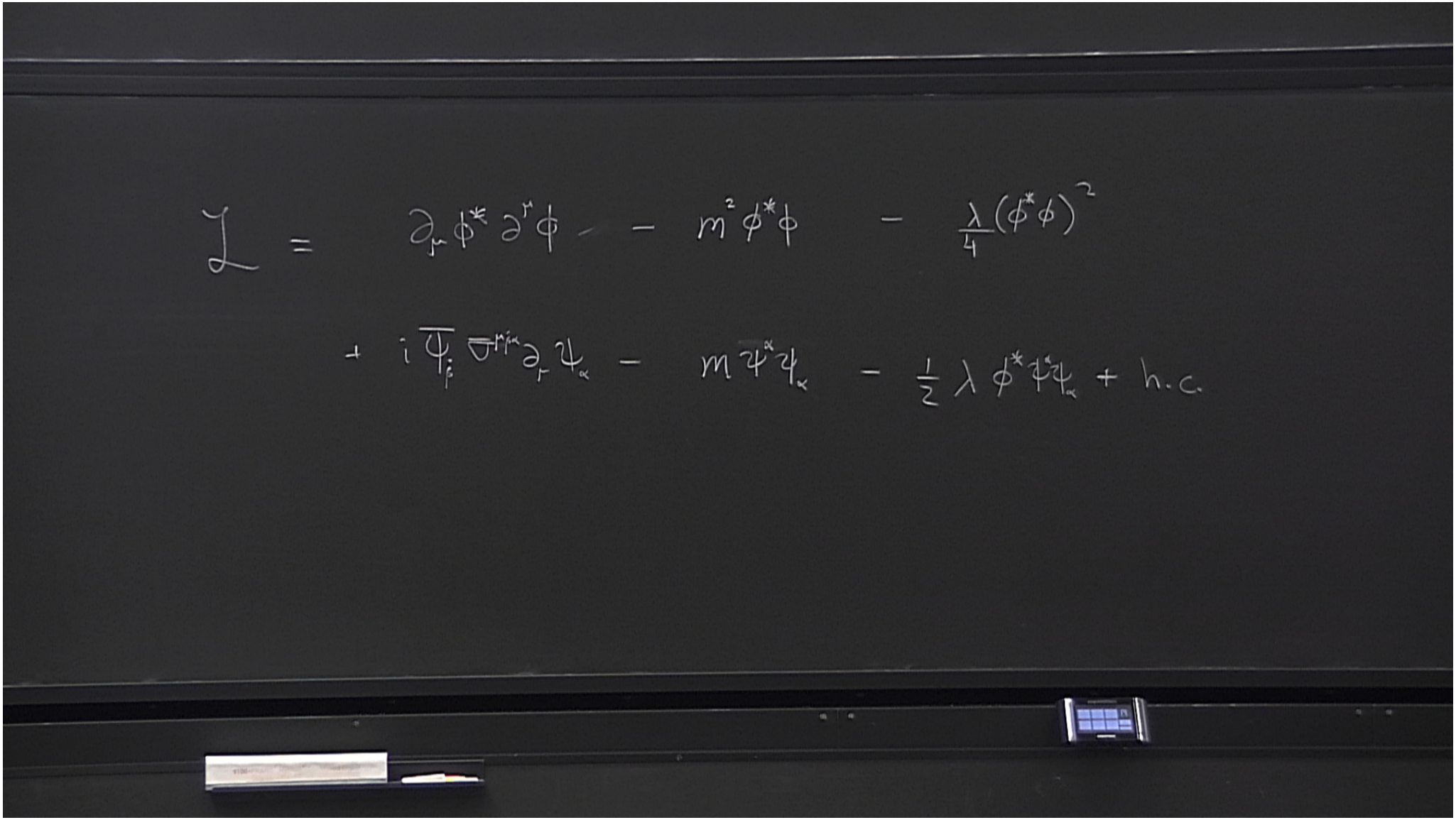
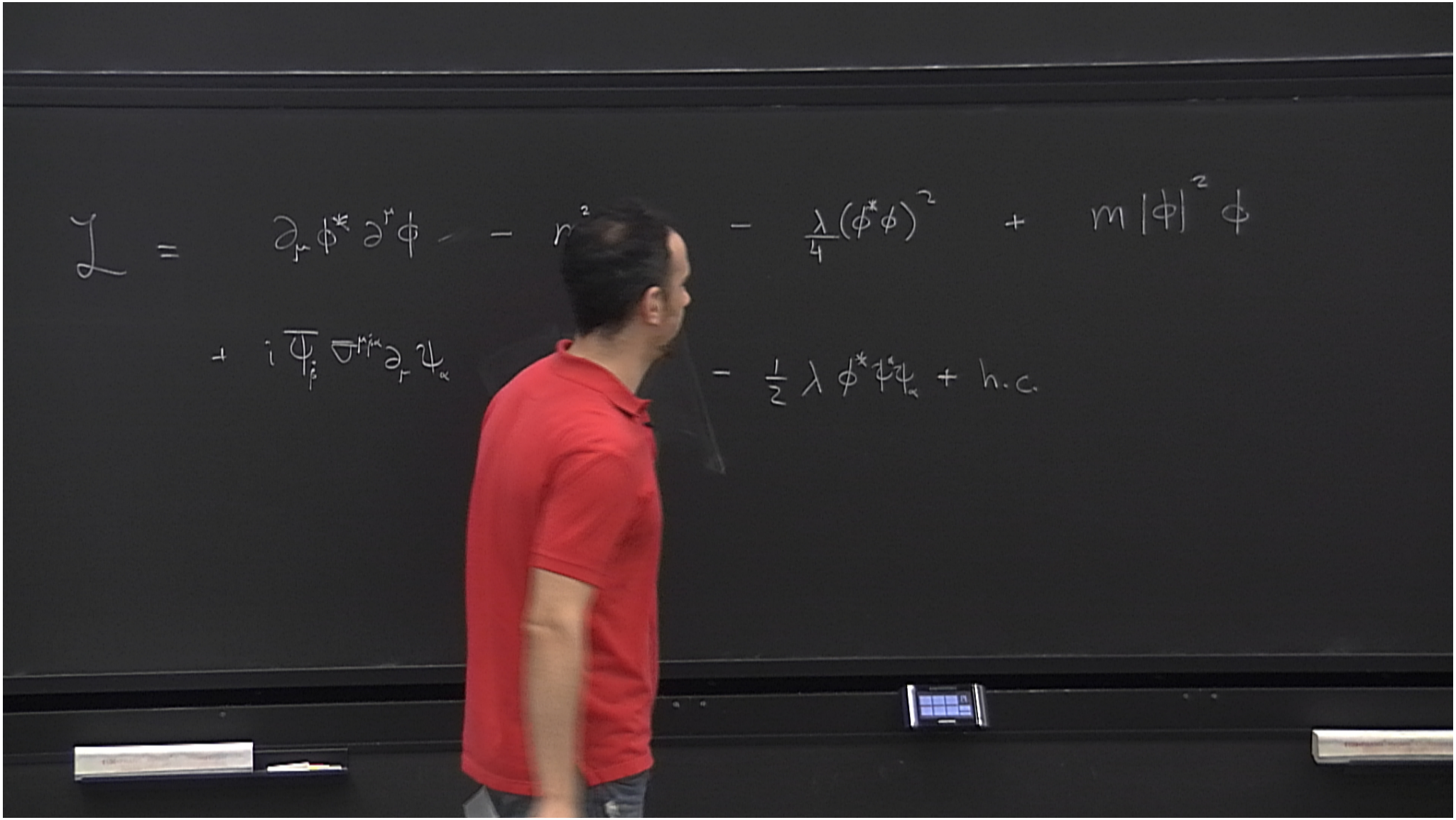
Title: 12/13 PSI - Beyond the Standard Model Lecture 5

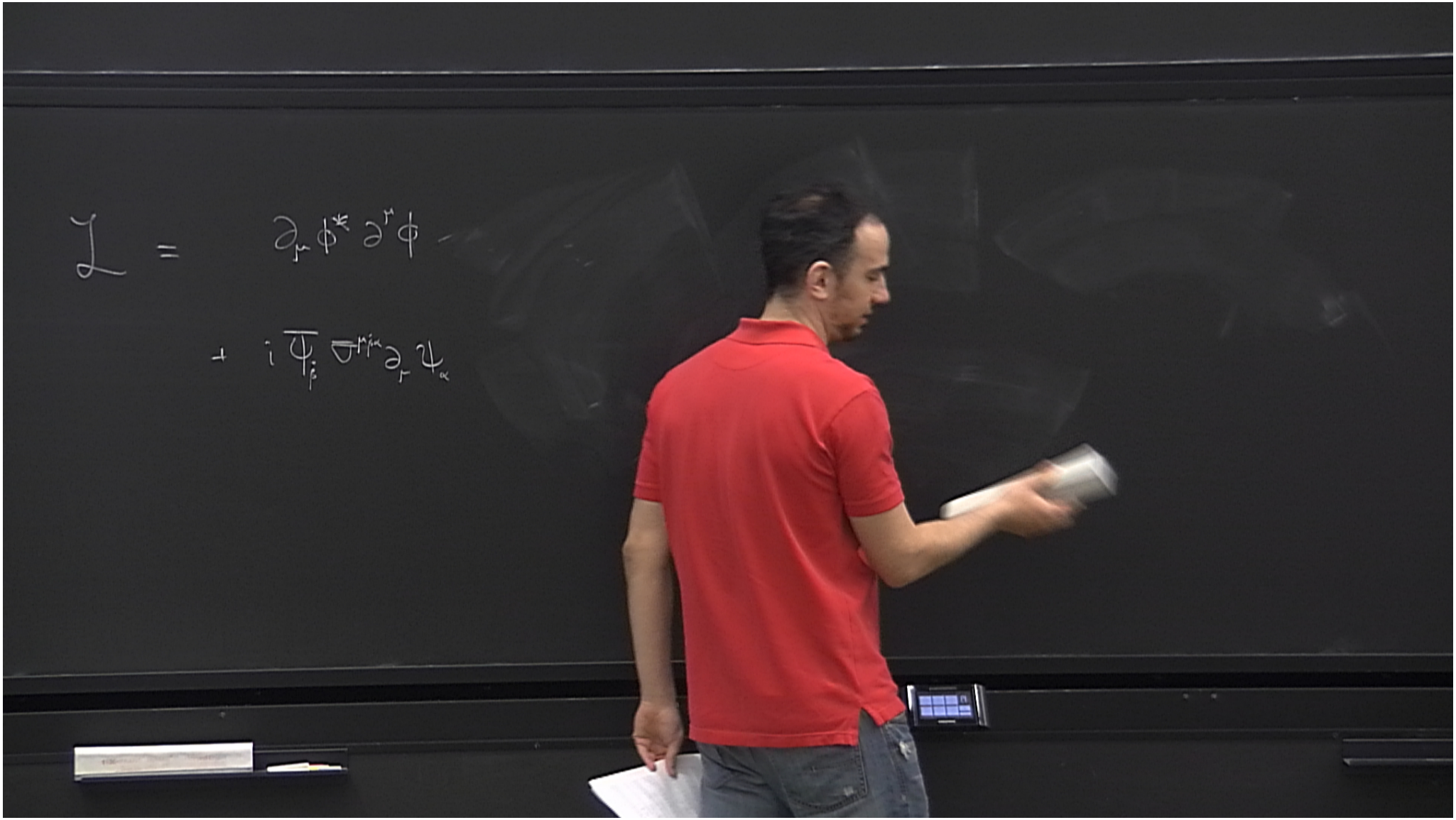
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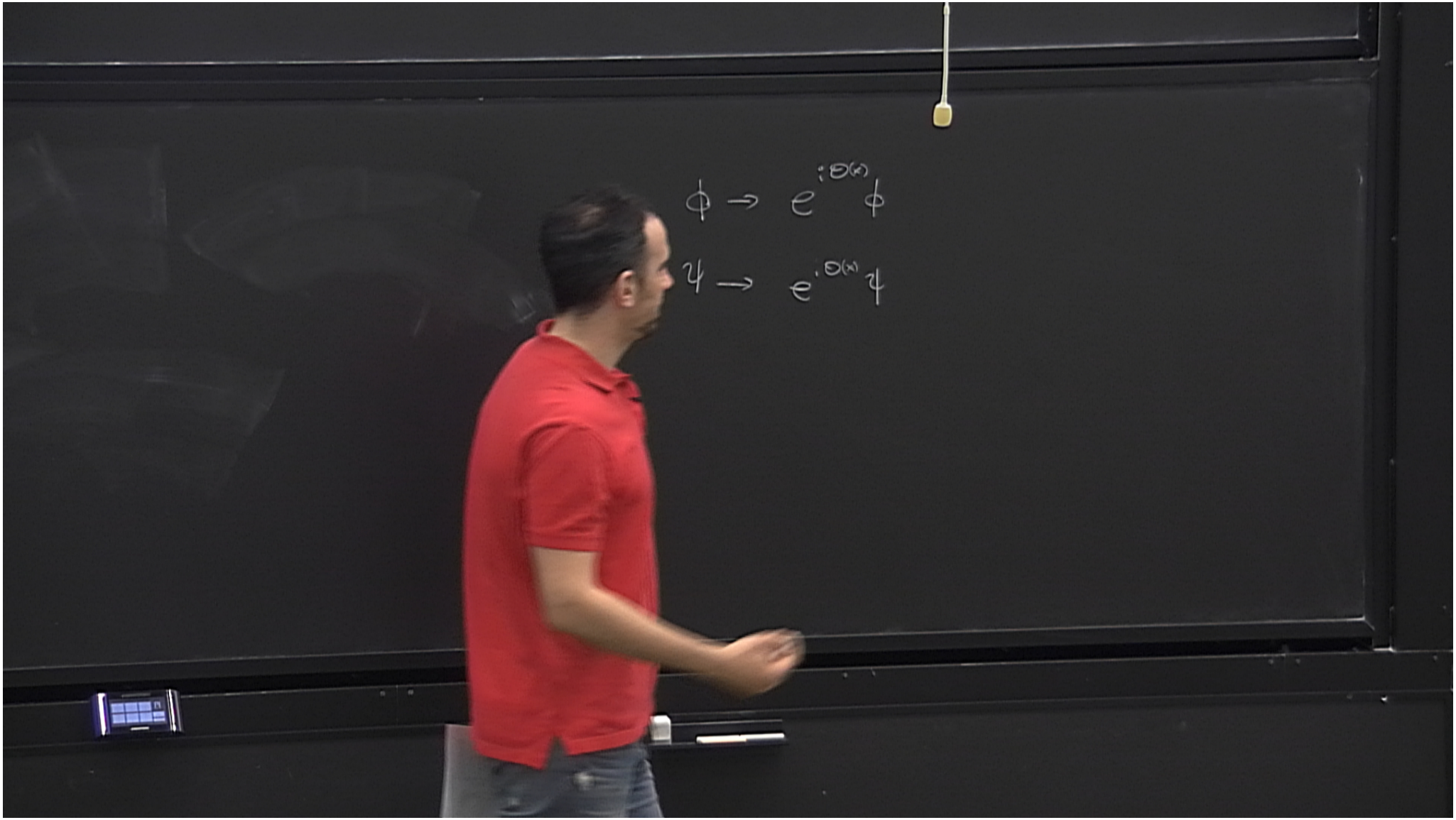
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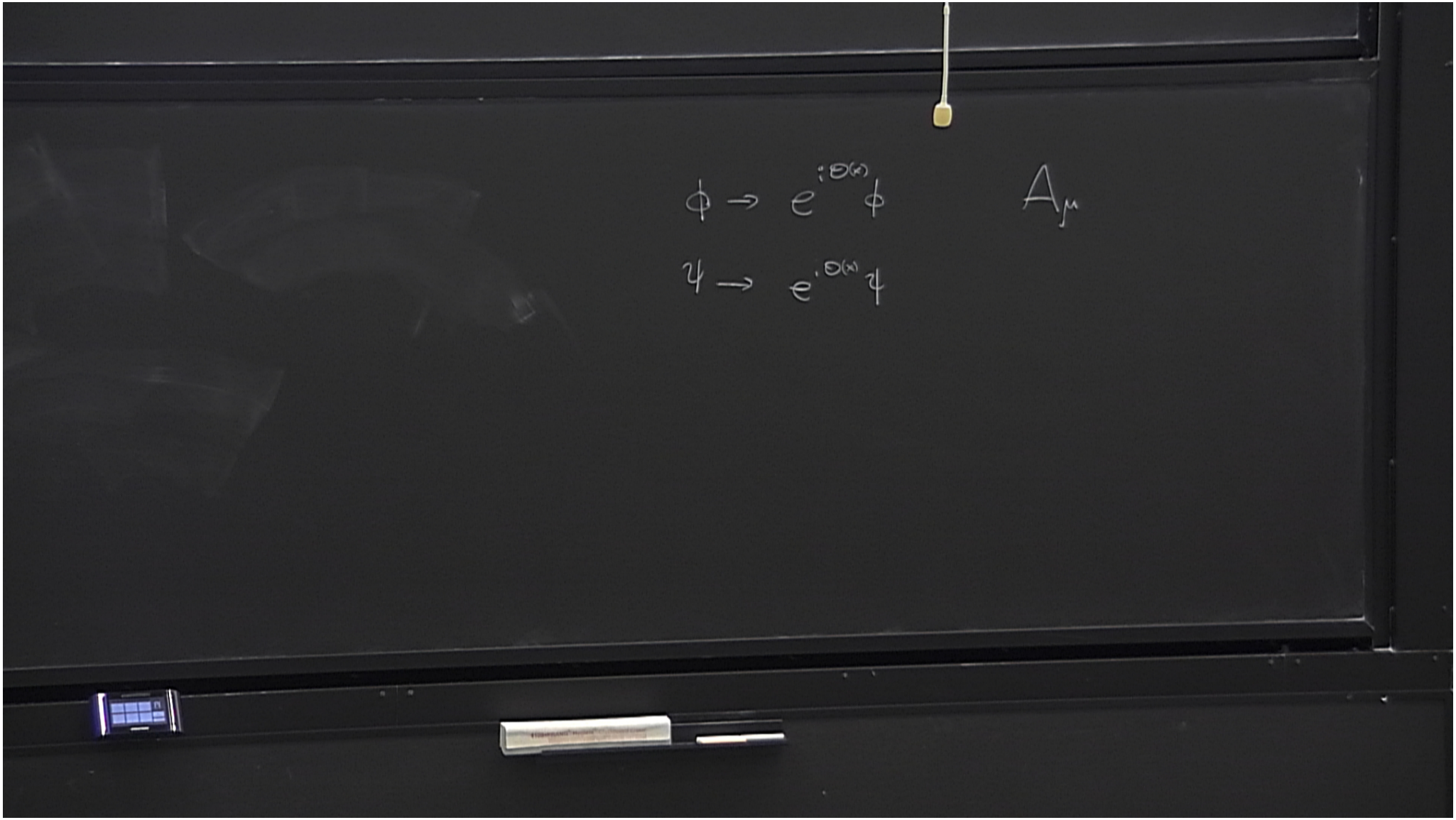
Abstract:

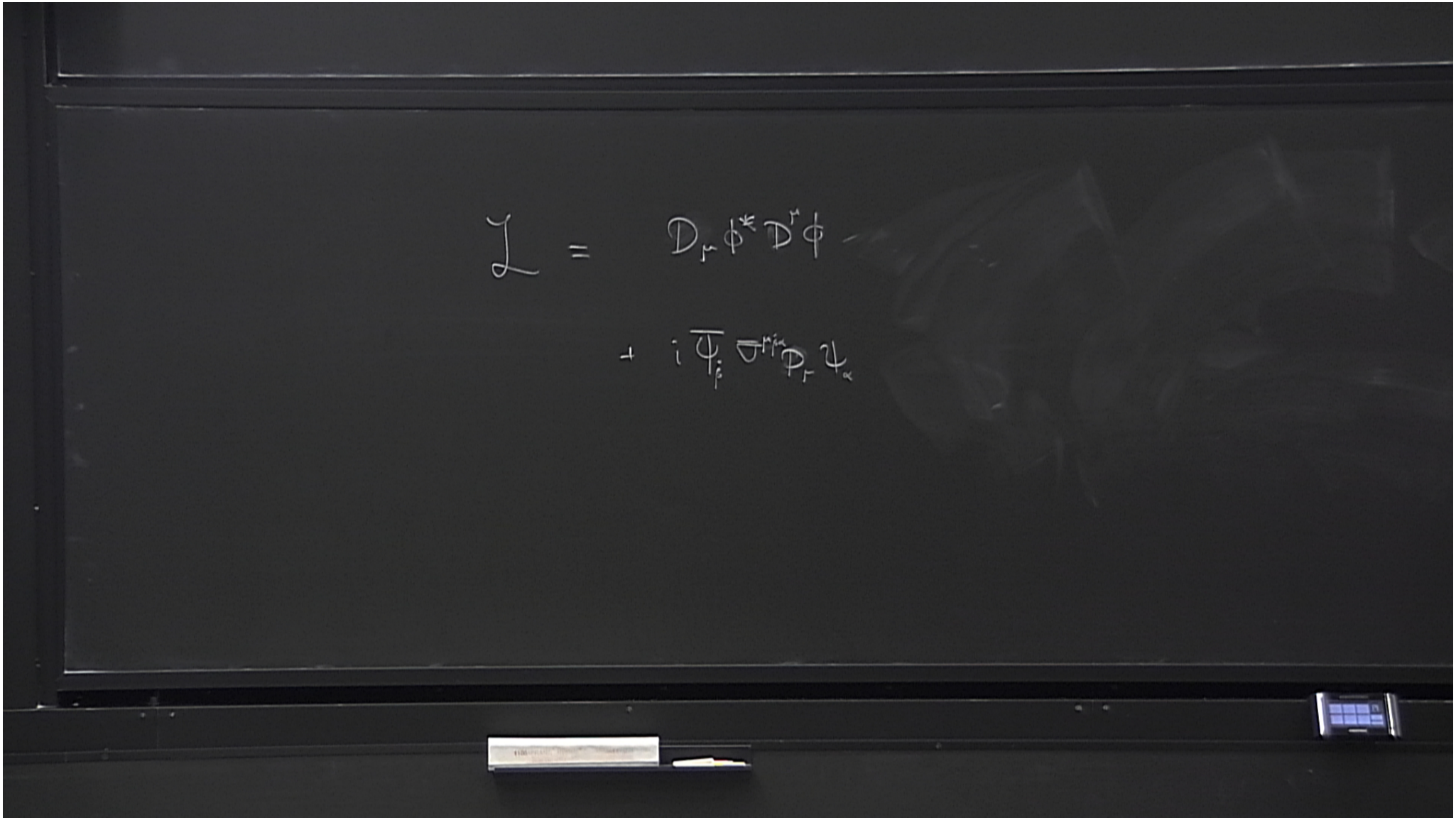

$\mathcal{L} = \partial_\mu \phi^* \partial^\mu \phi - m^2 \phi^* \phi - \frac{\lambda}{4}(\phi^* \phi)^2$
$+ i \bar{\psi}_{\dot{\beta}} \bar{\sigma}^{\mu \dot{\beta}\alpha} \partial_\mu \psi_\alpha - m \psi^\alpha \psi_\alpha - \frac{1}{2} \lambda \phi^* \psi^\alpha \psi_\alpha + h.c.$

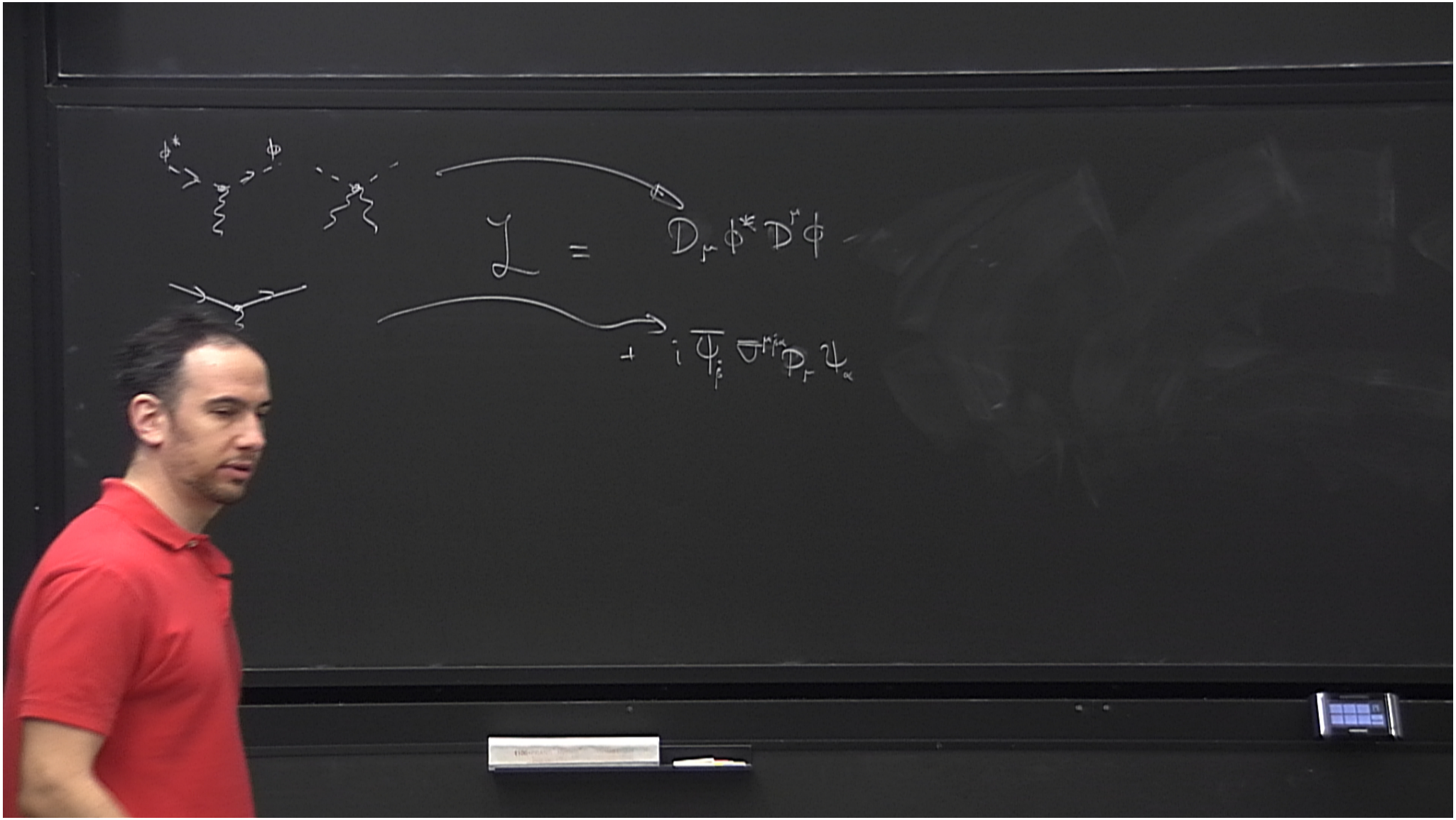

$\mathcal{L} = \partial_\mu \phi^* \partial^\mu \phi - r^2 - \frac{\lambda}{4}(\phi^*\phi)^2 + m|\phi|^2\phi$
$+ i\bar{\psi}_i \bar{\sigma}^{\mu ij} \partial_\mu \psi_\alpha - \frac{1}{2}\lambda \phi^* \psi^\alpha \psi_\alpha + h.c.$

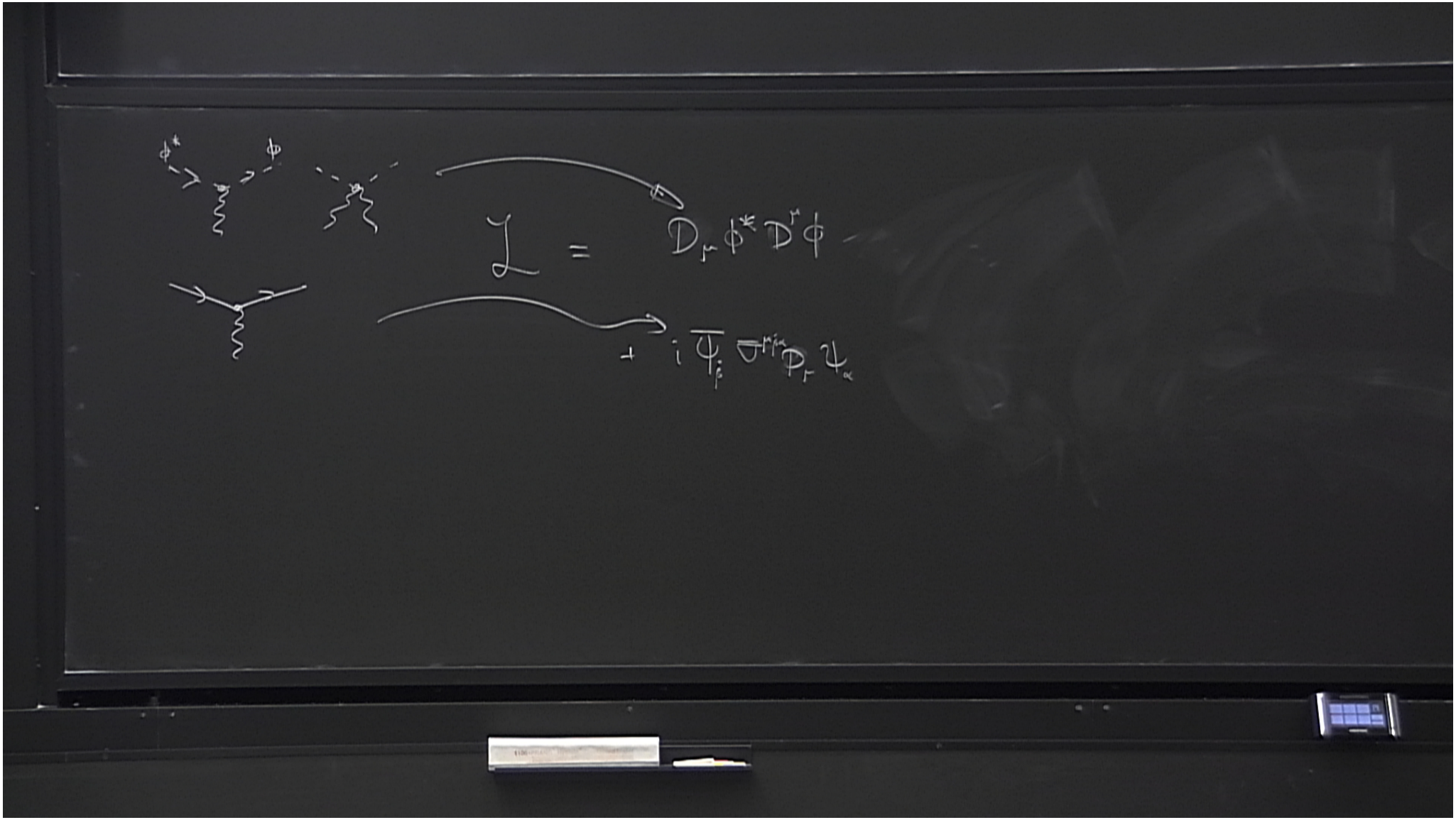

$\mathcal{L} = \partial_\mu \phi^* \partial^\mu \phi$
$+ i \bar{\psi}_i \bar{\sigma}^\mu \partial_\mu \psi_\alpha$

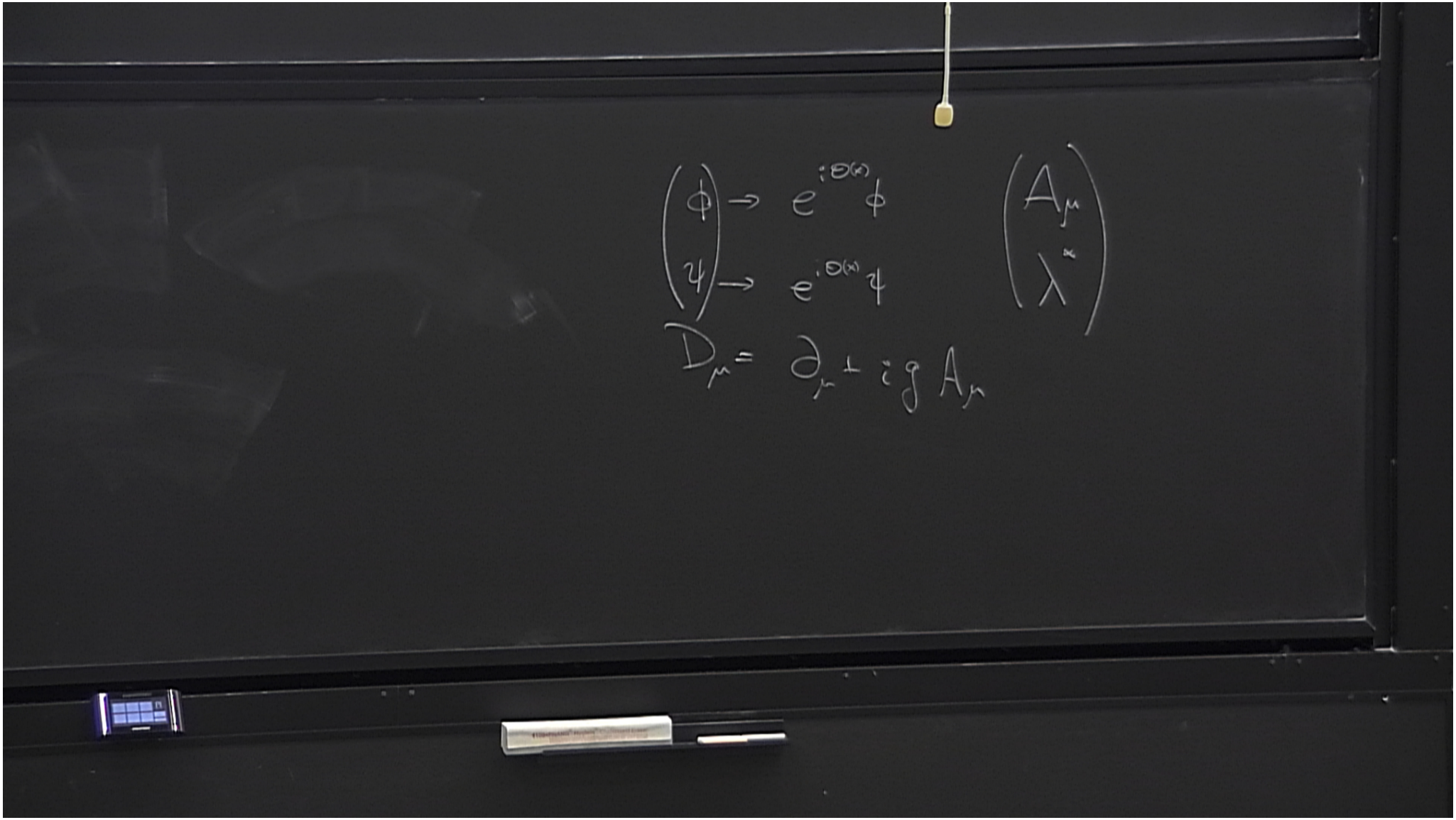

$\phi \to e^{i\Theta(x)}\phi$
$\psi \to e^{i\Theta(x)}\psi$

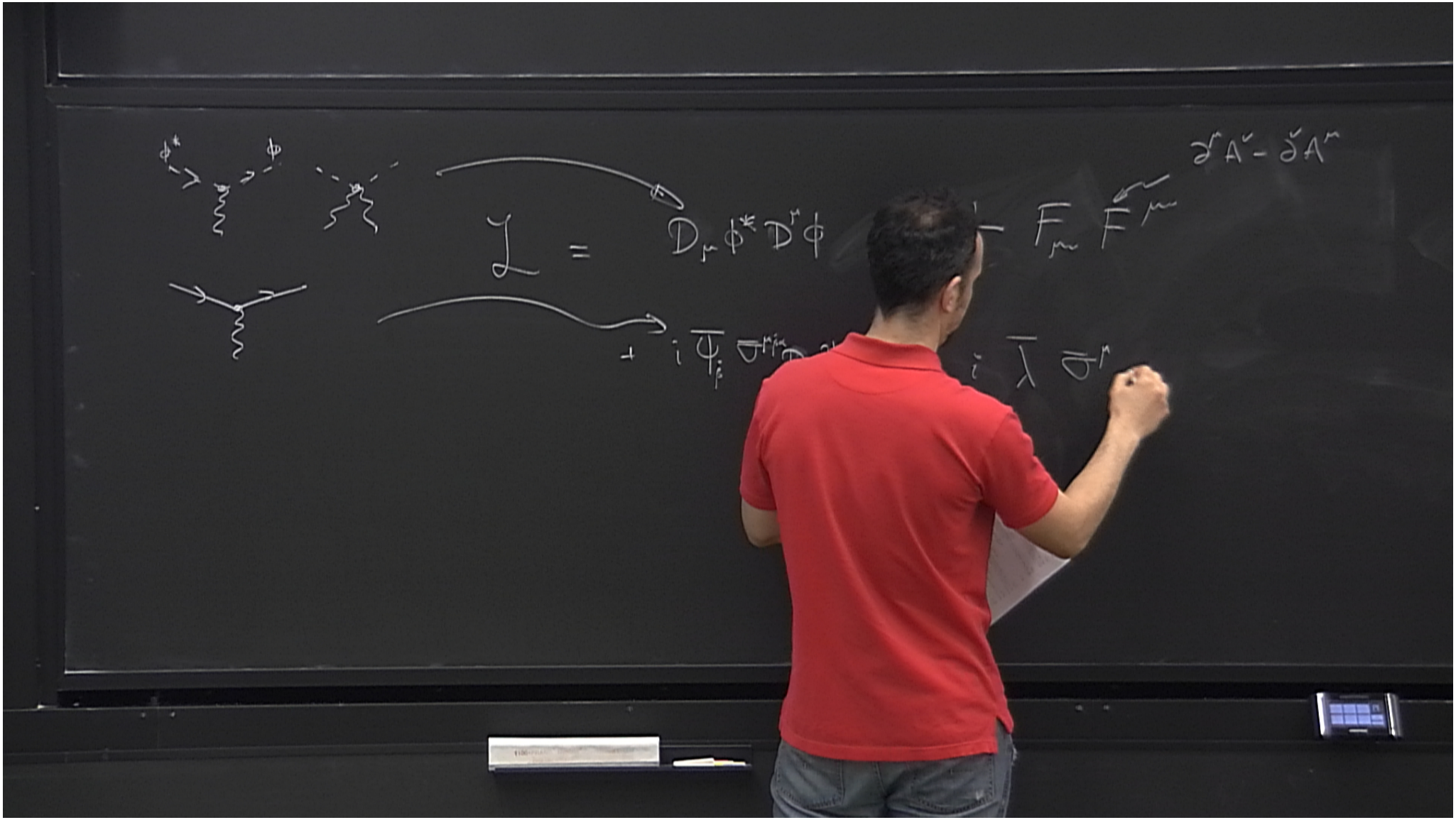

$\phi \to e^{i\Theta(x)}\phi$
$\psi \to e^{i\Theta(x)}\psi$
A_μ

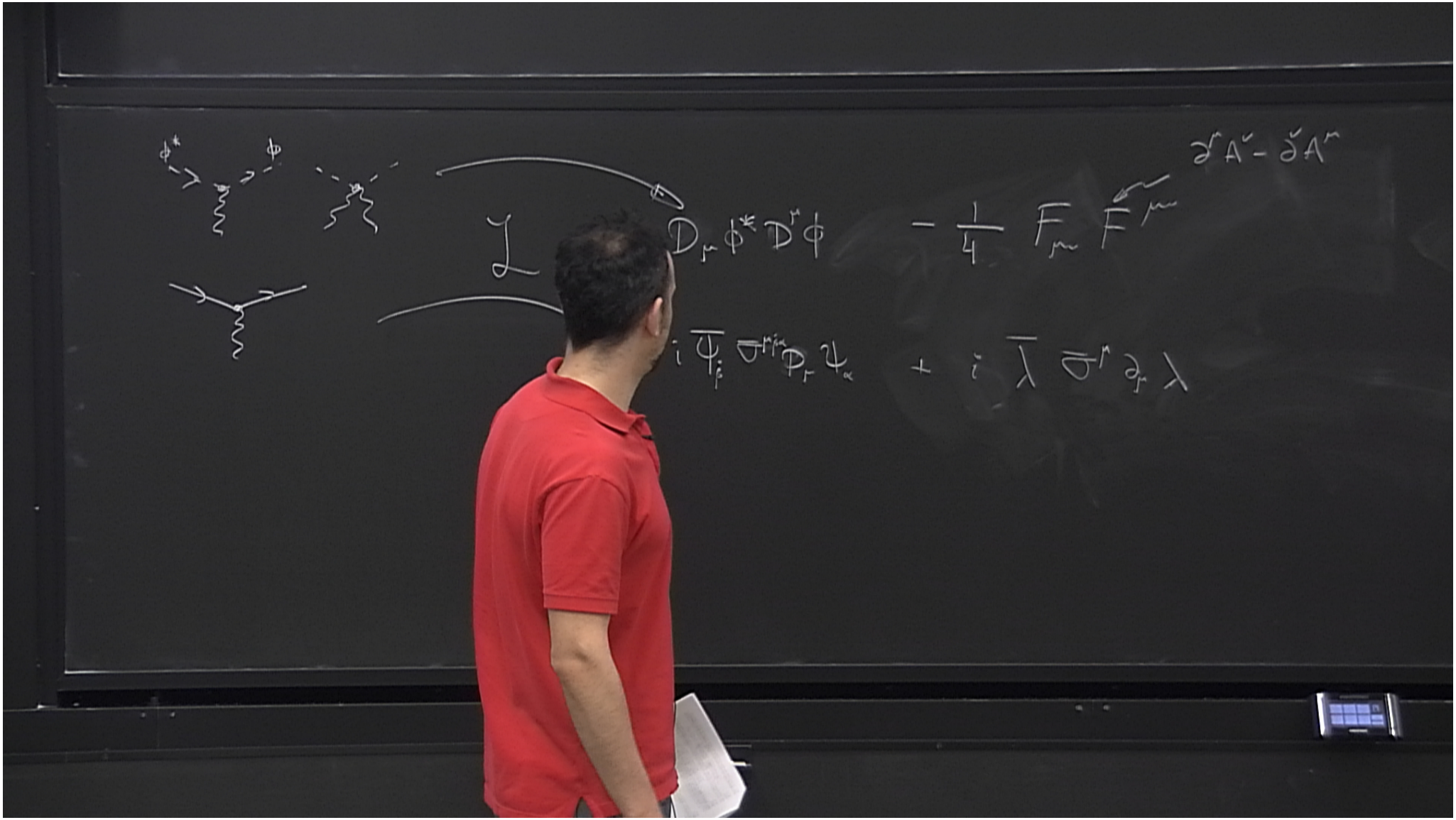

$\mathcal{L} = D_\mu \phi^* D^\mu \phi$
$+ i \bar{\psi}_i \bar{\sigma}^\mu D_\mu \psi$


$\mathcal{L} = D_\mu \phi^* D^\mu \phi$
$+ i \bar{\psi}_{\dot{\alpha}} \bar{\sigma}^{\mu \dot{\alpha}\alpha} D_\mu \psi_\alpha$


$\mathcal{L} = D_\mu \phi^* D^\mu \phi$
$+ i \bar{\psi}_{\dot{\alpha}} \bar{\sigma}^{\mu \dot{\alpha} \alpha} D_\mu \psi_\alpha$


$\begin{pmatrix} \phi \\ \psi \end{pmatrix} \to \begin{matrix} e^{i\theta(x)}\phi \\ e^{i\theta(x)}\psi \end{matrix}$
$\begin{pmatrix} A_\mu \\ \lambda \end{pmatrix}$
$D_\mu = \partial_\mu + igA_\mu$


$\mathcal{L} = D_\mu \phi^* D^\mu \phi$
$\partial^\mu A^\nu - \partial^\nu A^\mu$
$F_{\mu\nu} F^{\mu\nu}$
$i \bar{\psi}_i \bar{\sigma}^\mu$
$i \bar{\lambda} \bar{\sigma}^\mu$


$\mathcal{L}$
$D_\mu \phi^* D^\mu \phi$
$-\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$\partial^\mu A^\nu - \partial^\nu A^\mu$
$i \bar{\psi}_{\dot{\alpha}} \bar{\sigma}^{\mu\dot{\alpha}\alpha} D_\mu \psi_\alpha$
$+ i \bar{\lambda} \bar{\sigma}^\mu \partial_\mu \lambda$

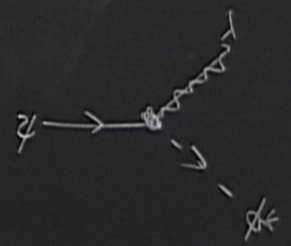
$\partial^\mu A^\nu - \partial^\nu A^\mu$

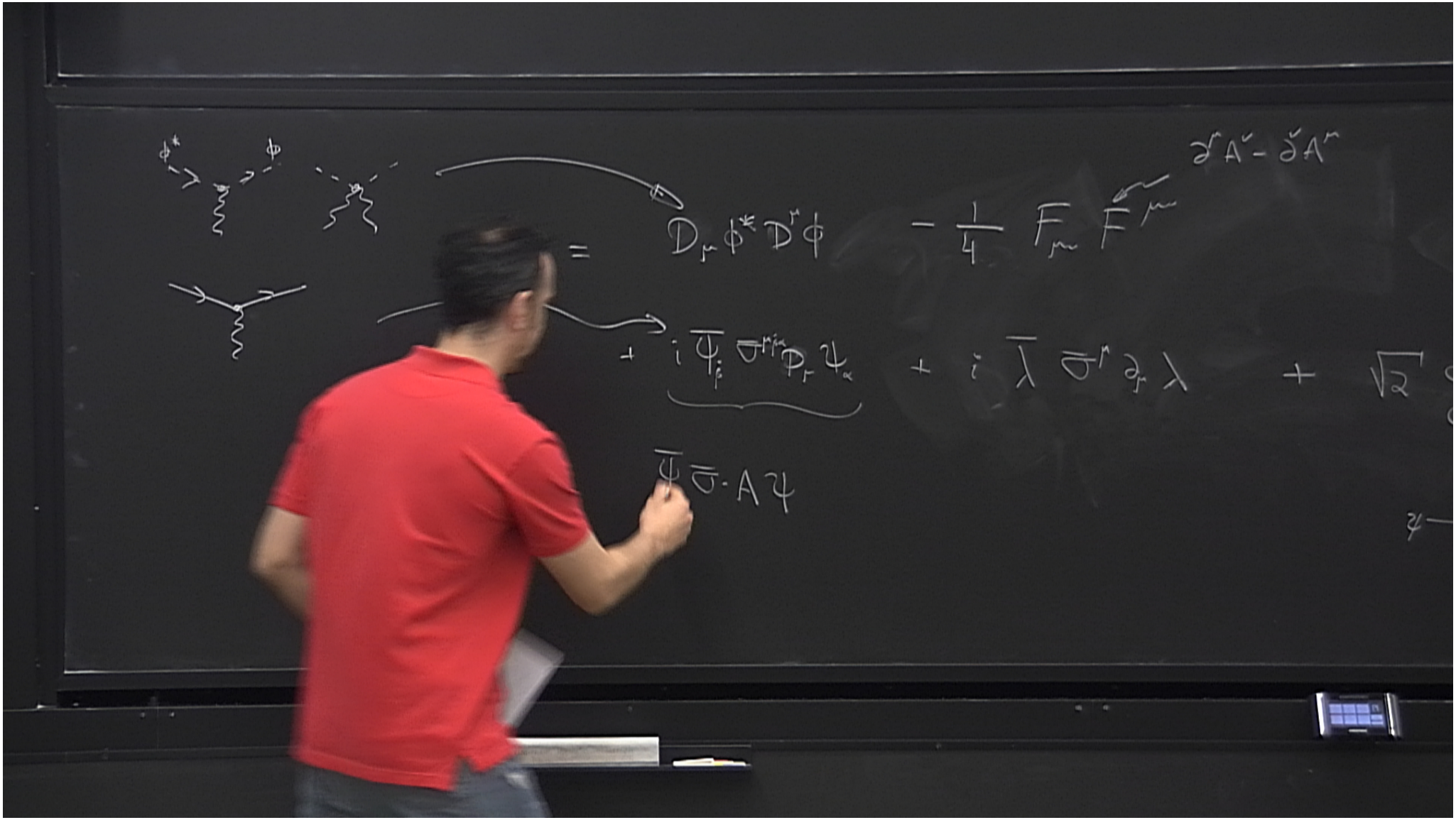
$D_\mu \phi^* D^\mu \phi \quad - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$

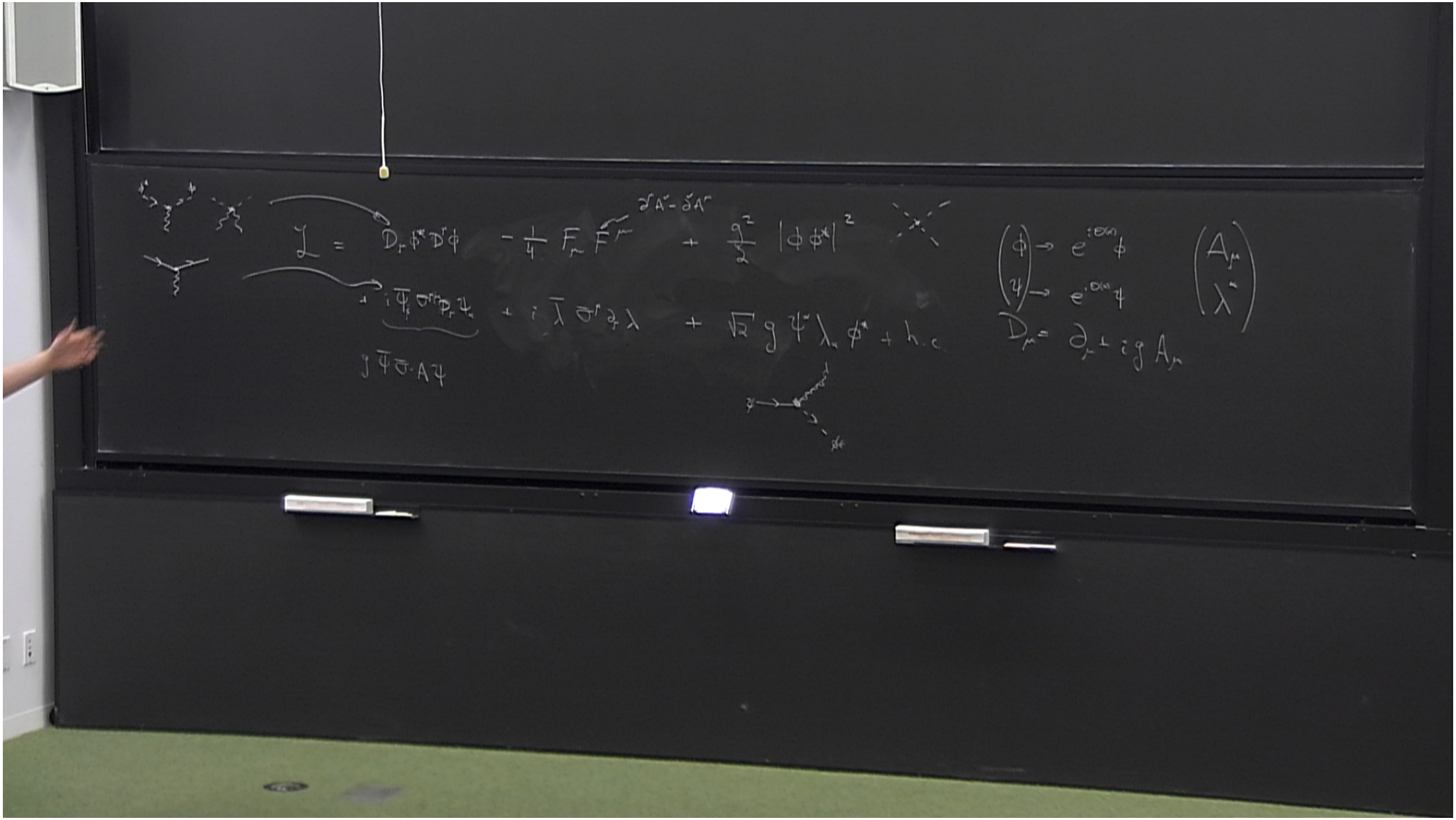
$\begin{pmatrix} \phi \\ \psi \end{pmatrix} \rightarrow \begin{matrix} e^{i\theta(x)}\phi \\ e^{i\theta(x)}\psi \end{matrix}$

$\bar{\psi}_i \bar{\sigma}^\mu D_\mu \psi_\alpha \quad + \; i \bar{\lambda} \bar{\sigma}^\mu \partial_\mu \lambda \quad + \; \sqrt{2}\, g\, \psi^\alpha \lambda_\alpha \phi^* + h.c.$

$D_\mu = \partial_\mu + i$




ϕ^*
ϕ
$= D_\mu \phi^* D^\mu \phi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$\partial^\mu A^\nu - \partial^\nu A^\mu$
$+ i \bar{\psi}_i \bar{\sigma}^\mu \partial_\mu \psi_\alpha + i \bar{\lambda} \bar{\sigma}^\mu \partial_\mu \lambda + \sqrt{2}$
$\bar{\psi} \bar{\sigma} \cdot A \psi$


$\mathcal{L} = D_\mu \phi^* D^\mu \phi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{g^2}{2} |\phi \phi^*|^2$
$+ i \bar{\psi} \bar{\sigma}^\mu \partial_\mu \psi + i \bar{\lambda} \bar{\sigma}^\mu \partial_\mu \lambda + \sqrt{2} g \psi^* \lambda_* \phi^* + h.c.$
$g \bar{\psi} \bar{\sigma} \cdot A \psi$
$\partial A^* - \partial A^*$
$\begin{pmatrix} \phi \\ \psi \end{pmatrix} \to \begin{matrix} e^{i\alpha(x)} \phi \\ e^{i\alpha(x)} \psi \end{matrix}$
$\begin{pmatrix} A_\mu \\ \lambda^* \end{pmatrix}$
$D_\mu = \partial_\mu + i g A_\mu$

$\partial^\nu - \partial A^\mu$

$+ \frac{g^2}{2} |\phi \phi^*|^2$



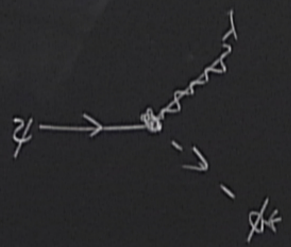
spin 0 $\begin{pmatrix} \phi \end{pmatrix} \rightarrow e^{i\theta(x)} \phi$

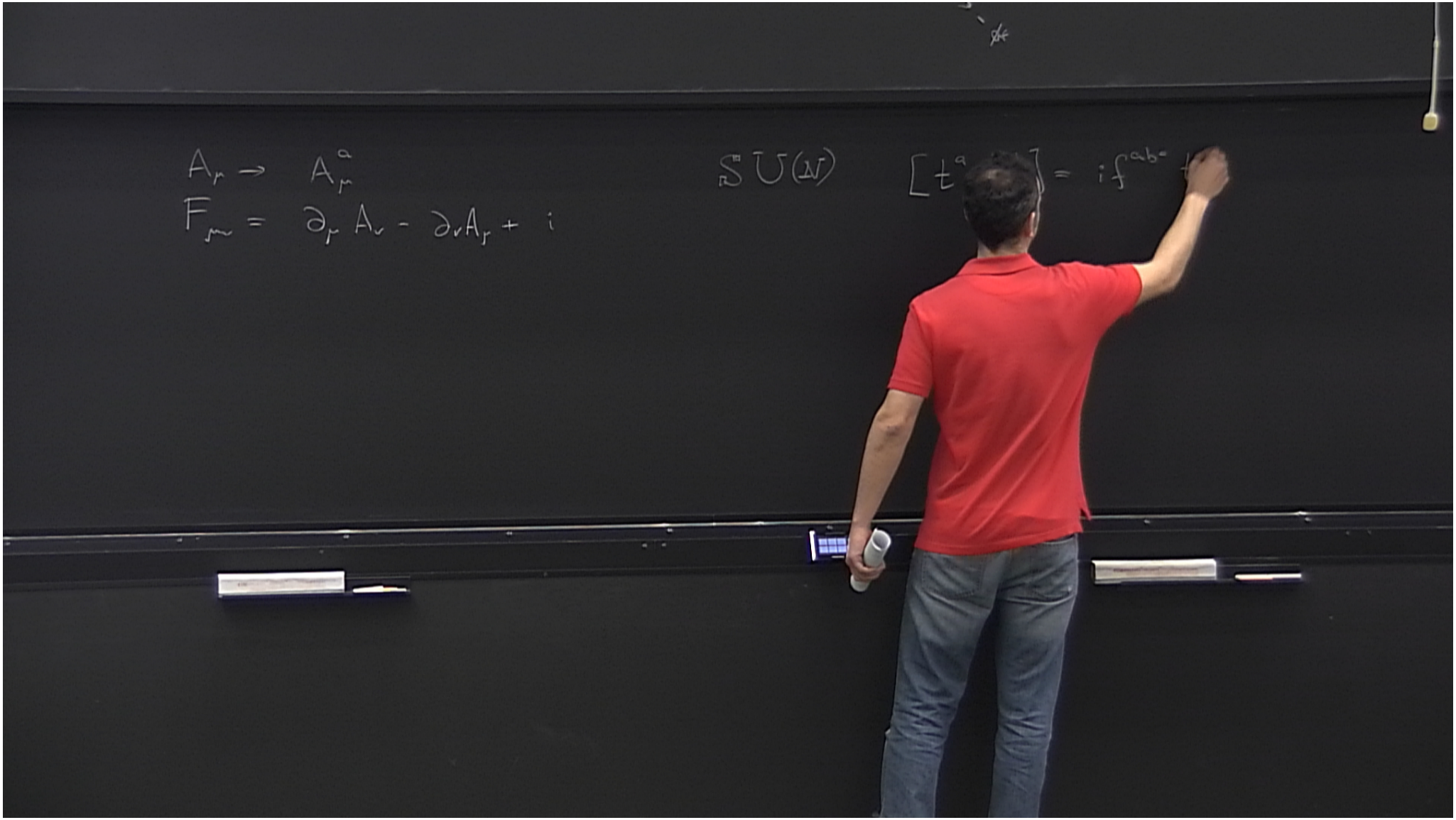
spin ½ $\begin{pmatrix} \psi \end{pmatrix} \rightarrow e^{i\theta(x)} \psi$

$\begin{pmatrix} A_\mu \\ \lambda^\alpha \end{pmatrix}$ Spin-1 / Spin-½

$+ \sqrt{2}\, g\, \psi^\alpha \lambda_\alpha \phi^* + h.c$

$D_\mu = \partial_\mu + i g A_\mu$



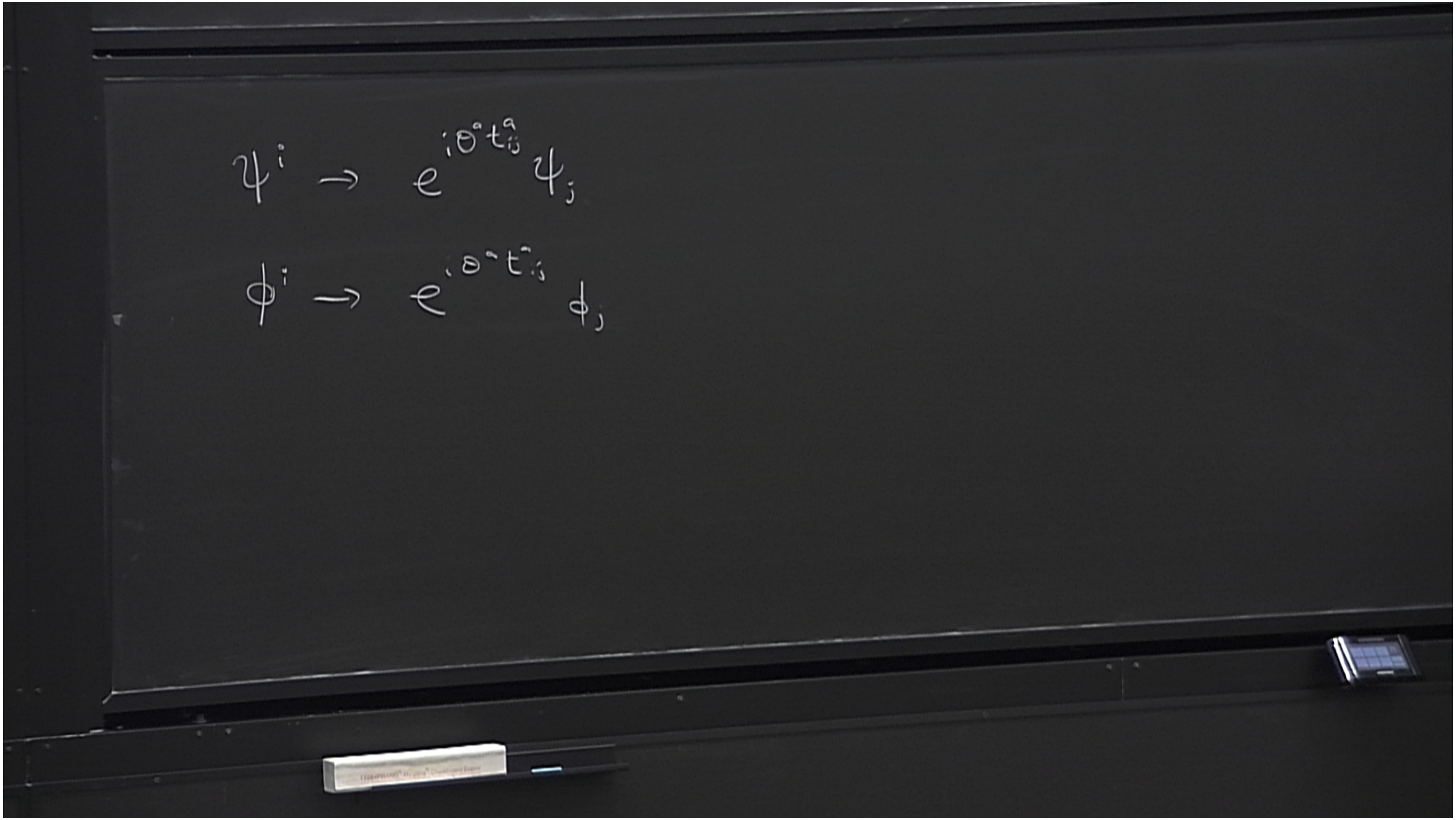

$A_\mu \to A^a_\mu$
$SU(N)$
$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + i$

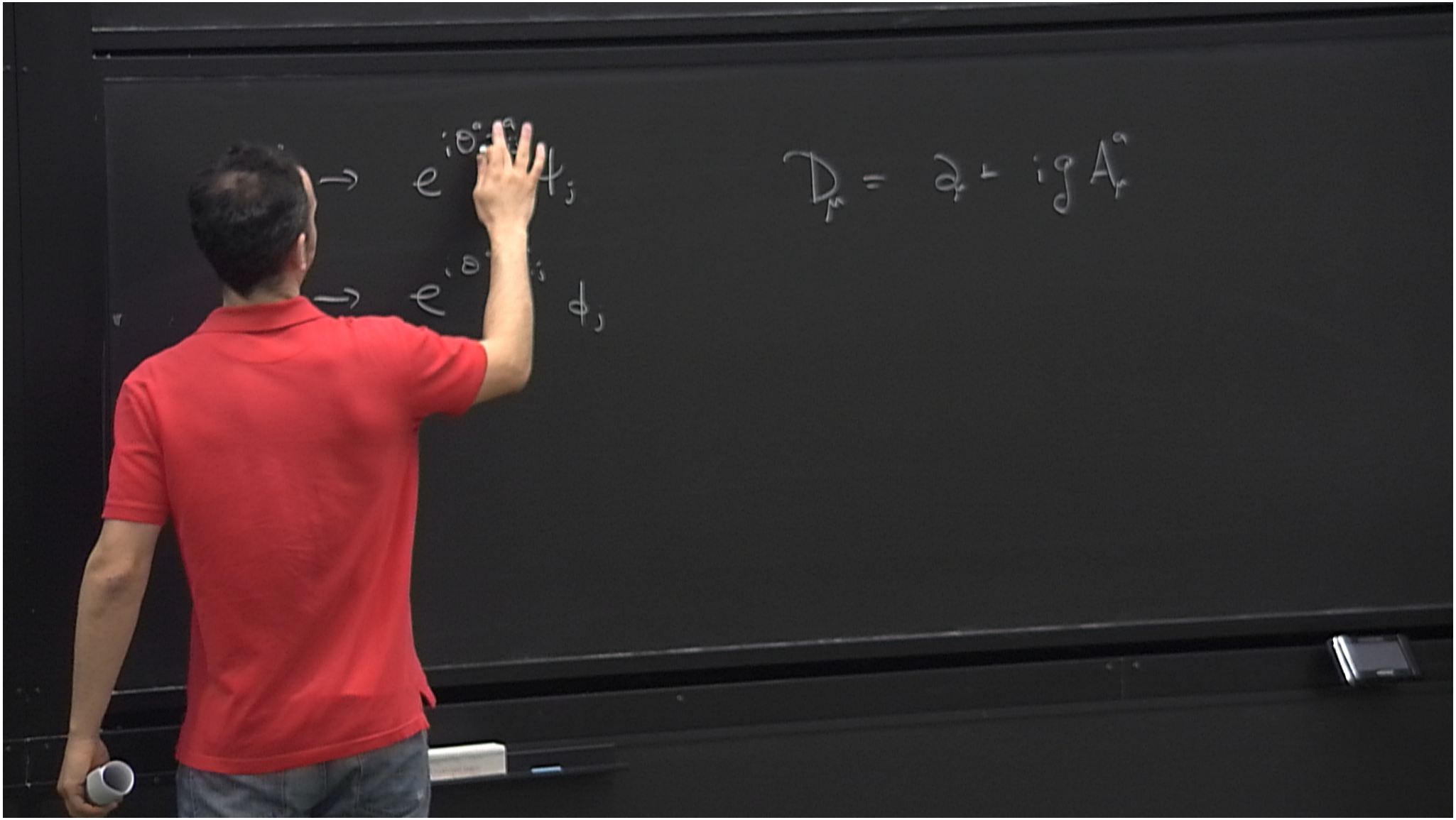
$A_\mu \to A_\mu^a t^a$ $\quad SU(N) \quad [t^a, t^b] = i f^{abc} t^c$

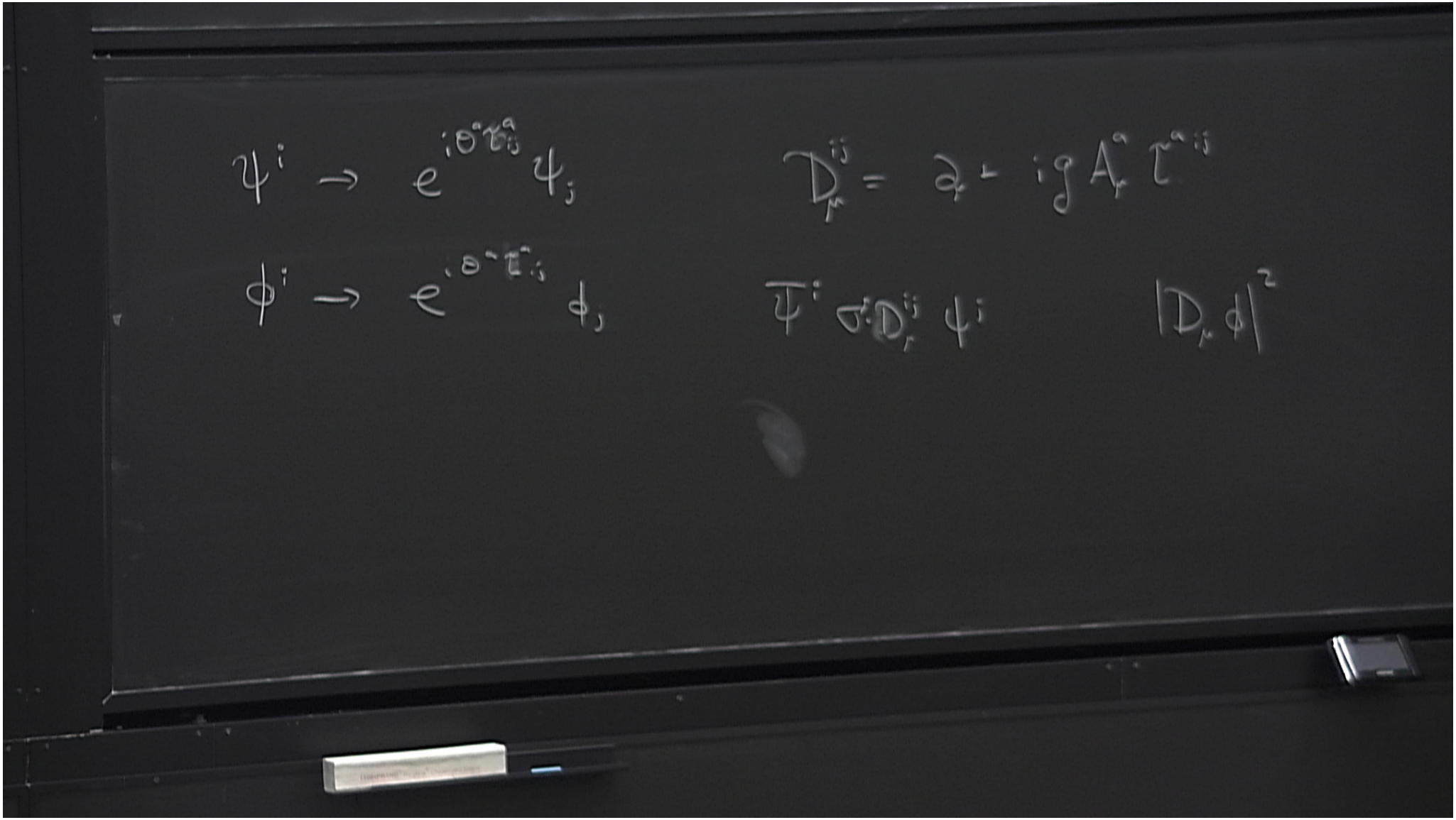
$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + [A_\mu, A_\nu]$ $\quad [A_\mu^a t^a, A_\nu^b t^b] = A_\mu^a A_\nu^b [t^a, t^b]$

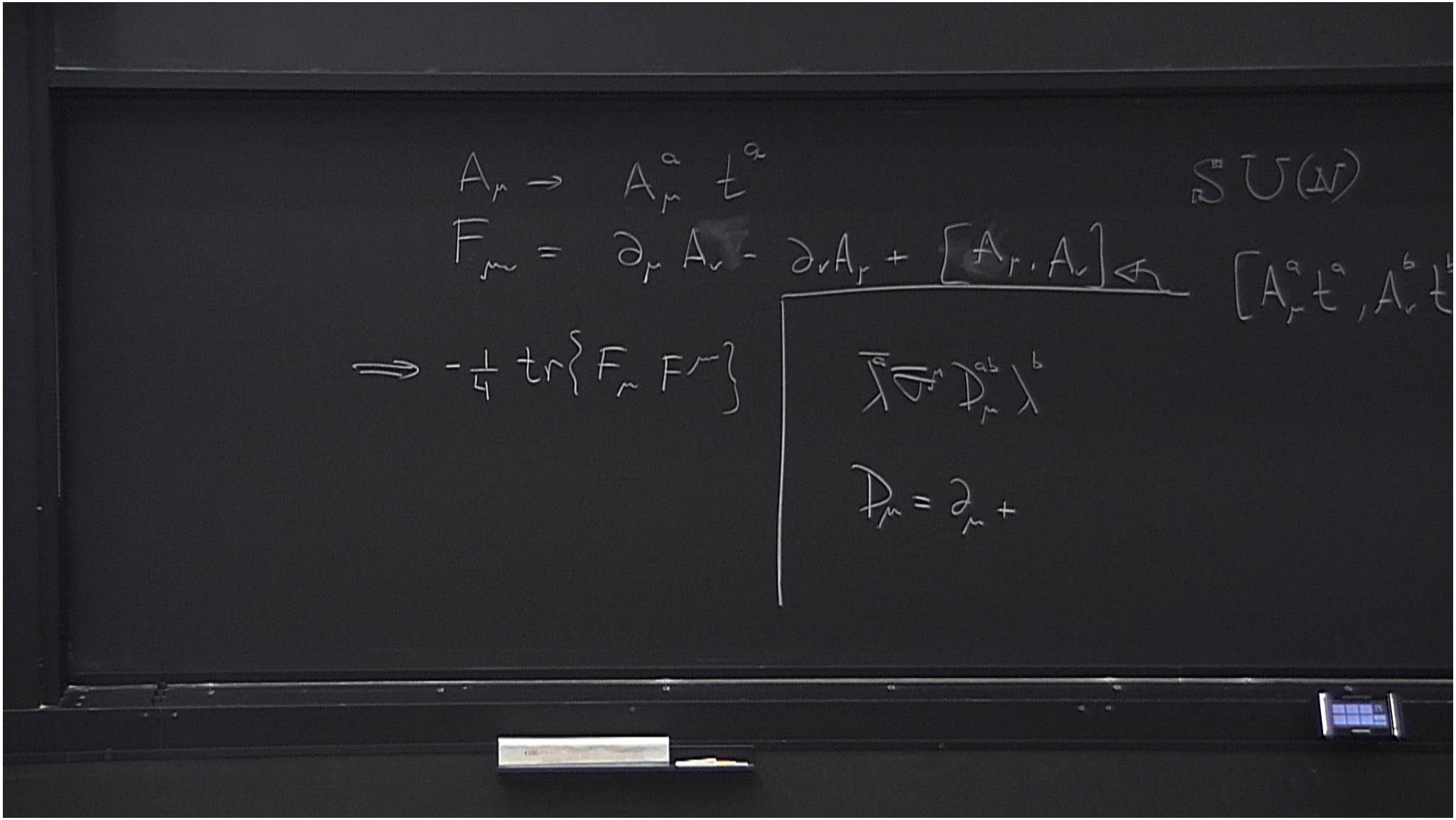
$= i A_\mu^a A_\nu^b f^{abc} t^c$

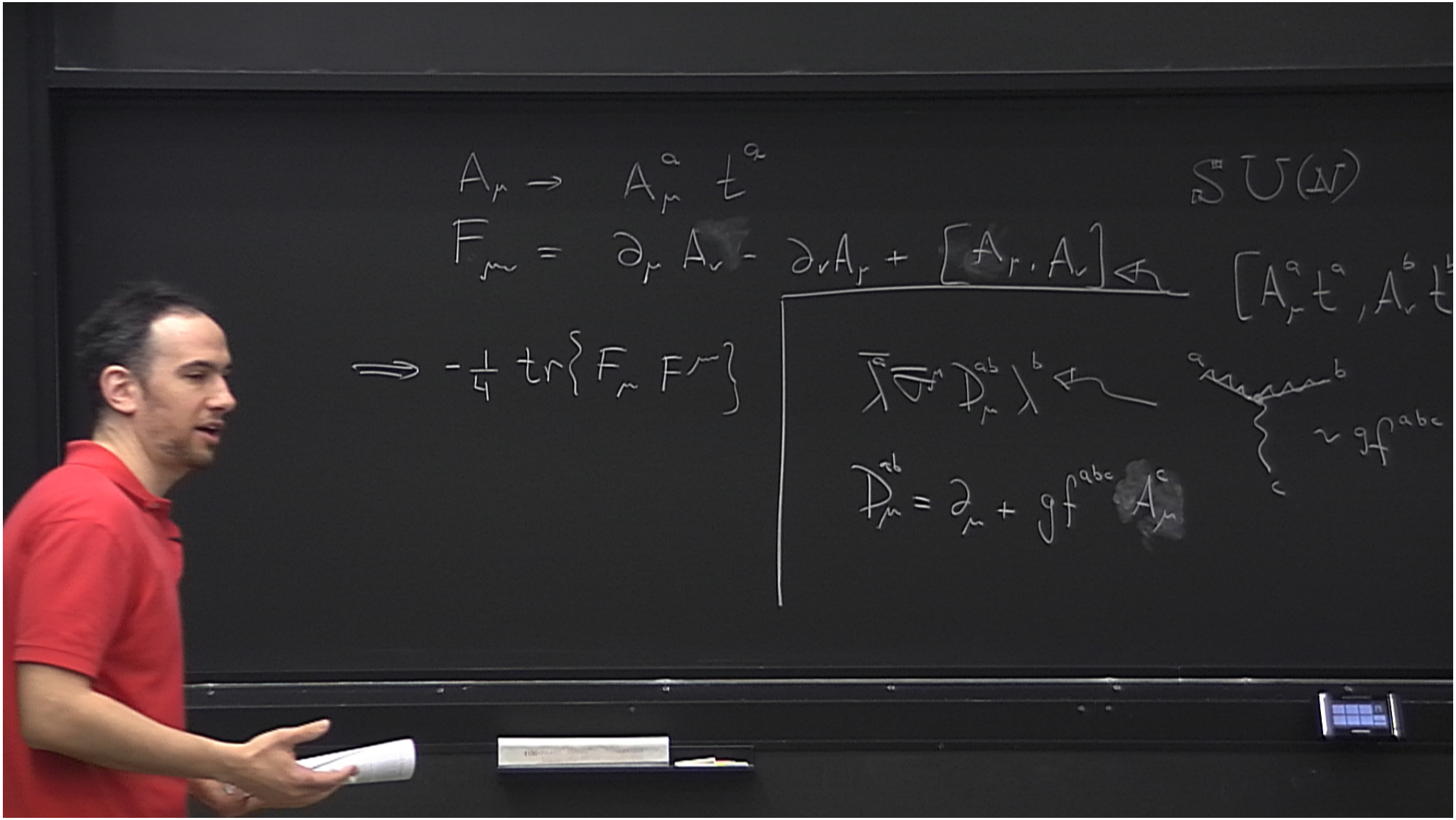
$\Rightarrow -\frac{1}{4} \mathrm{tr}\{F_{\mu\nu} F^{\mu\nu}\}$

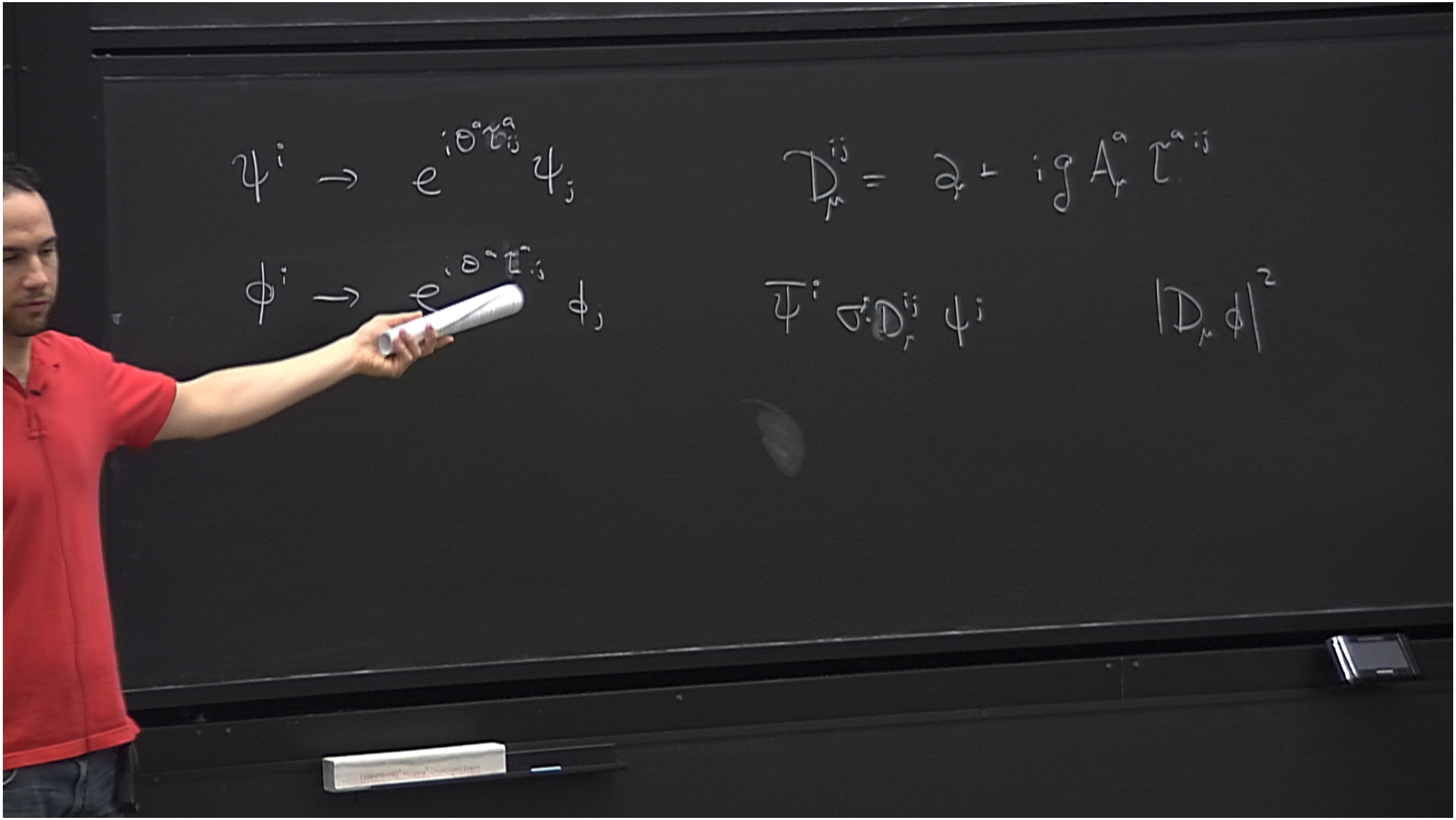

$\psi^i \to e^{i\theta^a t^a_{ij}} \psi_j$
$\phi^i \to e^{i\theta^a t^a_{ij}} \phi_j$

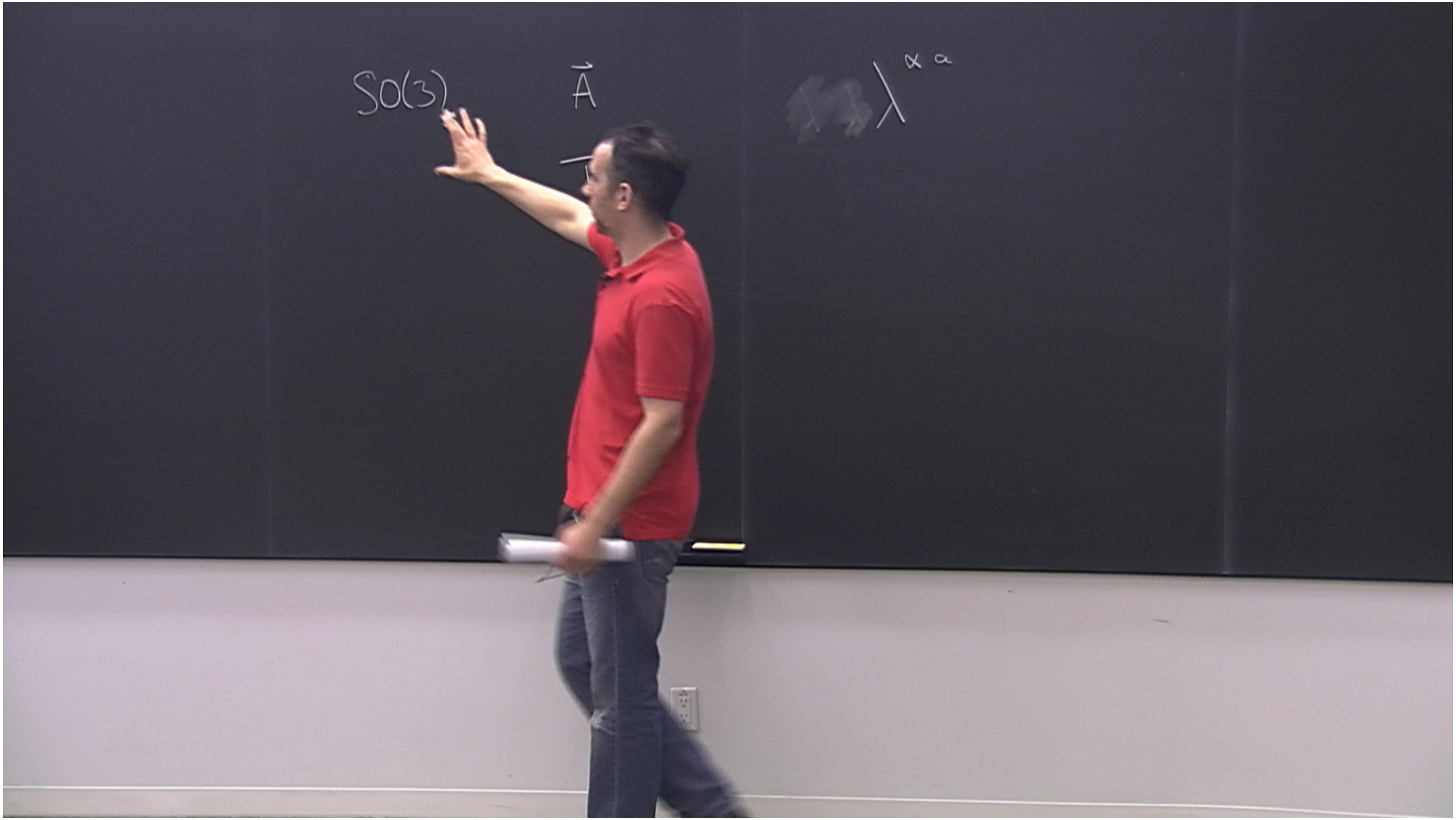

$\rightarrow e^{i\theta^a T^a_{ij}} \phi_j$
$\rightarrow e^{-i\theta^a T^a_{ij}} \phi_j$
$D_\mu = \partial_\mu - igA^a_\mu$

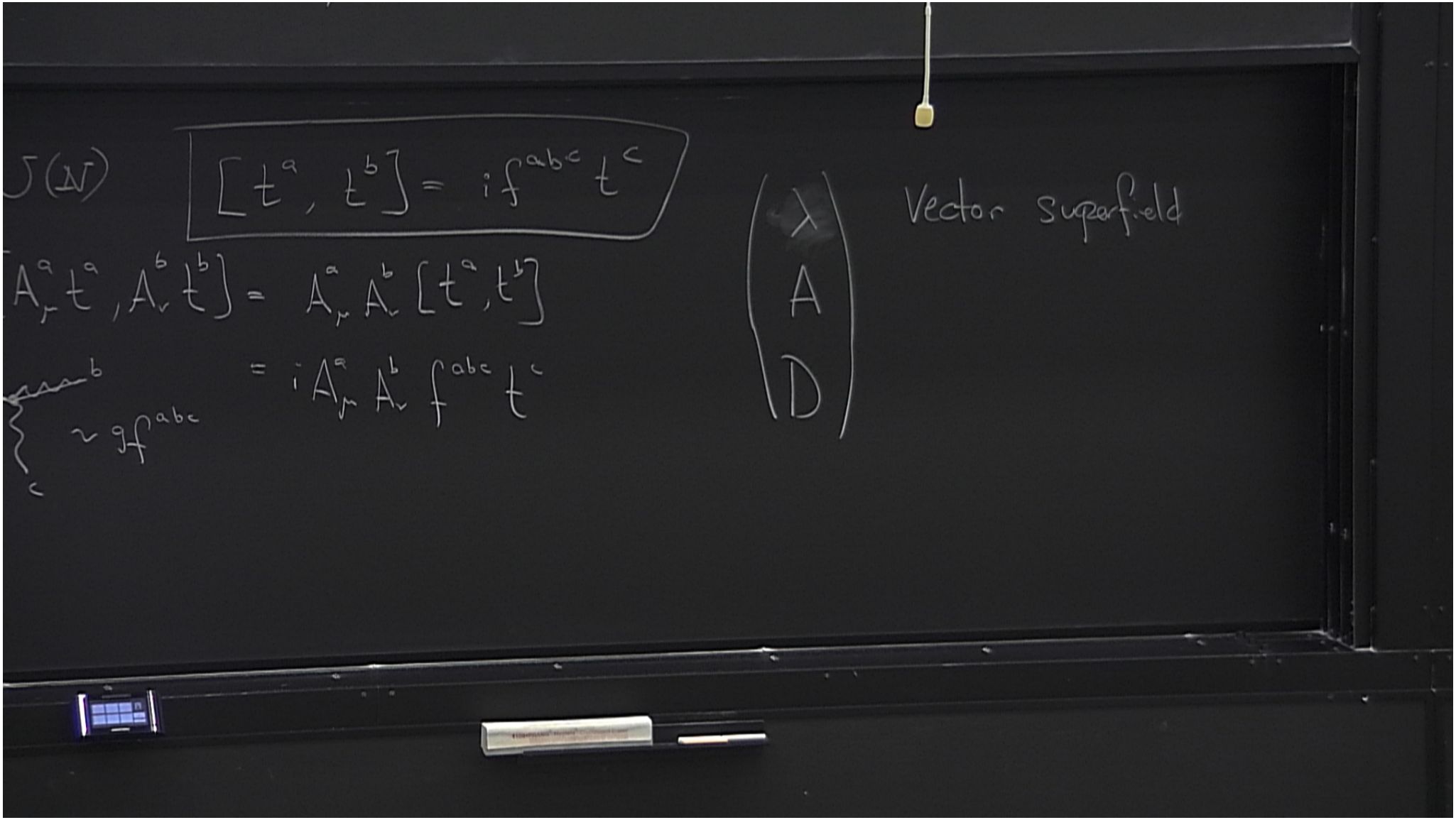

$\psi^i \to e^{i\theta^a T^a_{ij}} \psi_j$
$D_\mu^{ij} = \partial_\mu - igA_\mu^a T^{a\,ij}$
$\phi^i \to e^{i\theta^a T^a_{ij}} \phi_j$
$\bar{\psi}^i \sigma^\mu D_\mu^{ij} \psi^i$
$|D_\mu \phi|^2$


$A_\mu \to A^a_\mu t^a$
$SU(N)$
$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + [A_\mu, A_\nu]$
$[A^a_\mu t^a, A^b_\nu t^b$
$\Rightarrow -\frac{1}{4} tr\{F_{\mu\nu} F^{\mu\nu}\}$
$\bar{\lambda}^a \gamma^\mu D^{ab}_\mu \lambda^b$
$D_\mu = \partial_\mu +$


$A_\mu \to A_\mu^a t^a$
$SU(N)$
$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + [A_\mu, A_\nu]$
$[A_\mu^a t^a, A_\nu^b t^b$
$\Rightarrow -\frac{1}{4} tr\{F_{\mu\nu} F^{\mu\nu}\}$
$\bar{\lambda}^a \not{D}^{ab} \lambda^b$
$\sim g f^{abc}$
$D_\mu^{ab} = \partial_\mu + g f^{abc} A_\mu^c$


$\psi^i \to e^{i\theta^a \tau^a_{ij}} \psi_j$
$D^{ij}_\mu = \partial_\mu - igA^a_\mu \tau^{a\,ij}$
$\phi^i \to e^{i\theta^a \tau^a_{ij}} \phi_j$
$\bar{\psi}^i \sigma^\mu D^{ij}_\mu \psi^i$
$|D_\mu \phi|^2$

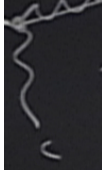

SO(3)
$\vec{A}$
$\propto a$


$U(N)$
$[t^a, t^b] = i f^{abc} t^c$
$[A^a_\mu t^a, A^b_\nu t^b] = A^a_\mu A^b_\nu [t^a, t^b]$
$= i A^a_\mu A^b_\nu f^{abc} t^c$
$\sim g f^{abc}$
$\begin{pmatrix} \lambda \\ A \\ D \end{pmatrix}$
Vector superfield

$U(N)$ $\quad [t^a, t^b] = i f^{abc} t^c$

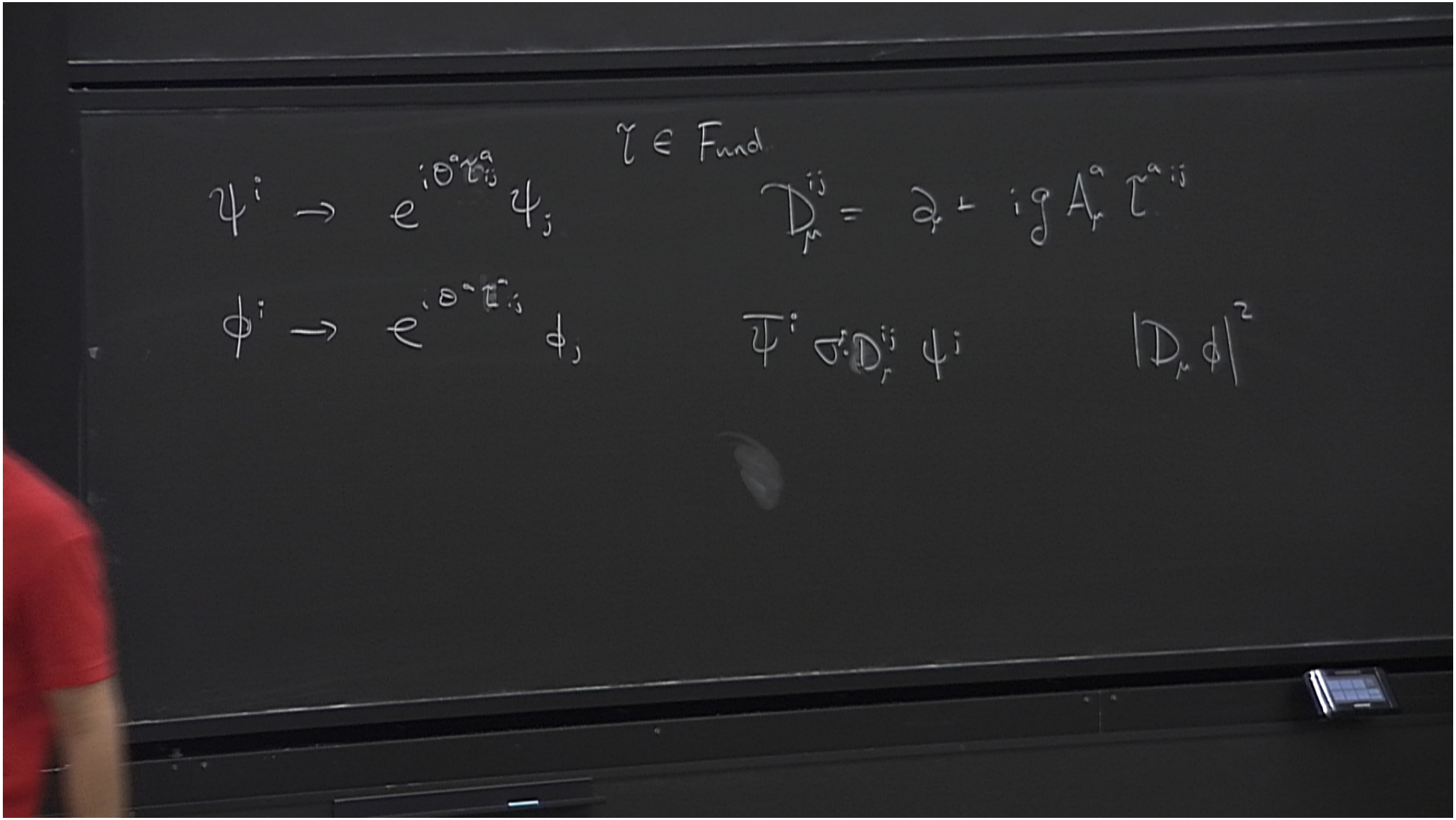
$[A_\mu^a t^a, A_\nu^b t^b] = A_\mu^a A_\nu^b [t^a, t^b]$

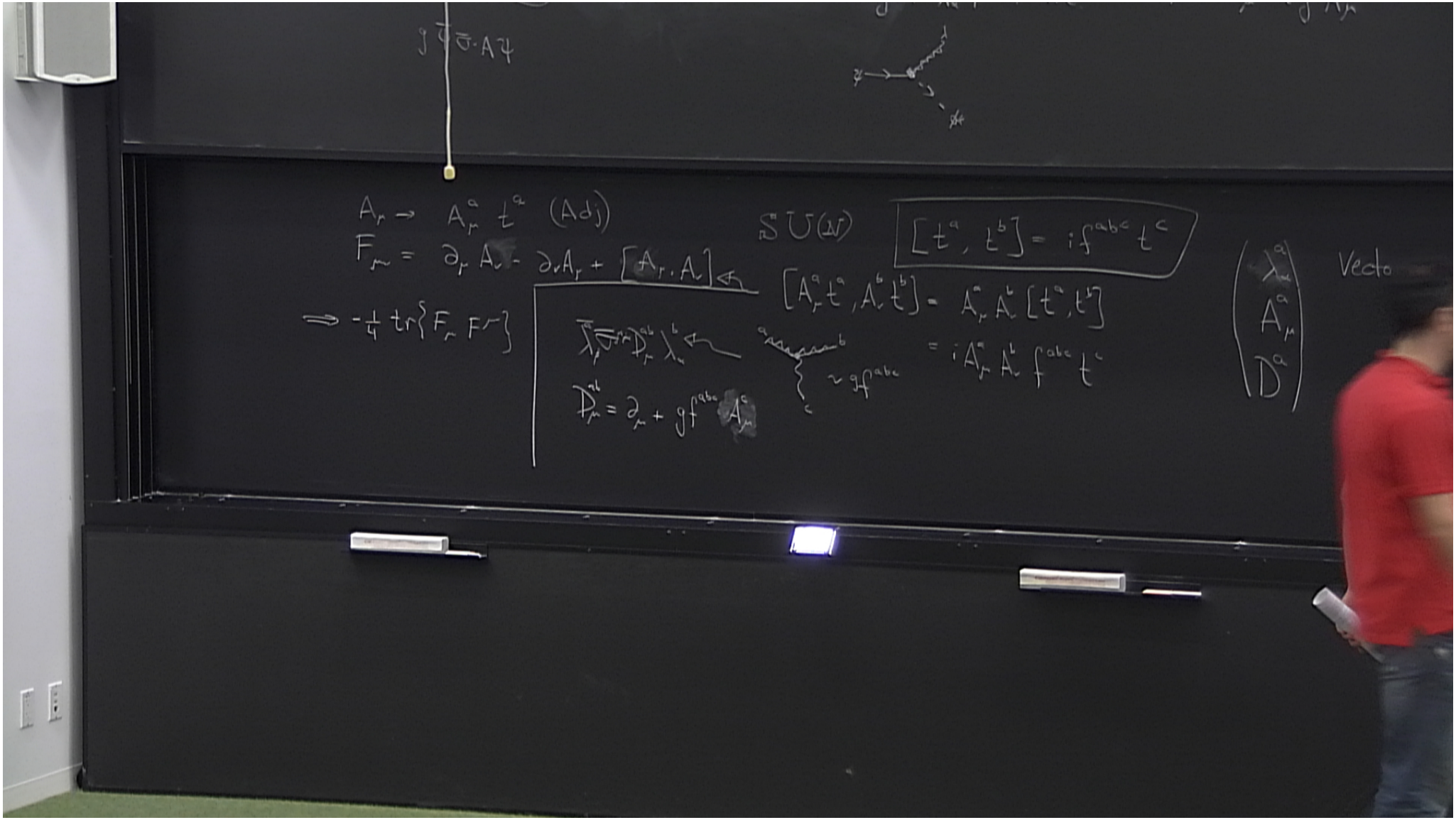
$= i A_\mu^a A_\nu^b f^{abc} t^c$



$\sim g f^{abc}$

$\begin{pmatrix} \lambda^a \\ A^a \\ D^a \end{pmatrix}$ Vector superfield


$r \in \text{Fund}$
$\psi^i \to e^{i\theta^a T^a_{ij}} \psi_j$
$D^{ij}_\mu = \partial_\mu + i g A^a_\mu T^{a\,ij}$
$\phi^i \to e^{i\theta^a T^a_{ij}} \phi_j$
$\bar{\psi}^i \sigma^\mu D^{ij}_\mu \psi^i$
$|D_\mu \phi|^2$

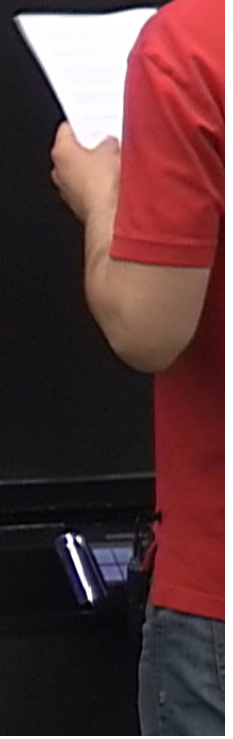

$A_\mu \to A_\mu^a t^a$ (Adj)
$SU(N)$
$[t^a, t^b] = i f^{abc} t^c$
$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + [A_\mu, A_\nu]$
$[A_\mu^a t^a, A_\nu^b t^b] = A_\mu^a A_\nu^b [t^a, t^b]$
$= i A_\mu^a A_\nu^b f^{abc} t^c$
$\Rightarrow -\frac{1}{4} \mathrm{tr}\{F_{\mu\nu} F^{\mu\nu}\}$
$D_\mu^{ab} = \partial_\mu + g f^{abc} A_\mu^c$
$\sim g f^{abc}$
Vecto

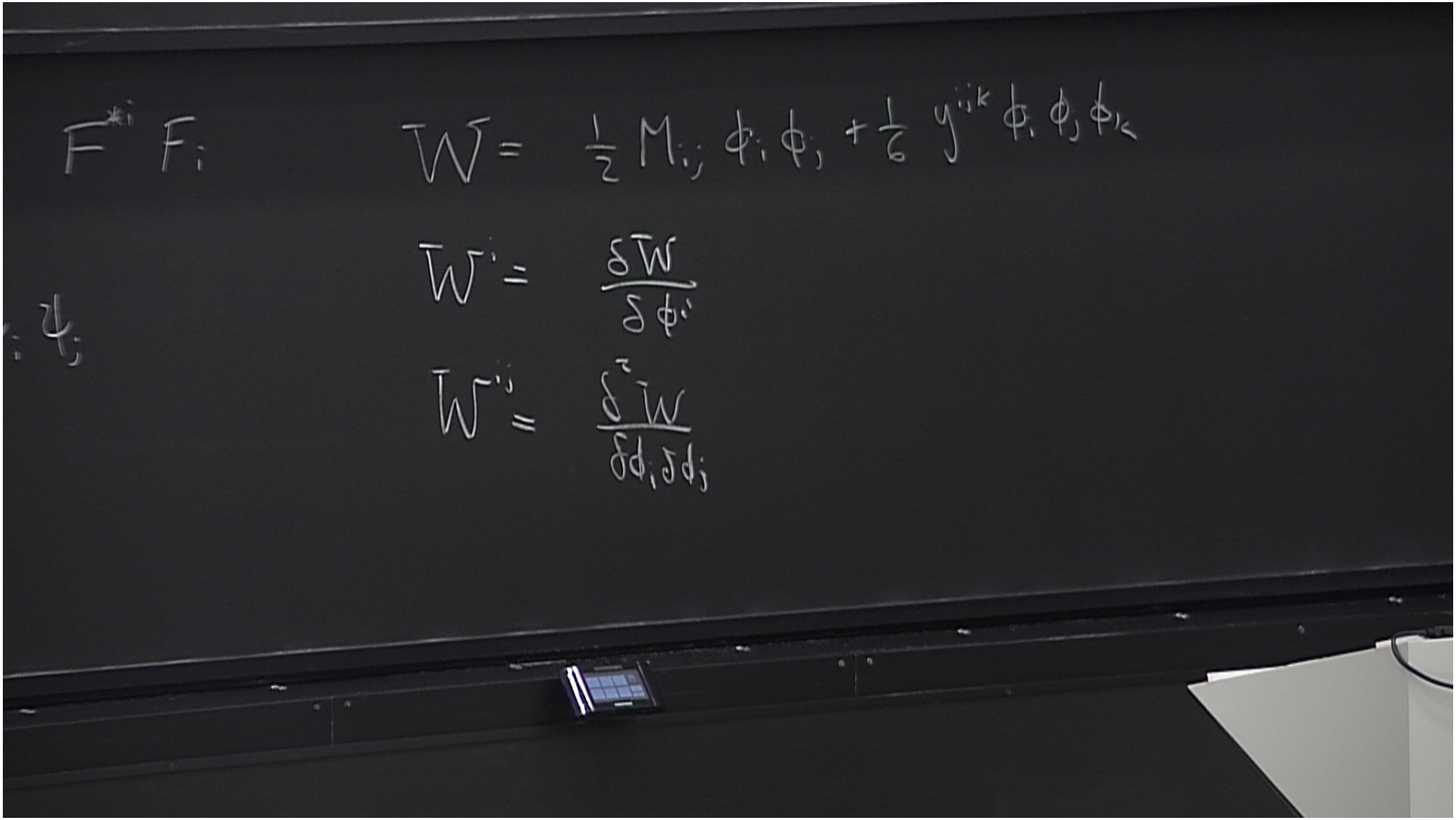
$$\mathcal{L}_{free} = |\partial_\mu \phi|^2 + i\bar{\psi}\bar{\sigma}\cdot\partial\psi + F^{*i}F_i$$

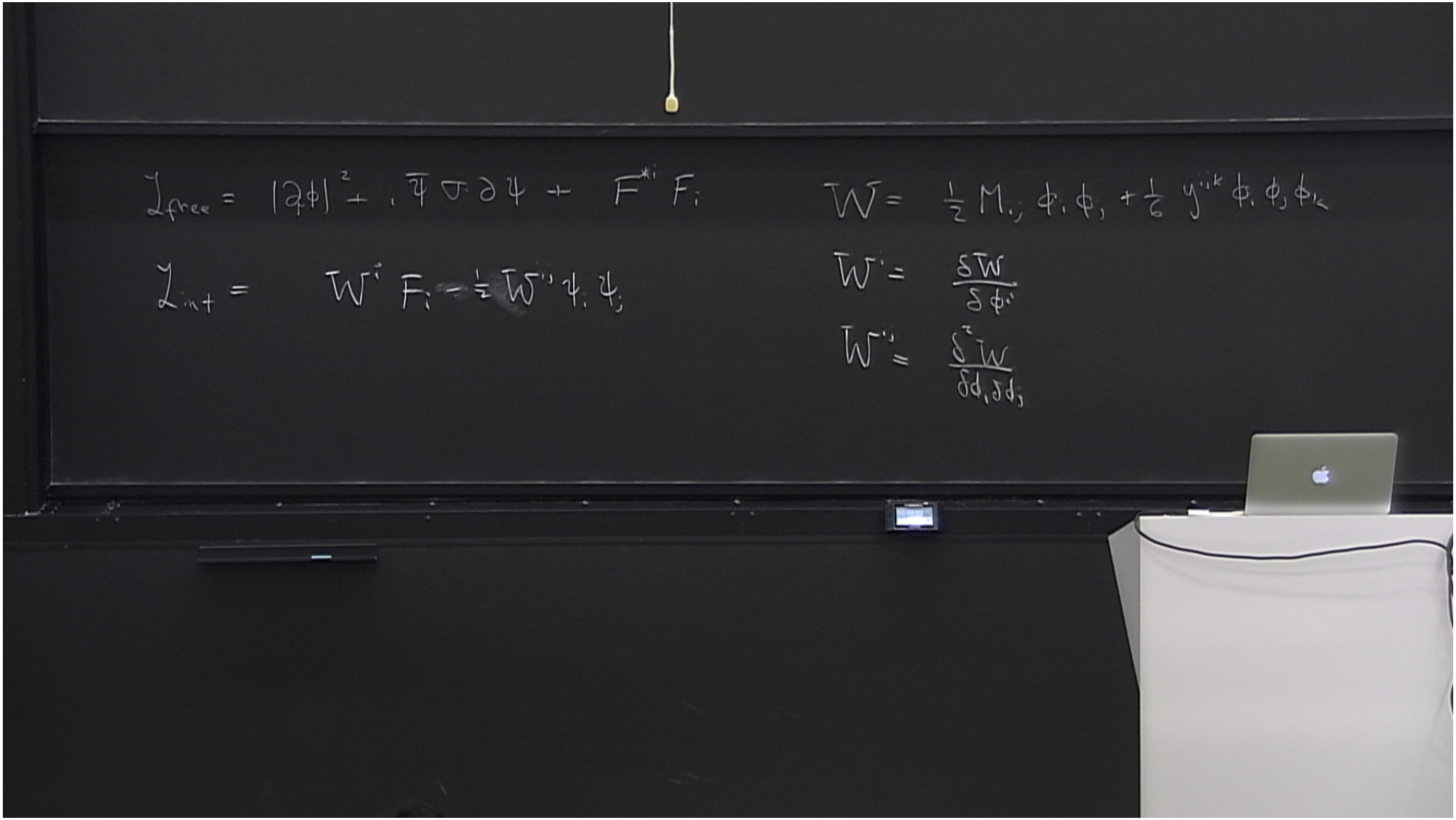
$$\mathcal{L}_{int} = W^i F_i - \tfrac{1}{2} W^{ij}\psi_i\psi_j$$

$$\mathcal{L}_{free} = |\partial_\mu \phi|^2 + i\bar{\psi}\sigma\cdot\partial\psi + F^{*i}F_i \qquad W = \frac{1}{2}M$$

$$\mathcal{L}_{int} = W^i F_i - \frac{1}{2}W^{ij}\psi_i\psi_j$$




$F^{*i} F_i$
$W = \frac{1}{2} M_{ij} \phi_i \phi_j + \frac{1}{6} y^{ijk} \phi_i \phi_j \phi_k$
$W^i = \frac{\delta W}{\delta \phi_i}$
$W^{ij} = \frac{\delta^2 W}{\delta \phi_i \delta \phi_j}$


$\mathcal{L}_{free} = |\partial\phi|^2 + \bar{\psi}\,\bar{\sigma}\cdot\partial\psi + F^{*i}F_i$
$\mathcal{L}_{int} = W^i F_i - \frac{1}{2}W^{ij}\psi_i\psi_j$
$W = \frac{1}{2}M_{ij}\phi_i\phi_j + \frac{1}{6}y^{ijk}\phi_i\phi_j\phi_k$
$W^i = \frac{\delta W}{\delta\phi_i}$
$W^{ij} = \frac{\delta^2 W}{\delta\phi_i\delta\phi_j}$