Title: PSI 2018/2019 - Beyond Standard Model - Lecture 12

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Collection: PSI 2018/2019 - Beyond Standard Model (Boyle)

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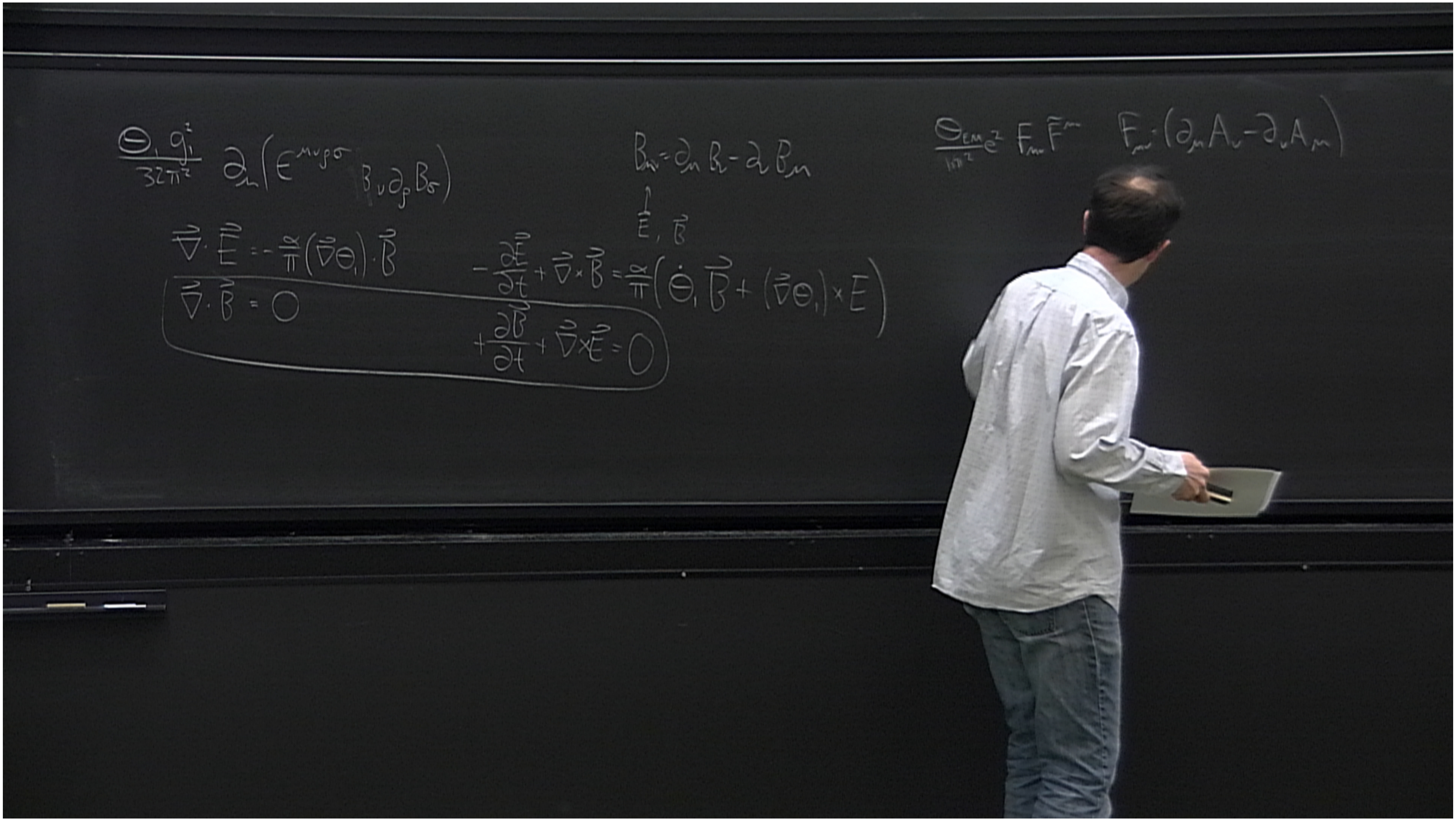
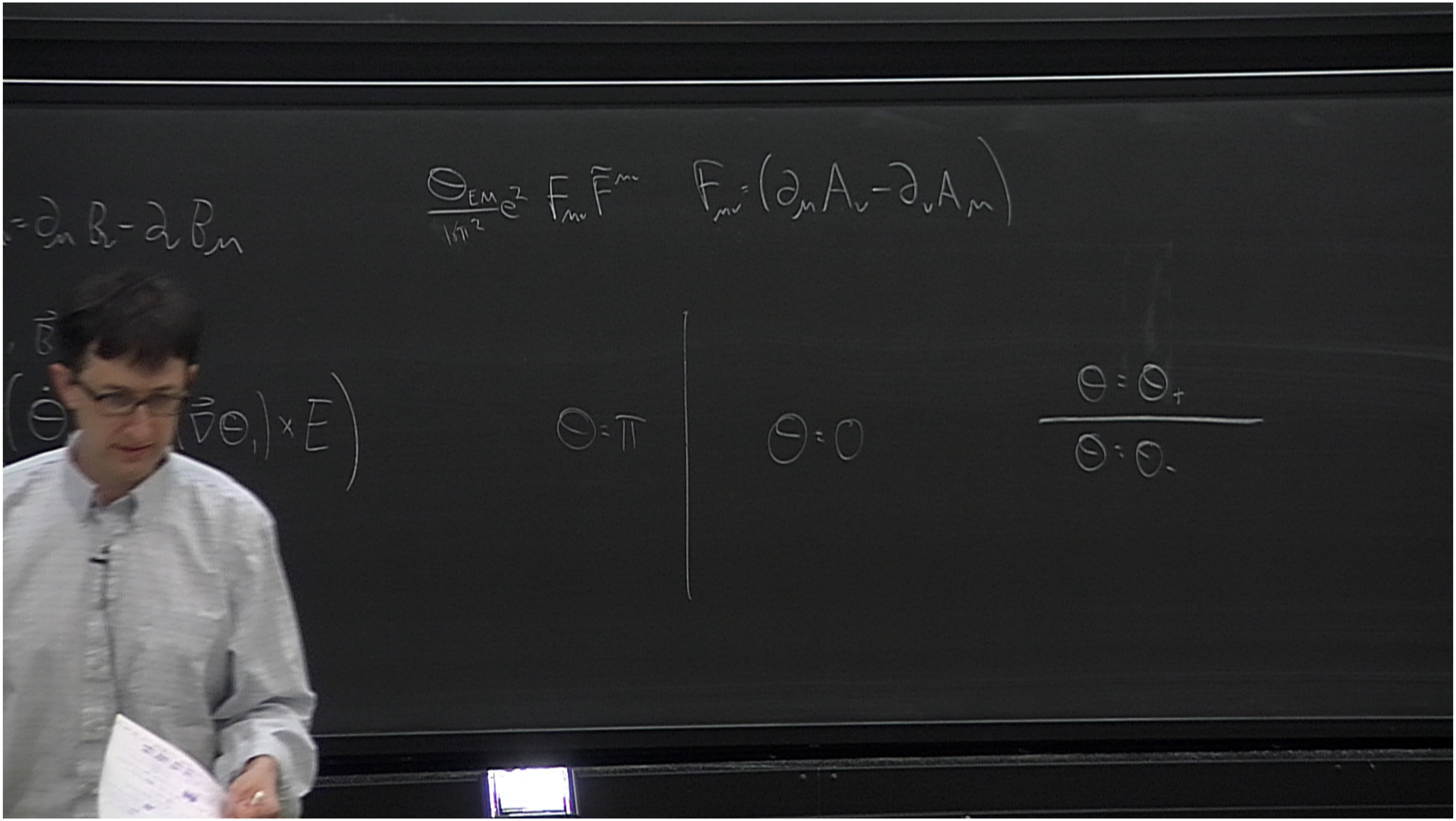
Recall:

$$\mathcal{L}_{SM} = (\text{bosonic terms}) + (\text{kinetic for fermions})$$
$$- \left[\bar{q}_L V_{CKM}\, y_d\, h\, d_R + \bar{q}_L\, y_u\, \hat{h}\, u_R + \bar{\ell}_L\, y_e\, h\, e_R + h.c. \right]$$
$$+ \frac{\theta_3 g_3^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}_a^{\mu\nu} + \frac{\theta_2 g_2^2}{32\pi^2} W^a_{\mu\nu} \tilde{W}_a^{\mu\nu} + \frac{\theta_1 g_1^2}{16\pi^2} B_{\mu\nu} \tilde{B}^{\mu\nu}$$



$\frac{\Theta_1 g_1^2}{32\pi^2} \partial_\mu \left(\epsilon^{\mu\nu\rho\sigma} B_\nu \partial_\rho B_\sigma \right)$
$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$
$\vec{E}, \vec{B}$
$\frac{\Theta_{EM}}{16\pi^2} e^2 F_{\mu\nu} \tilde{F}^{\mu\nu}$
$F_{\mu\nu} = (\partial_\mu A_\nu - \partial_\nu A_\mu)$
$\vec{\nabla} \cdot \vec{E} = -\frac{\alpha}{\pi} (\vec{\nabla}\Theta_1) \cdot \vec{B}$
$-\frac{\partial \vec{E}}{\partial t} + \vec{\nabla} \times \vec{B} = \frac{\alpha}{\pi} \left(\dot{\Theta}_1 \vec{B} + (\vec{\nabla}\Theta_1) \times E \right)$
$\vec{\nabla} \cdot \vec{B} = 0$
$+\frac{\partial \vec{B}}{\partial t} + \vec{\nabla} \times \vec{E} = 0$


$\frac{\theta_{EM} e^2}{16\pi^2} F_{\mu\nu} \tilde{F}^{\mu\nu}$
$F_{\mu\nu} = (\partial_\mu A_\nu - \partial_\nu A_\mu)$
$\theta = \pi$
$\theta = 0$
$\theta = \theta_+$
$\theta = \theta_-$

$$m\ddot{\vec{x}} = e(\vec{E} + \dot{\vec{x}} \times \vec{B})$$

$$-\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \propto (\vec{E}^2 + \vec{B}^2)$$

$$\theta F\tilde{F}$$

$$F_{0i} = E_i$$

$$F_{ij} = \epsilon_{ijk} B_k$$

$\underline{\underline{P}}$: $\vec{x} \to -\vec{x}$, $\vec{E} \to -\vec{E}$, $\vec{B} \to +\vec{B}$

$\underline{\underline{T}}$: $t \to -t$, $E \to \vec{E}$, $B \to -\vec{B}$

$m\ddot{\vec{x}} = e\left(\vec{E} + \dot{\vec{x}} \times \vec{B}\right)$

$-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \propto \left(\vec{E}^2 + \vec{B}^2\right)$

$\theta F\tilde{F} \propto \vec{E}\cdot\vec{B}$

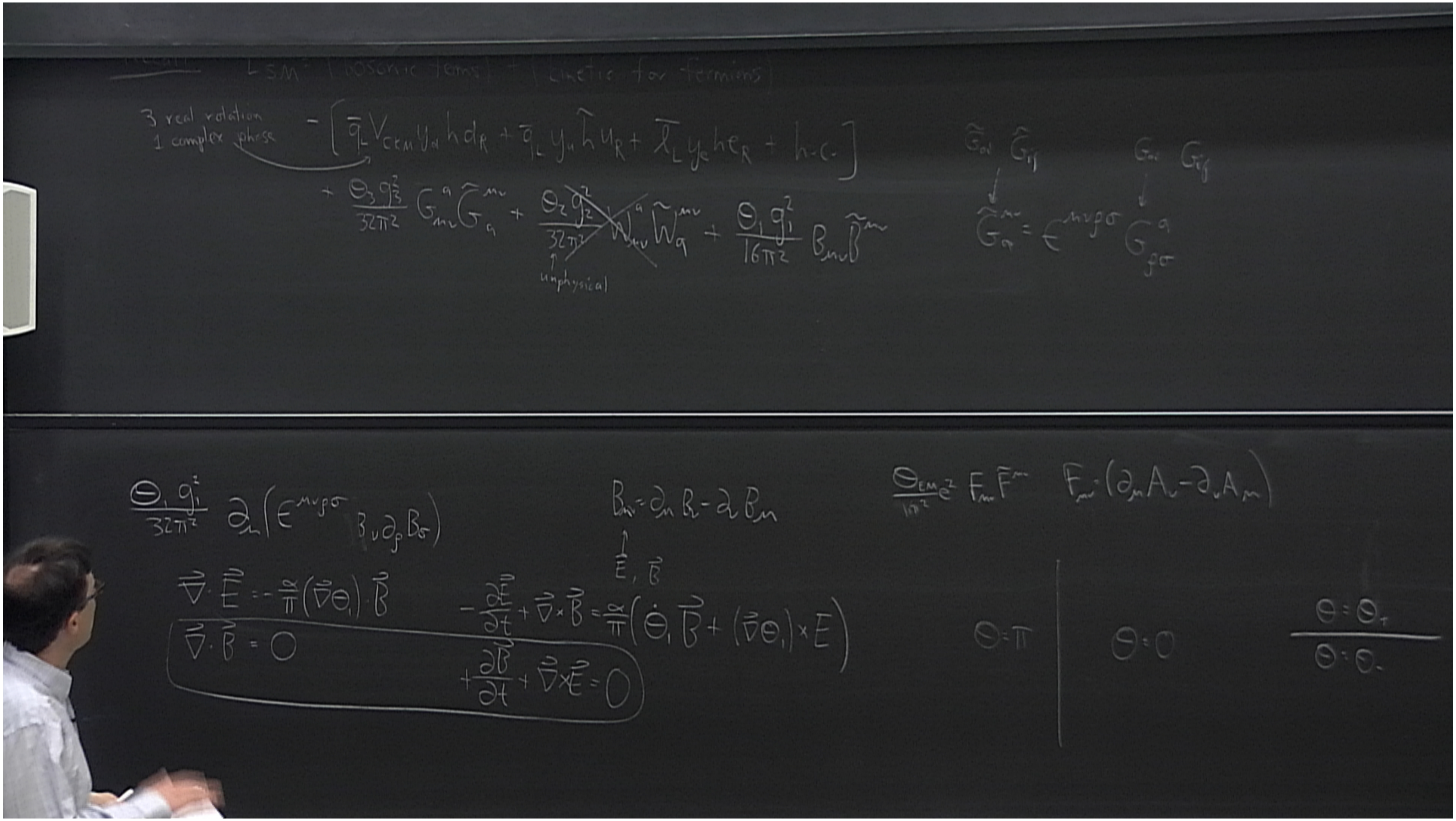
Violates P (so is CT)
and T (so is CP)

$F_{0i} = E_i$

$F_{ij} = \epsilon_{ijk}B_k$

$\underline{\underline{P}}$: $\vec{x} \to -\vec{x}$, $\vec{E} \to -\vec{E}$, $\vec{B} \to +\vec{B}$

$\underline{\underline{T}}$: $t \to -t$, $E \to \vec{E}$, $B \to -\vec{B}$


3 real rotation
1 complex phase
$-\left[\bar{q}_L V_{CKM} y_d h d_R + \bar{q}_L y_u \tilde{h} u_R + \bar{\ell}_L y_e h e_R + h.c.\right]$
$+ \frac{\theta_3 g_3^2}{32\pi^2} G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a + \cancel{\frac{\theta_2 g_2^2}{32\pi^2} W^a_{\mu\nu}\tilde{W}^{\mu\nu}_a} + \frac{\theta_1 g_1^2}{16\pi^2} B_{\mu\nu}\tilde{B}^{\mu\nu}$
unphysical
$\tilde{G}_{\alpha\beta}$ $\tilde{G}_{\gamma\delta}$
$G_{\alpha\beta}$ $G_{\gamma\delta}$
$\tilde{G}^{\mu\nu}_a = \epsilon^{\mu\nu\rho\sigma} G^a_{\rho\sigma}$
$\frac{\theta_1 g_1^2}{32\pi^2} \partial_\mu\left(\epsilon^{\mu\nu\rho\sigma} B_\nu \partial_\rho B_\sigma\right)$
$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$
$\vec{E}, \vec{B}$
$\frac{\theta_{EM} e^2}{16\pi^2} F_{\mu\nu}\tilde{F}^{\mu\nu}$ $F_{\mu\nu} = (\partial_\mu A_\nu - \partial_\nu A_\mu)$
$\vec{\nabla}\cdot\vec{E} = -\frac{\alpha}{\pi}(\vec{\nabla}\theta_1)\cdot\vec{B}$
$-\frac{\partial\vec{E}}{\partial t} + \vec{\nabla}\times\vec{B} = \frac{\alpha}{\pi}\left(\dot{\theta}_1\vec{B} + (\vec{\nabla}\theta_1)\times E\right)$
$\vec{\nabla}\cdot\vec{B} = 0$
$+\frac{\partial\vec{B}}{\partial t} + \vec{\nabla}\times\vec{E} = 0$
$\theta = \pi$
$\theta = 0$
$\theta = \theta_+$
$\theta = \theta_-$

$$\frac{\Theta_3 g_3^2}{32\pi^2} G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a \qquad G^a_{0i} = E^a_i \quad G^a_{ij} = B^a_k \epsilon_{ijk}$$

$$\propto \underline{\Theta_3}\, E^a \cdot B^a$$

1) massless up quark
2) parity soln
3) CP
4) axion/Peccei-Quinn

massless up

y_u^i, y_d^i, y_e^i's

$m_u^i, m_d^i, m_e^i \neq 0$.

$m_u^i = \frac{v}{\sqrt{2}} y_u^i$

massless up

y_u^i, y_d^i, y_e^i's

$m_u^i, m_d^i, m_e^i \neq 0$.

$$\boxed{m_u^1 = \frac{v}{\sqrt{2}} y_u^1}$$

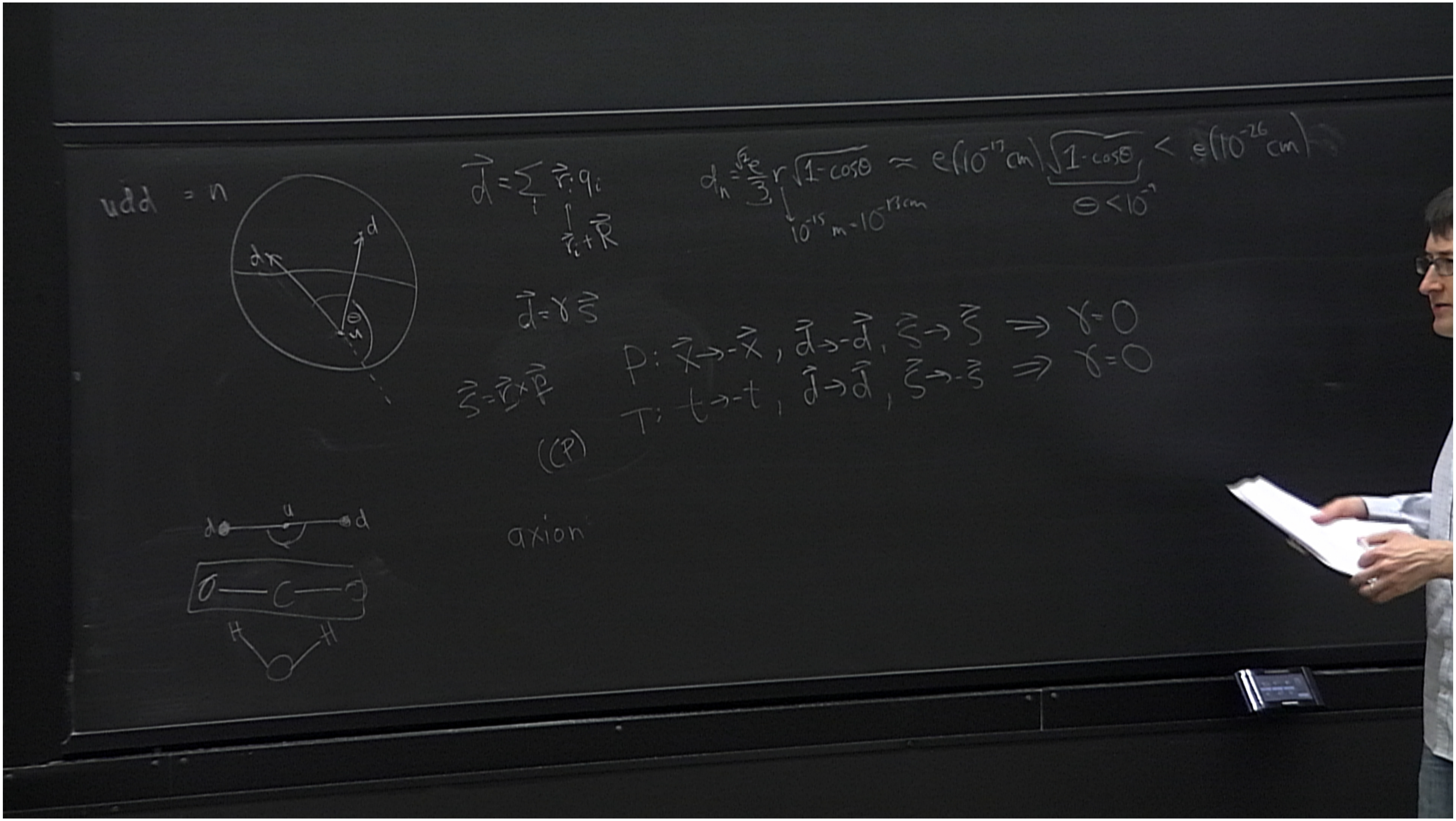
if y_u^1, $u_R^1 \to e^{i\beta} u_R^1$

$m_u = (2 \pm .5)\,\text{MeV}$ (compare $m_t = 200$ GeV

$\mathbb{Z}_2 : u_R^1 \to -u_R^1$

$\mathbb{Z}_2 : \nu_R^1 \to -\nu_R^1$

νSM


udd = n
d = Σ_i r_i q_i
r_i + R
d_n = √2 e/3 r √(1 - cos θ) ≈ e(10^-17 cm) √(1 - cos θ) < e(10^-26 cm)
θ < 10^-9
10^-15 m = 10^-13 cm
d = γ S
S = r × p
P: x → -x , d → -d , S → S ⇒ γ = 0
T: t → -t , d → d , S → -S ⇒ γ = 0
CP
axion

Parity soln:

$$SU(3) \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

	$SU(3)$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
q_L	3	2	1	1/3
q_R	3	1	2	1/3
ℓ_L	1	2	1	-1
ℓ_R	1	1	2	-1
h_L	1	2	1	x_L
h_R	1	1	2	x_R