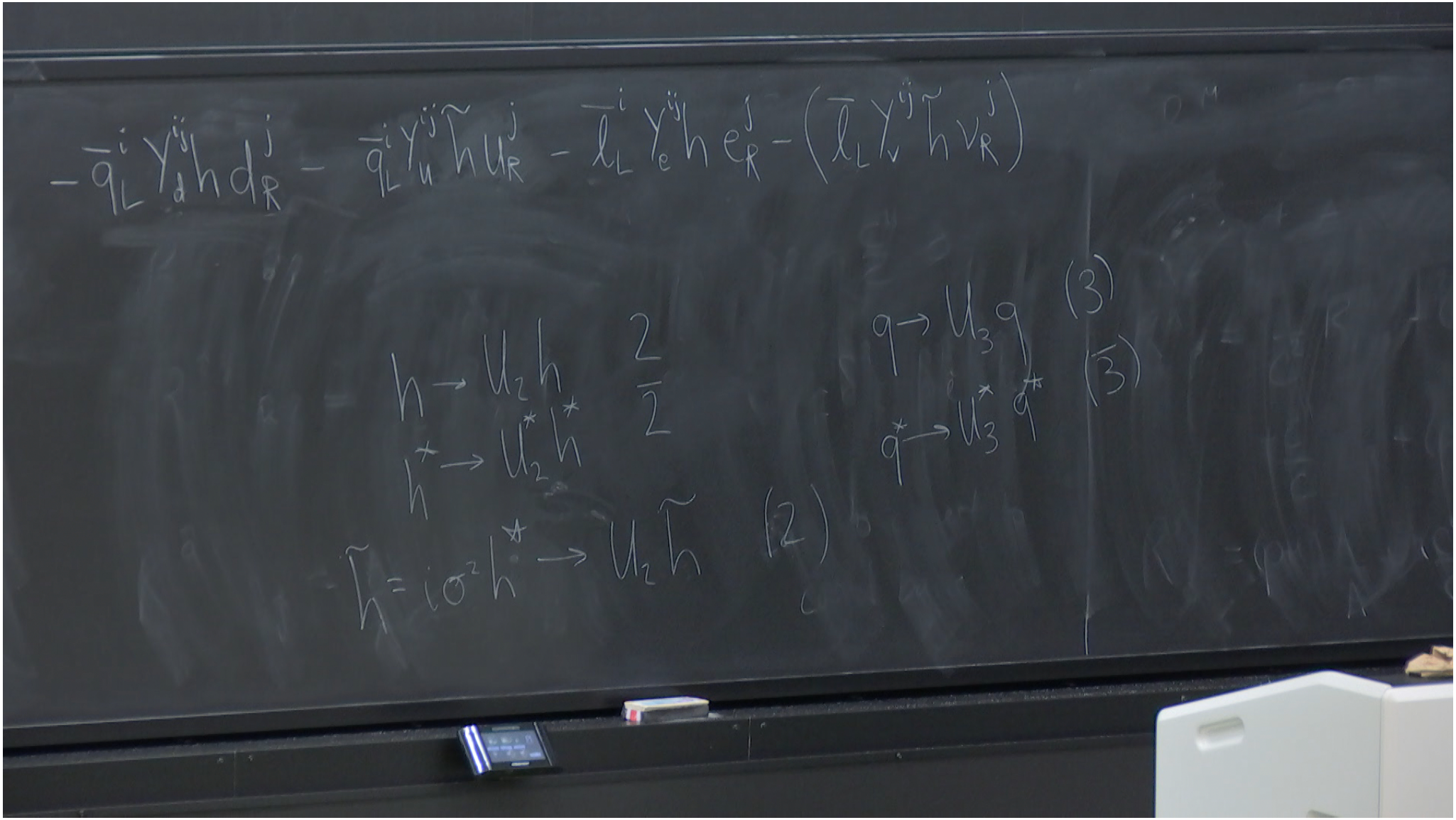

h
1
2
½
$-\frac{1}{4}B_{\mu\nu}B^{\mu\nu}$
$\frac{\lambda}{4}(h^\dagger h)^2$
$V(h) = -m^2(h^\dagger h) + \frac{\lambda}{4}(h^\dagger h)^2$
$\bar{l}_L \not{D} l_L + (\bar{\nu}_R \not{D} \nu_R) + \bar{e}_R \not{D} e_R]$

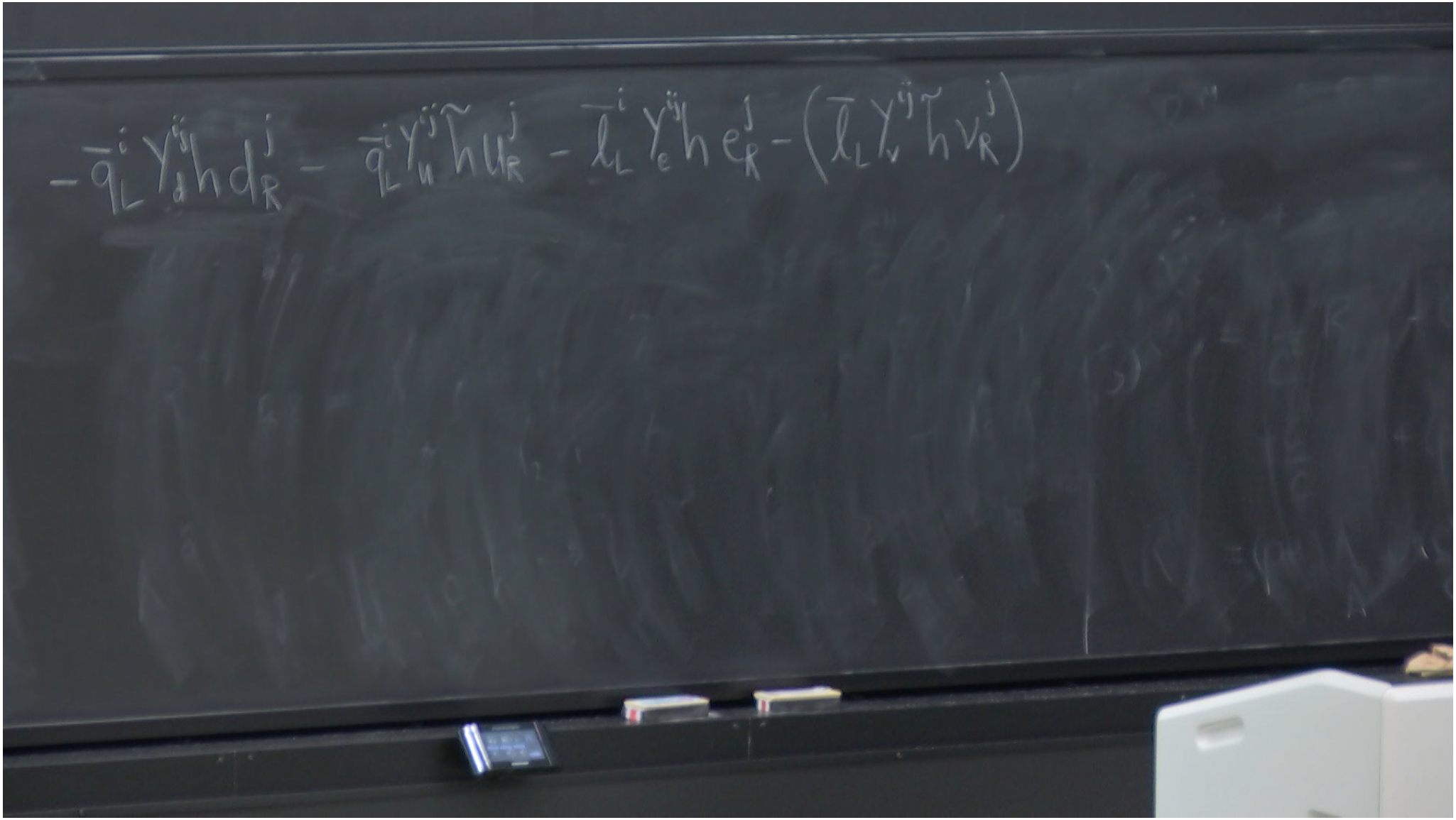

$\mathcal{L}_{SM} = -\frac{1}{4}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}] - \frac{1}{4}\mathrm{Tr}[W_{\mu\nu}W^{\mu\nu}] - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$
$-(D_\mu h)^\dagger (D^\mu h) + m^2(h^\dagger h) - \frac{\lambda}{4}(h^\dagger h)^2$
$V(h) = -m^2($
$i[\bar{q}_L^i \not{D} q_L^i + \bar{u}_R \not{D} u_R + \bar{d}_R \not{D} d_R + \bar{l}_L \not{D} l_L + (\bar{\nu}_R \not{D} \nu_R) + \bar{e}_R \not{D} e_R]$
h

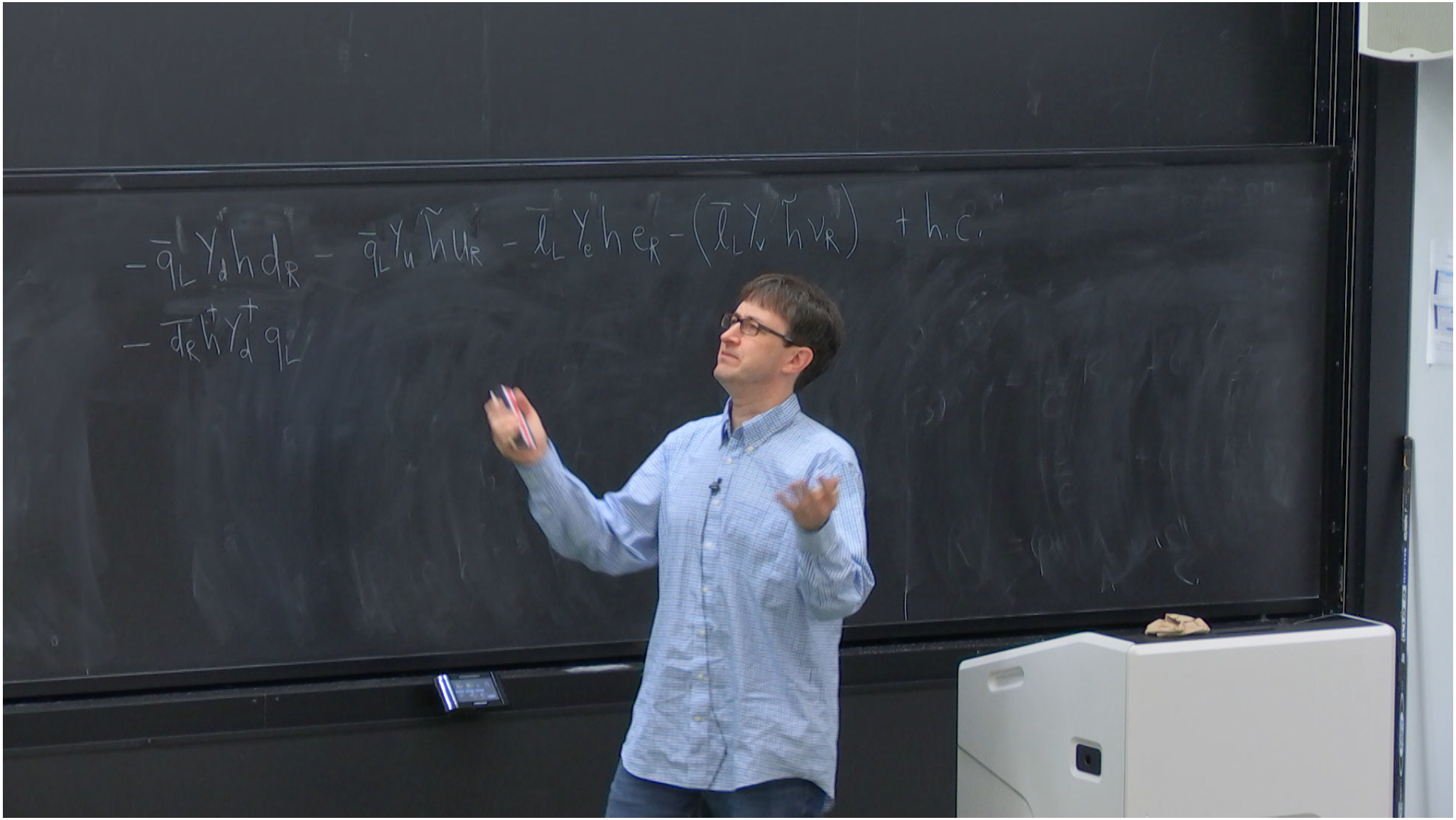

$\bar{\psi}_L \phi \chi_R$
$\bar{q}_L h d_R$
$-\frac{1}{6} + \frac{1}{2} + -\frac{1}{3} = 0$

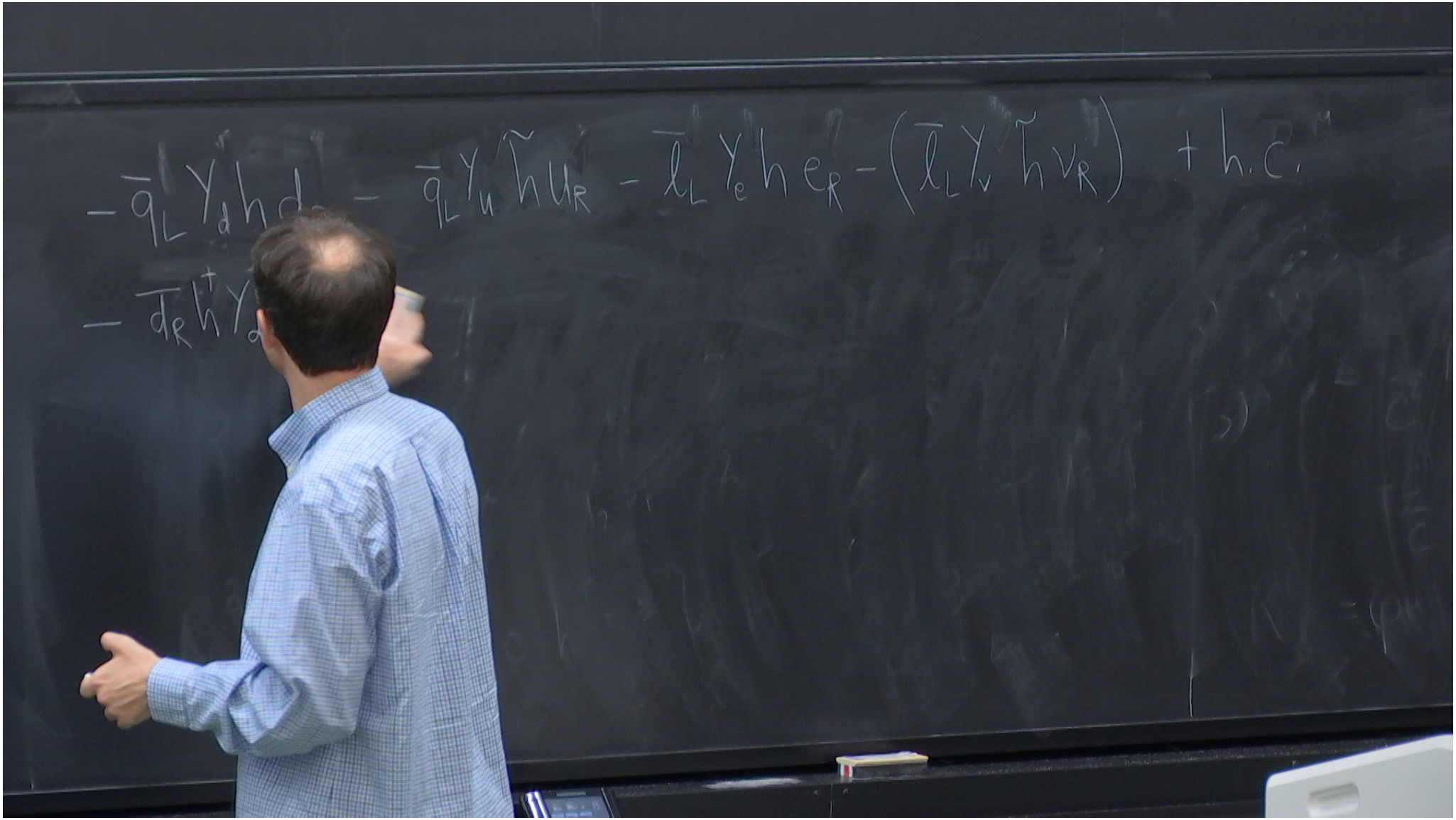

$-\bar{q}_L^i Y_d^{ij} h d_R^j - \bar{q}_L h u_R$
$-\frac{1}{6}$ $\frac{1}{2}$ $\frac{2}{3}$
$h \to U_2 h$ 2
$h^* \to U_2^* h^*$ $\bar{2}$
$\tilde{h} = i\sigma^2 h^* \to U_2 \tilde{h}$ (2)
$q \to U_3 q$ (3)
$q^* \to U_3^* q^*$ $(\bar{3})$

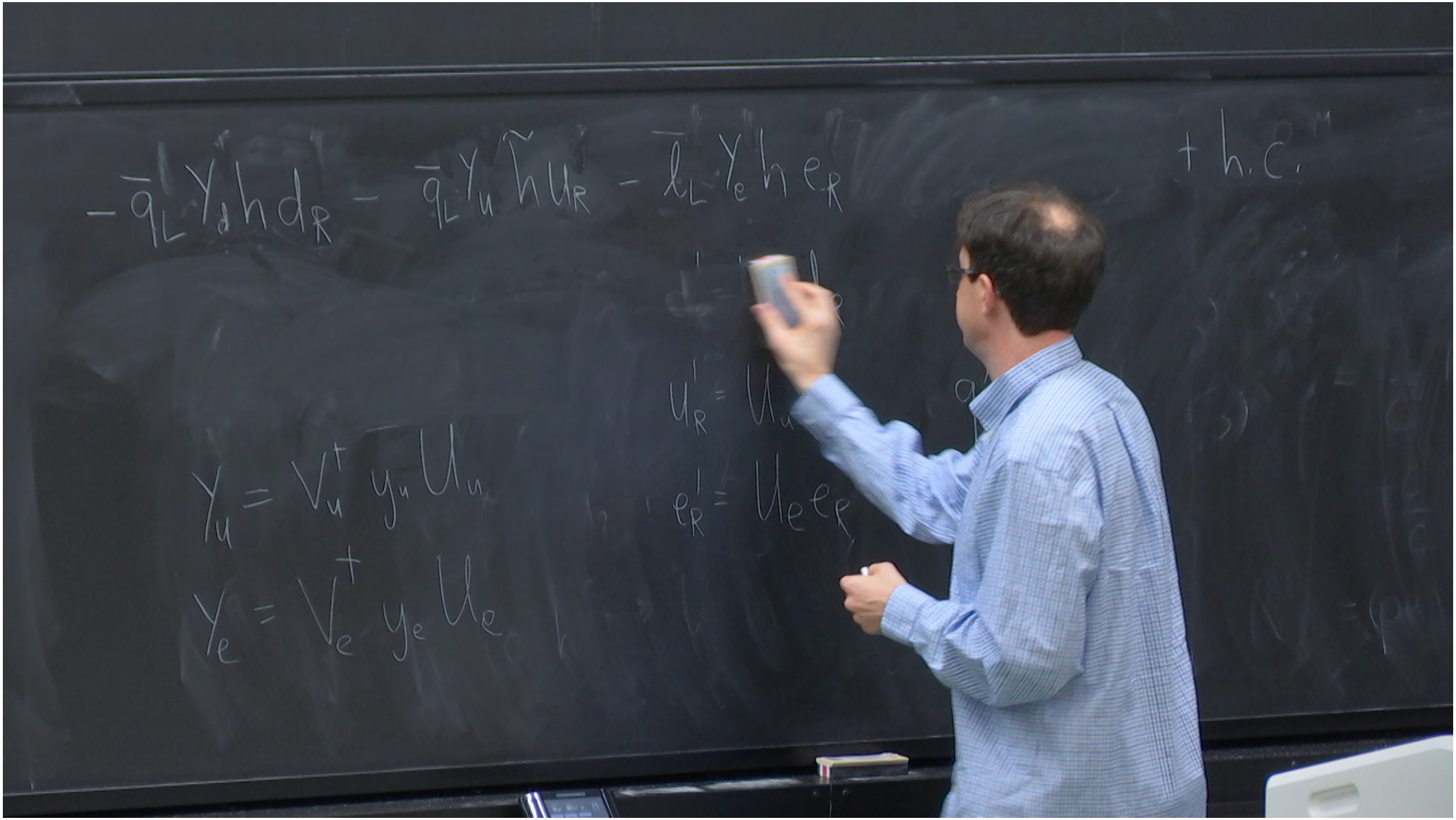

Complete SM Lagrangian
2×3×16 = 96
2×3×15 = 90
SU(3)
SU(2)
U(1)
q_L 3 2 1/6
u_R 3 1 2/3
d_R 3 1 −1/3
l_L 1 2 −1/2
ν_R 1 1 0
e_R 1 1 −1
h 1 2 1/2
$\bar{h}$ 1 2 −1/2
fermi

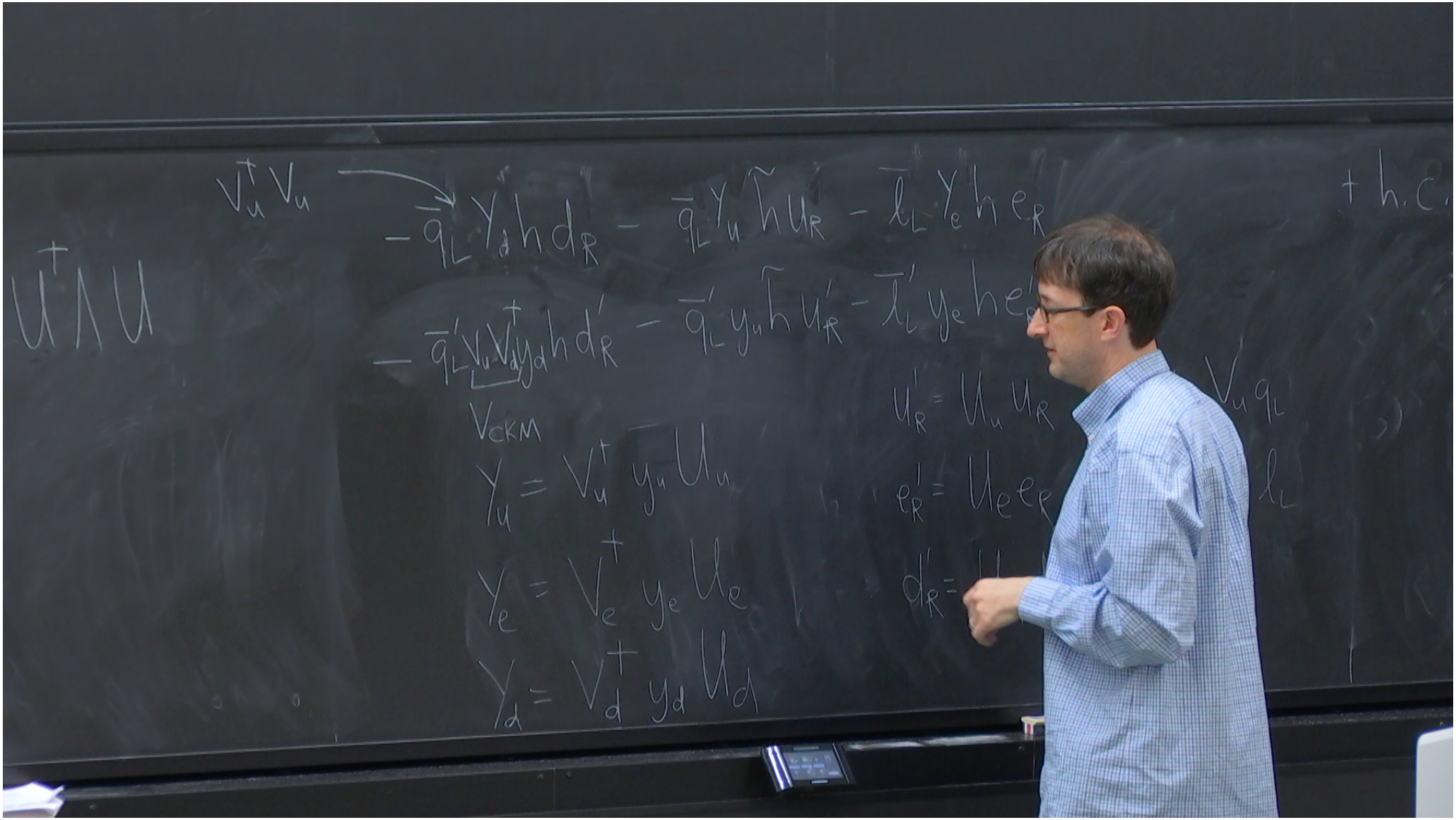

$-\bar{q}_L^i Y_d^{ij} h d_R^j - \bar{q}_L^i Y_u^{ij} \tilde{h} u_R^j - \bar{l}_L^i Y_e^{ij} h e_R^j - (\bar{l}_L Y_\nu^{ij} \tilde{h} \nu_R^j)$
$h \to U_2 h$ 2
$h^* \to U_2^* h^*$ $\bar{2}$
$\tilde{h} = i\sigma^2 h^* \to U_2 \tilde{h}$ (2)
$q \to U_3 q$ (3)
$q^* \to U_3^* q^*$ $(\bar{3})$

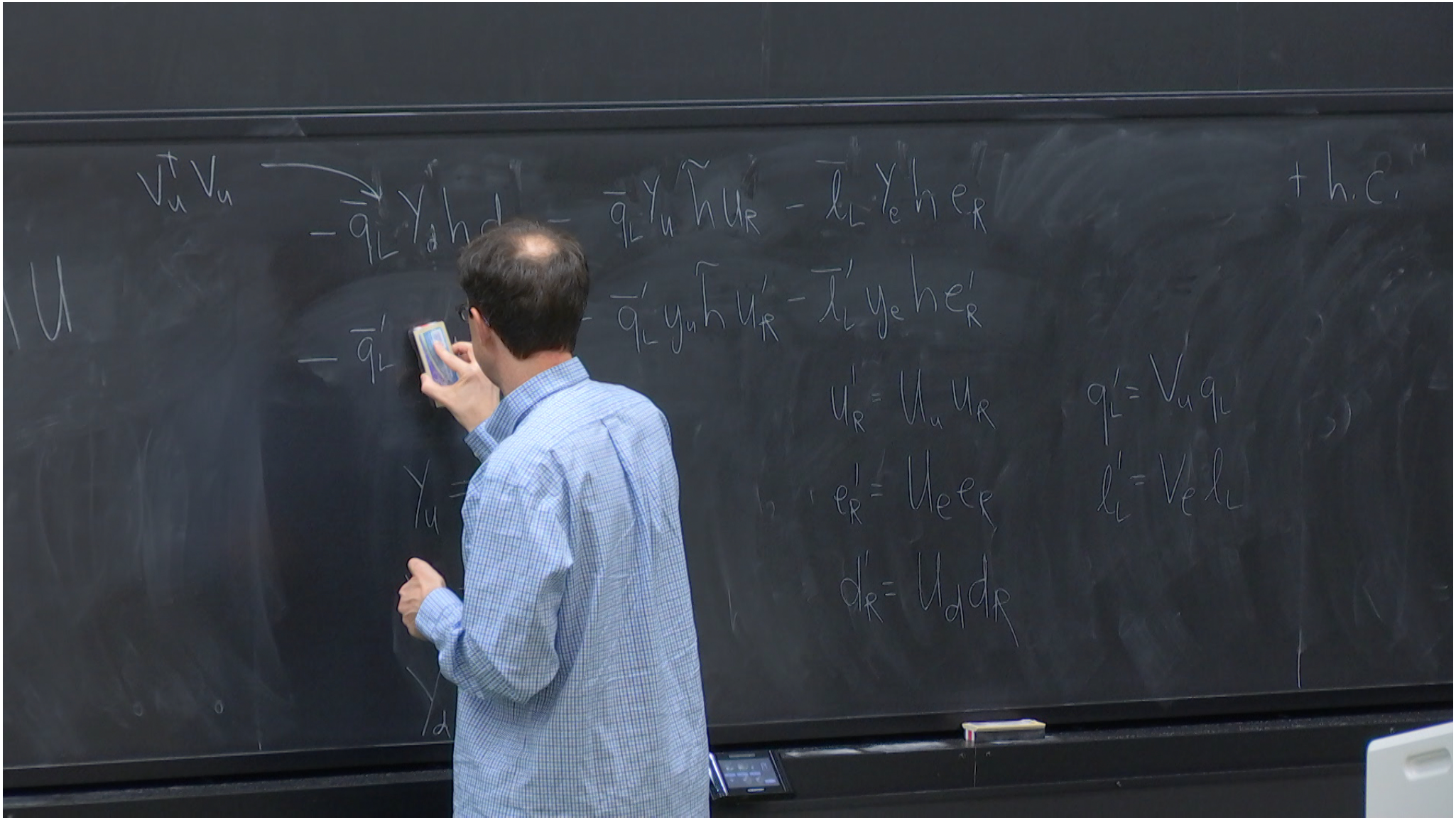

$-\bar{q}_L^i Y_d^{ij} h d_R^j - \bar{q}_L^i Y_u^{ij} \tilde{h} u_R^j - \bar{l}_L^i Y_e^{ij} h e_R^j - (\bar{l}_L Y_\nu^{ij} \tilde{h} \nu_R^j)$

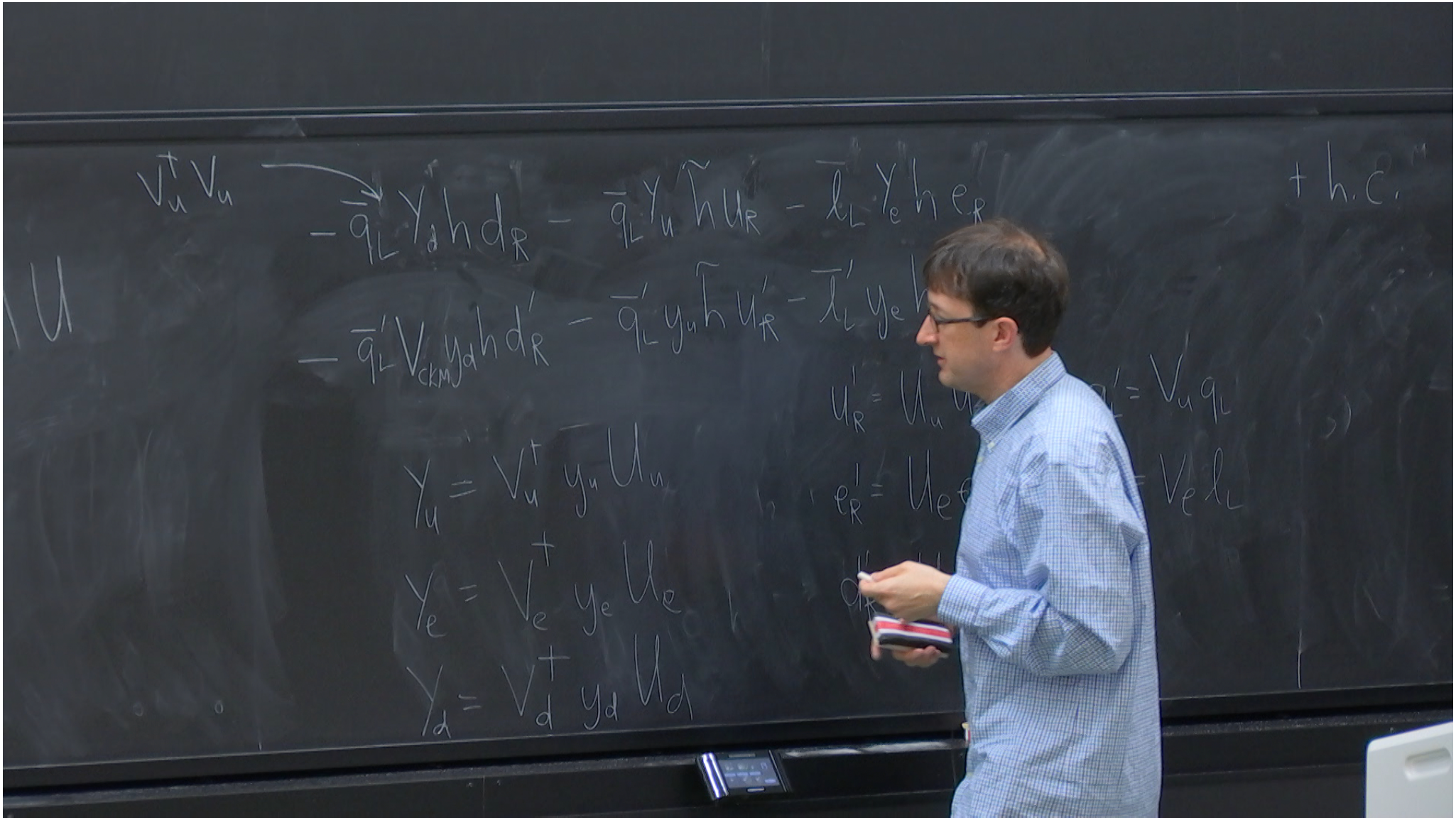

$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R - (\bar{l}_L Y_\nu \tilde{h} \nu_R) + h.c.$
$- \bar{d}_R h^\dagger Y_d^\dagger q_L$

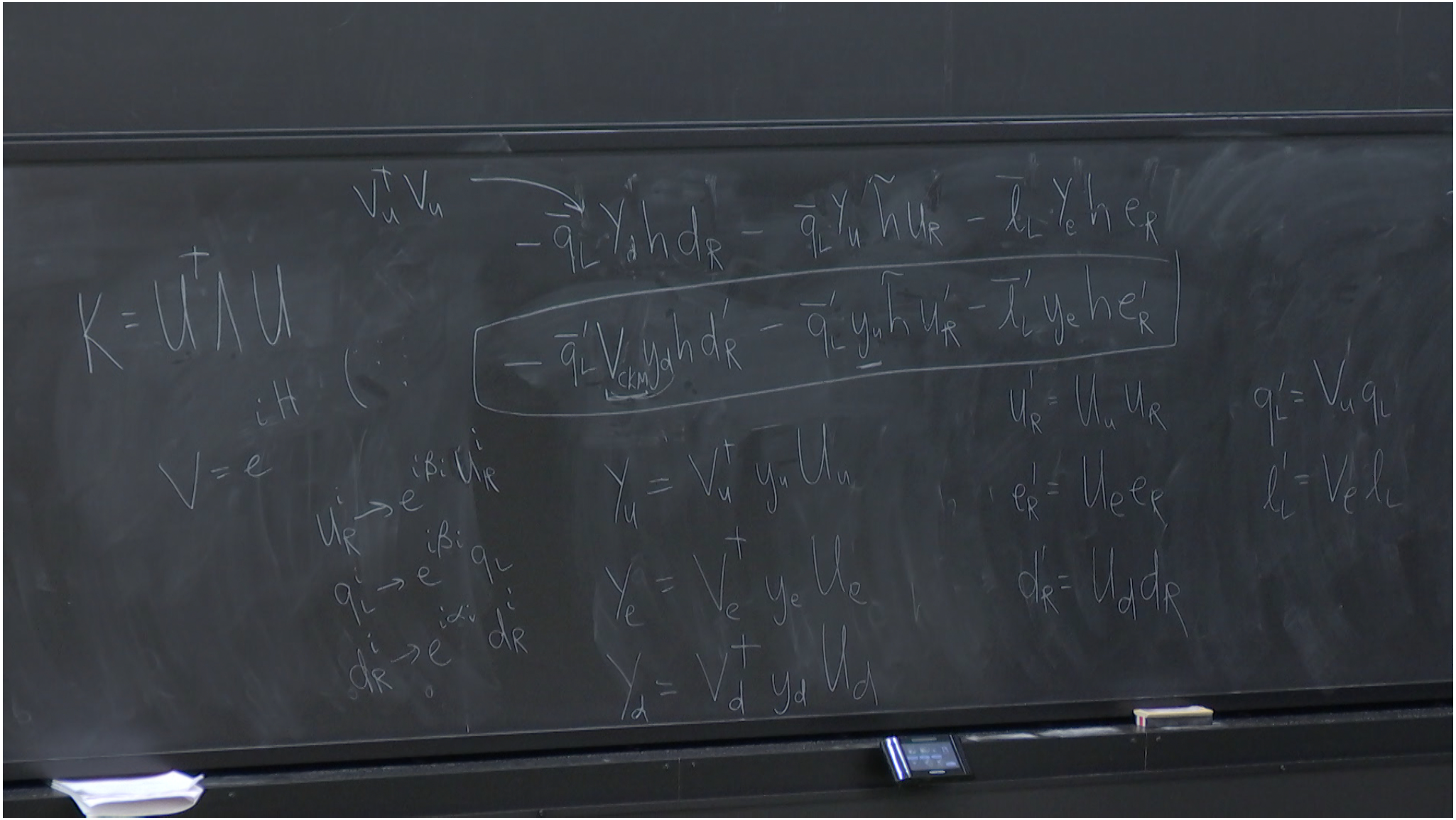

$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R - (\bar{l}_L Y_\nu \tilde{h} \nu_R) + h.c.$
$- \bar{d}_R h^\dagger Y_d$

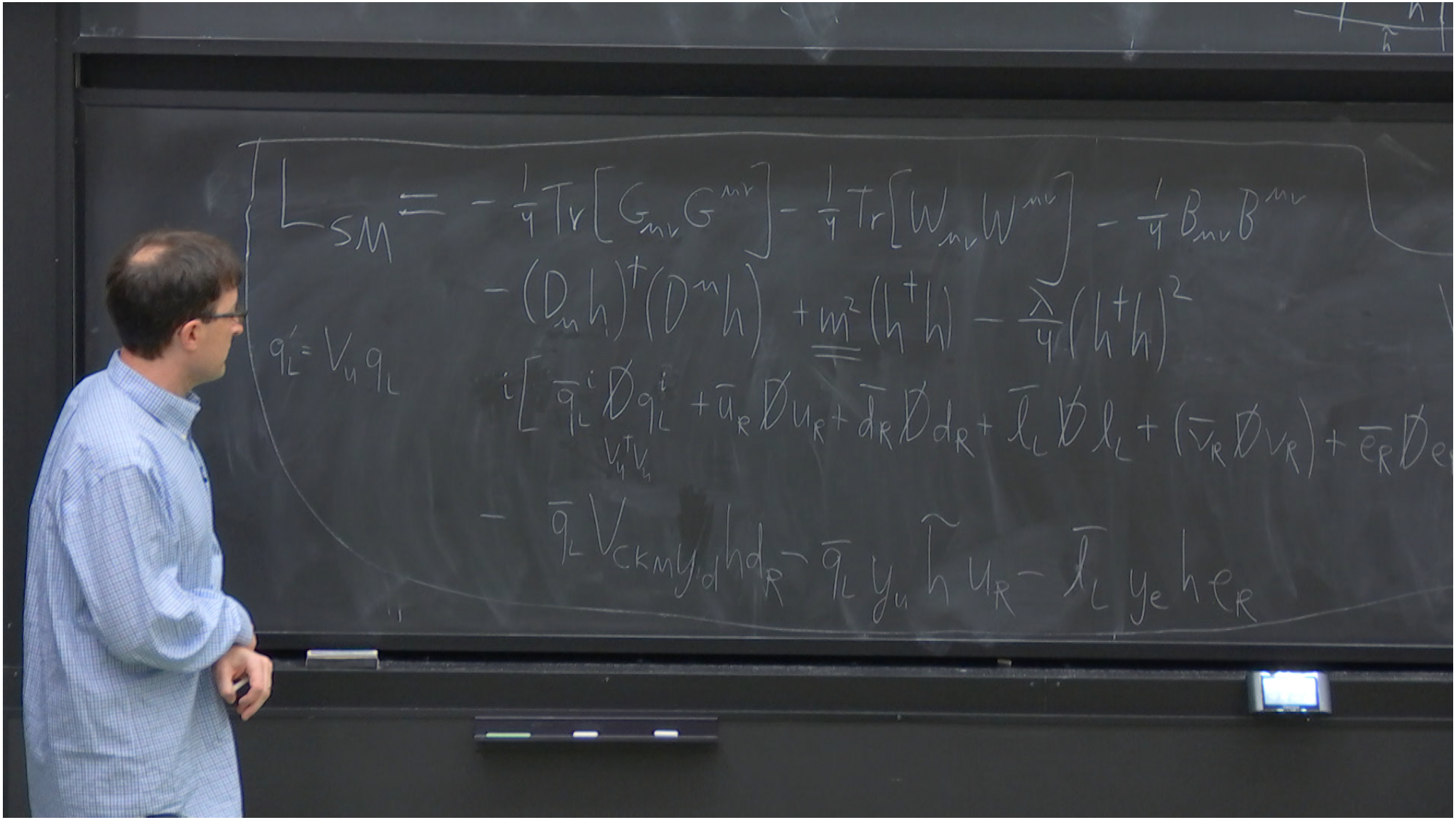

$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R$ + h.c.
$Y_u = V_u^\dagger y_u U_u$
$Y_e = V_e^\dagger y_e U_e$


$V_u^\dagger V_u$
$U^\dagger \Lambda U$
$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R$
$+ h.c.$
$-\bar{q}'_L V_u V_d^\dagger y_d h d'_R - \bar{q}'_L y_u \tilde{h} u'_R - \bar{l}'_L y_e h e'_R$
V_{CKM}
$u'_R = U_u u_R$
$V_u q_L$
$Y_u = V_u^\dagger y_u U_u$
$e'_R = U_e e_R$
l_L
$Y_e = V_e^\dagger y_e U_e$
$d'_R =$
$Y_d = V_d^\dagger y_d U_d$


$V_u^\dagger V_u$
$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R$ + h.c.
$-\bar{q}'_L y_d h d'_R - \bar{q}'_L y_u \tilde{h} u'_R - \bar{l}'_L y_e h e'_R$
$u'_R = U_u u_R$
$q'_L = V_u q_L$
$e'_R = U_e e_R$
$l'_L = V_e l_L$
$d'_R = U_d d_R$


$V_u^\dagger V_u$
$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R$
+ h.c.
$-\bar{q}'_L V_{CKM} y_d h d_R - \bar{q}'_L y_u \tilde{h} u'_R - \bar{l}'_L y_e$
$u'_R = U_u$
$q'_L = V_u q_L$
$e'_R = U_e$
$l'_L = V_e l_L$
$Y_u = V_u^\dagger y_u U_u$
$Y_e = V_e^\dagger y_e U_e$
$Y_d = V_d^\dagger y_d U_d$


$V_u^\dagger V_u$
$-\bar{q}_L Y_d h d_R - \bar{q}_L Y_u \tilde{h} u_R - \bar{l}_L Y_e h e_R$
$K = U^\dagger \Lambda U$
$-\bar{q}'_L V_{CKM} y_d h d'_R - \bar{q}'_L y_u \tilde{h} u'_R - \bar{l}'_L y_e h e'_R$
$u'_R = U_u u_R$
$q'_L = V_u q_L$
$V = e^{i\beta_i}$
$u_R^i \to e^{i\beta_i} u_R^i$
$Y_u = V_u^\dagger y_u U_u$
$e'_R = U_e e_R$
$l'_L = V_e l_L$
$q_L^i \to e^{i\beta_i} q_L^i$
$Y_e = V_e^\dagger y_e U_e$
$d'_R = U_d d_R$
$d_R^i \to e^{i\beta_i} d_R^i$
$Y_d = V_d^\dagger y_d U_d$


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