Title: Loop Quantum gravity #4

Date: Feb 14, 2008 06:30 PM

URL: http://pirsa.org/08020013

Abstract: Constrained systems, meaning of diffeomorphism invariance, loops and spin networks.

$$\{A_a^i(x), E^b_j(y)\} = \delta$$

$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j \, \delta^b_a \, \delta^{(3)}(\vec{x}-\vec{y})$$

$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j \, \delta^b_a \, \delta^{(3)}(\vec{x}-\vec{y})$$

$i = 1,2,3$

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$i = 1, 2, 3$

$$e^{\int A}$$

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$i = 1, 2, 3$

$$W_\gamma(A) = e^{\int_\gamma A}$$

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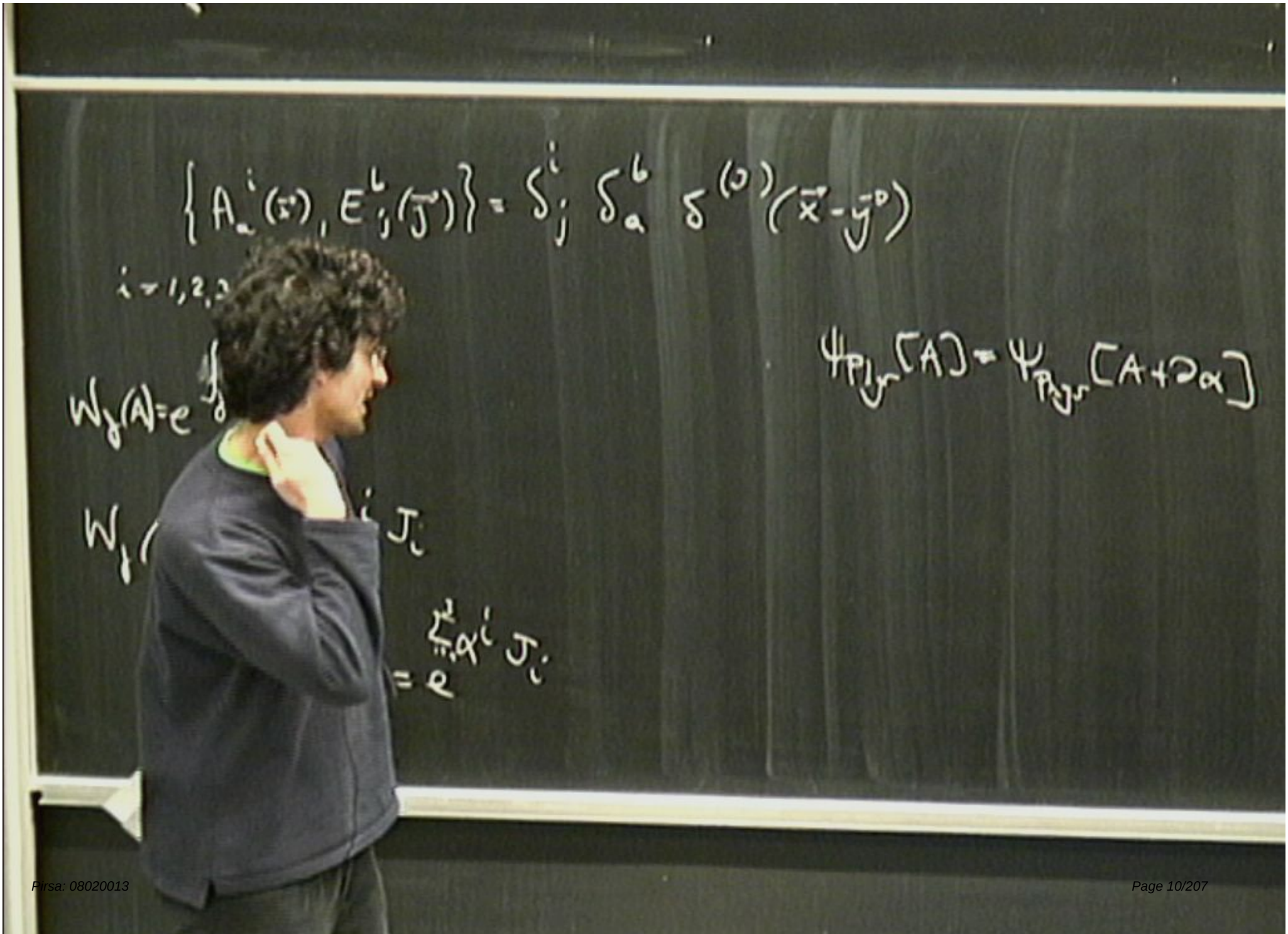
$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j \, \delta^b_a \, \delta^{(3)}(\vec{x}-\vec{y})$
$i = 1,2,3$
$\psi_{PJ}[A] = \psi_{PJ}[A + \partial\alpha]$
$W_\gamma(A) = e^{\int_\gamma}$
$W_\gamma($ i J_i
$= e^{\sum_{i=1}^{3} \alpha^i J_i}$

$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j \, \delta^b_a \, \delta^{(3)}(\vec{x}-\vec{y})$$

$i = 1,2,3$

$$W_\gamma(A) = e^{\oint_\gamma A}$$

$$\psi_{PI_{\mu\nu}}[A] = \psi_{PI_{\mu\nu}}[A + \partial\alpha]$$

$$W_\gamma(A) = e^{\int_\gamma A^i J_i}$$

$$SU(2) \ni g = e^{\sum_{i=1}^{3} \alpha^i J_i}$$

$$\begin{cases} \mathcal{H}(g_{ab}, \pi^{cd}) = 0 \\ \mathcal{H}^a(g_{ab}, \pi^{cd}) = 0 \end{cases}$$

$$\begin{cases} \mathcal{H}(g_{ab}, \pi^{cd}) = 0 \\ \mathcal{H}^a(g_{ab}, \pi^{cd}) = 0 \end{cases} \longrightarrow \begin{cases} \hat{\mathcal{H}}\,\psi = 0 \\ \hat{\mathcal{H}}^a\,\psi = 0 \end{cases}$$

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$$\mathcal{H}(A, E) = 0$$

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$i = 1,2,3$

$$W_\gamma(A) = e^{\oint_\gamma A}$$

$$\psi_{P_{\mu\nu}}[A] = \psi_{P_{\mu\nu}}[A + \partial\alpha]$$

$$W_\gamma(A) = e^{\int_\gamma A^i J_i}$$

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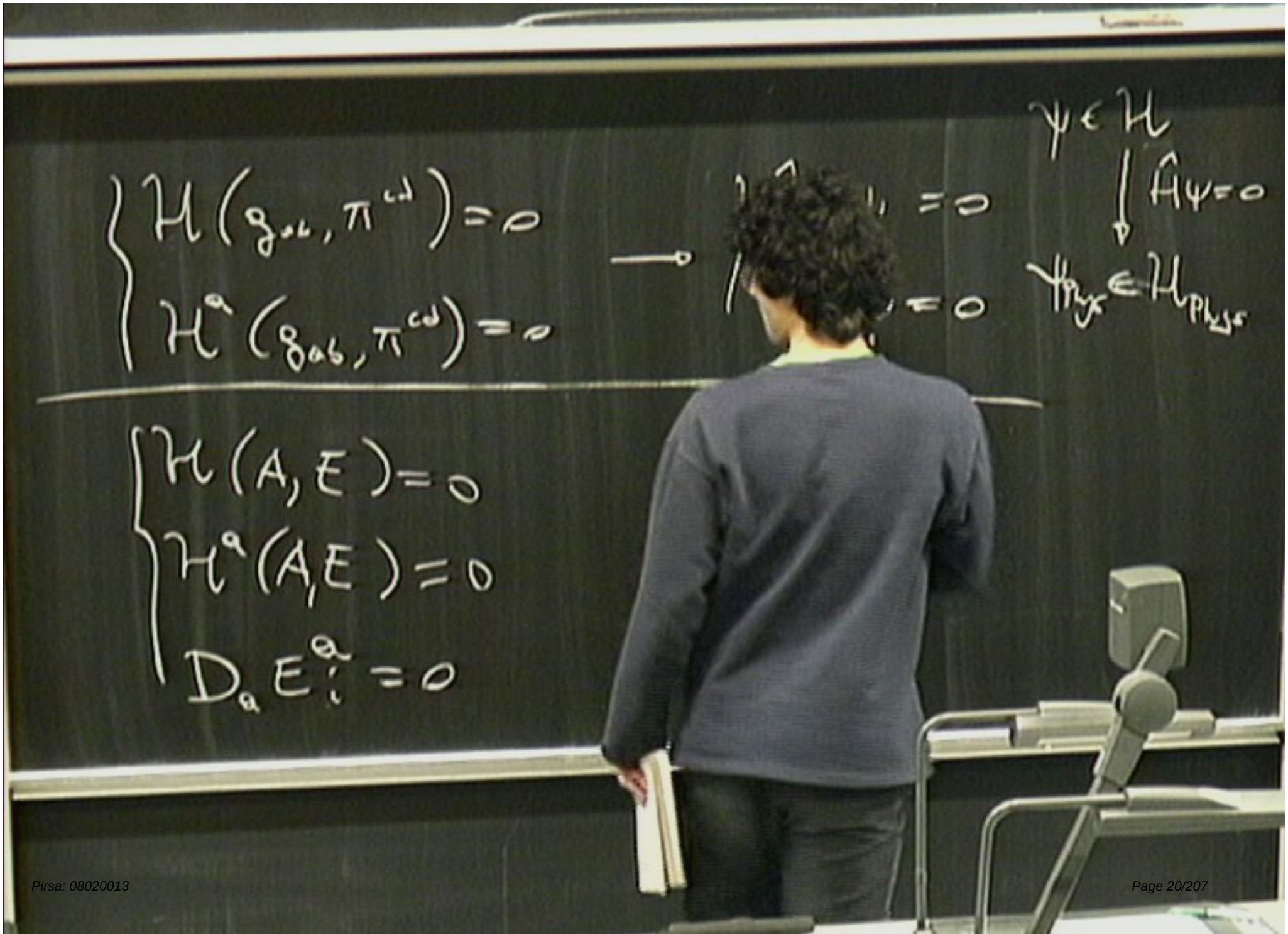

$\mathcal{H}(g_{ab}, \pi^{cd}) = 0$
$\mathcal{H}^a(g_{ab}, \pi^{cd}) = 0$
$\mathcal{H}(A, E) = 0$
$\mathcal{H}^a(A, E) = 0$
$D_a E^a_i = 0$
$\psi \in \mathcal{H}$
$\hat{H}\psi = 0$
$\psi_{phys} \in \mathcal{H}_{phys}$

$$\begin{cases} \mathcal{H}(g_{ab}, \pi^{cd}) = 0 \\ \mathcal{H}^a(g_{ab}, \pi^{cd}) = 0 \end{cases} \longrightarrow \begin{cases} \hat{\mathcal{H}}\psi = 0 \\ \hat{\mathcal{H}}^a\psi = 0 \end{cases}$$

$$\psi \in \mathcal{H} \xrightarrow{\hat{\mathcal{H}}\psi = 0} \psi_{phys} \in \mathcal{H}_{phys}$$

$$\begin{cases} \mathcal{H}(A, E) = 0 \\ \mathcal{H}^a(A, E) = 0 \\ D_a E^a_i = 0 \end{cases}$$

$$\begin{tikzcd} \mathcal{H} \arrow[r, "G_i = 0"] & \mathcal{H}_0 \\ \psi(A) \arrow[u, phantom, "\in"] & \end{tikzcd}$$

$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j \, \delta^b_a \, \delta^{(3)}(\vec{x}-\vec{y})$$

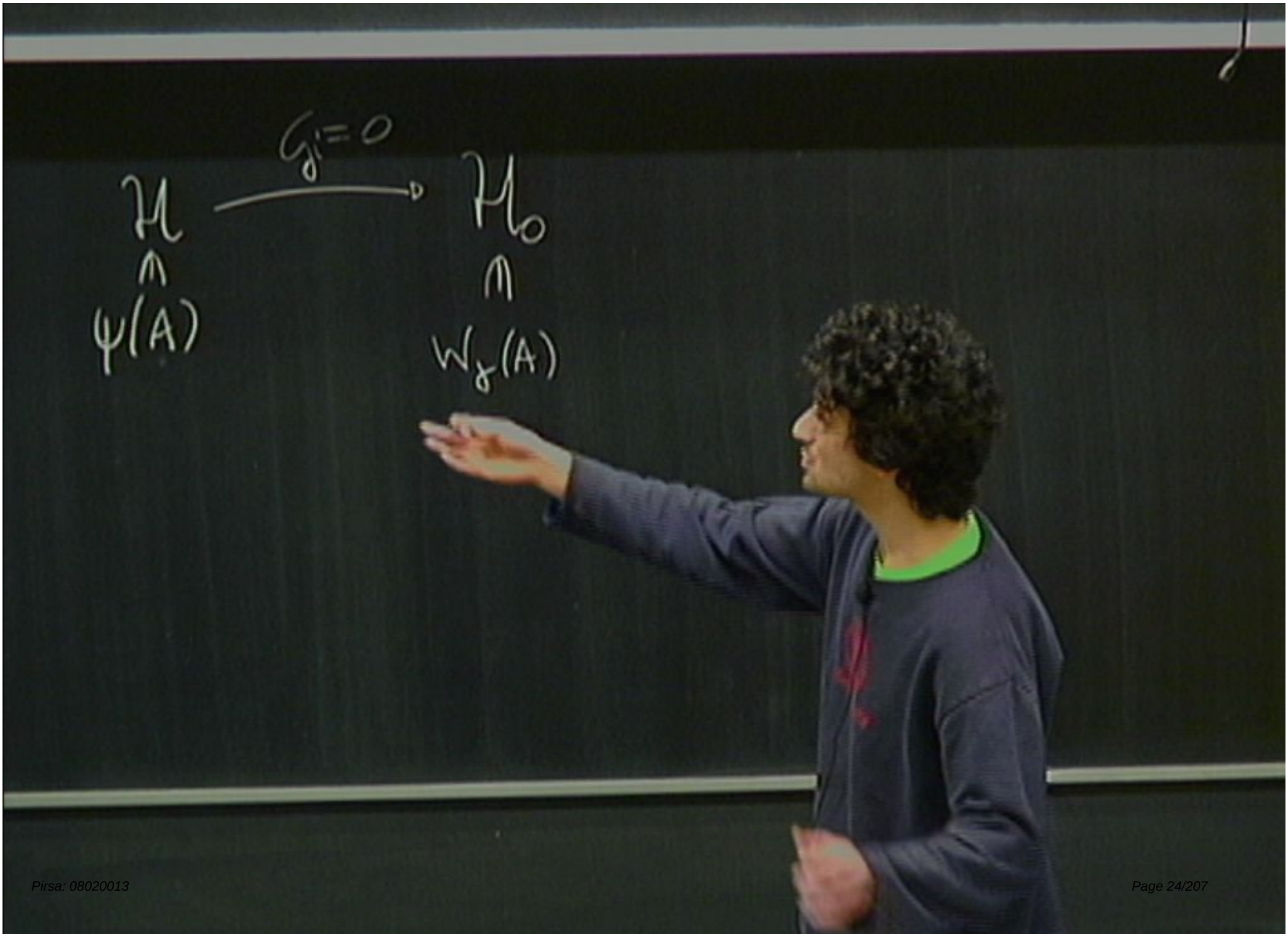
$i = 1,2,3$

$$W_\gamma(A) = e^{\oint_\gamma A}$$

$$\psi_{Phys}[A] = \psi_{Phys}[A + \partial\alpha]$$

$$W_\gamma(A) = e^{\int_\gamma A^i J_i} \longrightarrow \mathcal{H}_0 \ni W_\gamma[A] = \mathrm{Tr}\left(e^{\oint A^i J_i}\right)$$

$$SU(2) \ni g = e^{\xi^i \alpha^i J_i}$$


$G_i = 0$
$\mathcal{H} \longrightarrow \mathcal{H}_0$
$\cap \qquad\qquad \cap$
$\psi(A) \qquad W_\gamma(A)$

$$\begin{array}{ccccccc} \mathcal{H} & \xrightarrow{G_i=0} & \mathcal{H}_0 & \xrightarrow{\mathcal{H}^a=0} & \mathcal{H}_D & \xrightarrow{\mathcal{H}=0} & \mathcal{H}_{Phys.} \\ \cap & & \cap & & & & \\ \psi(A) & & W_\gamma(A) & & & & \end{array}$$

$$\begin{array}{ccccccc} \mathcal{H} & \xrightarrow{G_i=0} & \mathcal{H}_0 & \xrightarrow{\mathcal{H}^a=0} & \mathcal{H}_D & \xrightarrow{\mathcal{H}=0} & \mathcal{H}_{Phys.} \\ \cap & & \cap & & & & \\ \psi(A) & & W_\gamma(A) & & & & \end{array}$$

$$e^{\int_\gamma A^i J_i} =$$

$$V^{(1/2)} |\tfrac{1}{2}, m\rangle$$

$$d = 2j+1$$

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$$V^{(1/2)} |\tfrac{1}{2}, m\rangle$$

$d = 2j+1$ $\quad m = \uparrow, \downarrow$

$= +, -$

$= \tfrac{1}{2}, -\tfrac{1}{2}$

$$e^{\int_\gamma A^i J_i} = U_\gamma{}^A{}_B$$

$$V^{(1/2)} |\tfrac{1}{2}, m\rangle$$

$A = 1, 2$
$= -\tfrac{1}{2}, \tfrac{1}{2}$

$d = 2j+1$

$m = \uparrow, \downarrow$
$= +, -$
$= \tfrac{1}{2}, -\tfrac{1}{2}$

$$e^{\int_\gamma A^i J_i} = U_\gamma{}^A{}_B$$

$A = 1, 2$

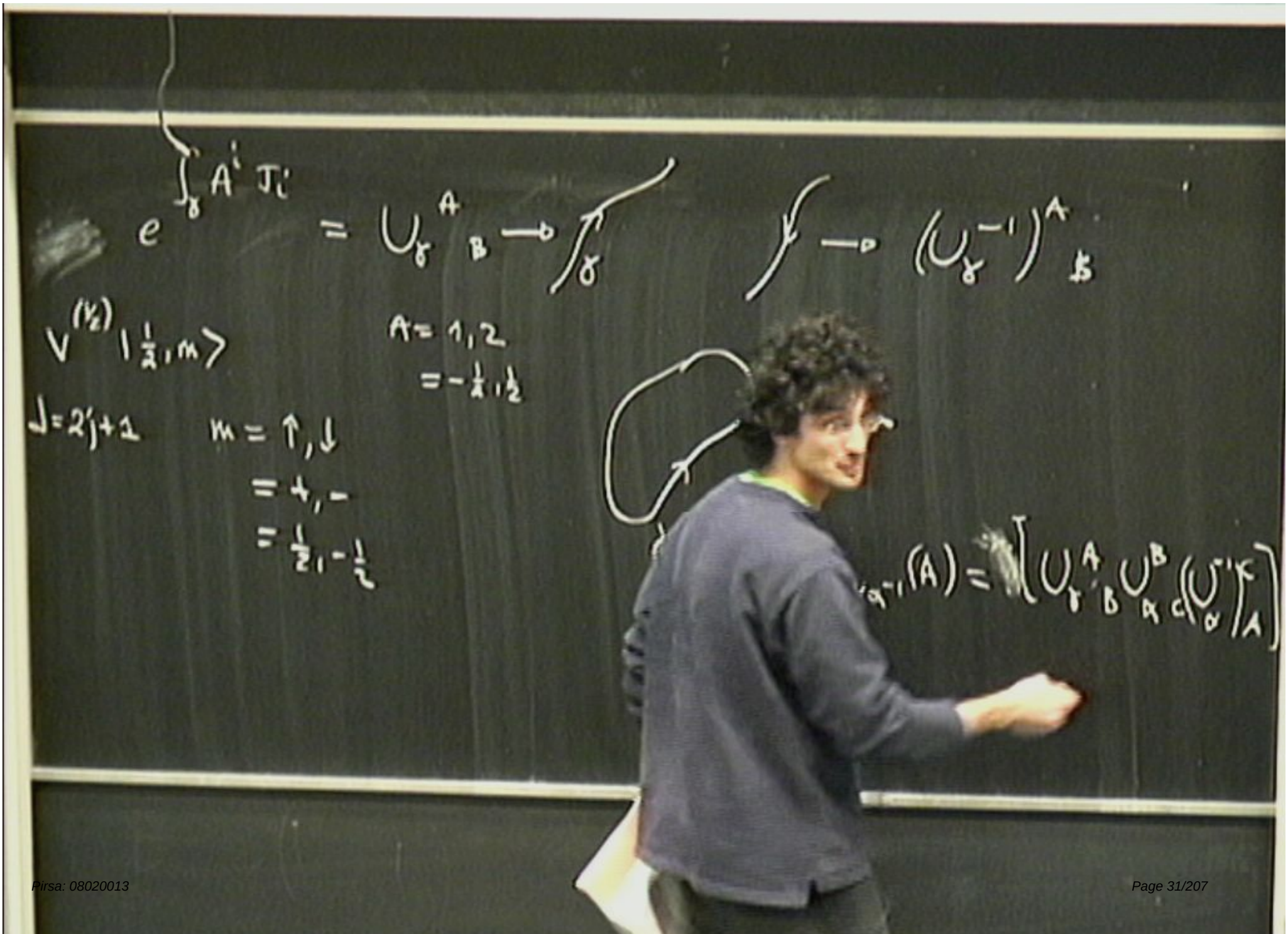
$= -\frac{1}{2}, \frac{1}{2}$

$V^{(1/2)} |\frac{1}{2}, m\rangle$

$2j+1$ $\quad m = \uparrow, \downarrow$

$= +, -$

$= \frac{1}{2}, -\frac{1}{2}$


$e^{\int_\gamma A^i J_i} = U_\gamma{}^A{}_B$
$V^{(1/2)} |\tfrac{1}{2}, m\rangle$
$A = 1, 2$
$= -\tfrac{1}{2}, \tfrac{1}{2}$
$J = 2j+1$
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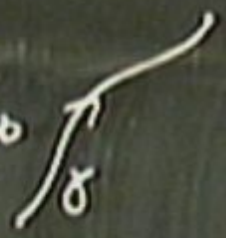
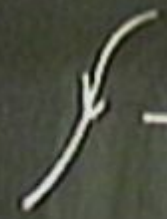
$$e^{\int_\gamma A^i J_i} = U_\gamma{}^A{}_B$$





$$\to (U_\gamma^{-1})^A{}_B$$

$V^{(1/2)} |\tfrac{1}{2}, m\rangle$

$A = 1, 2$

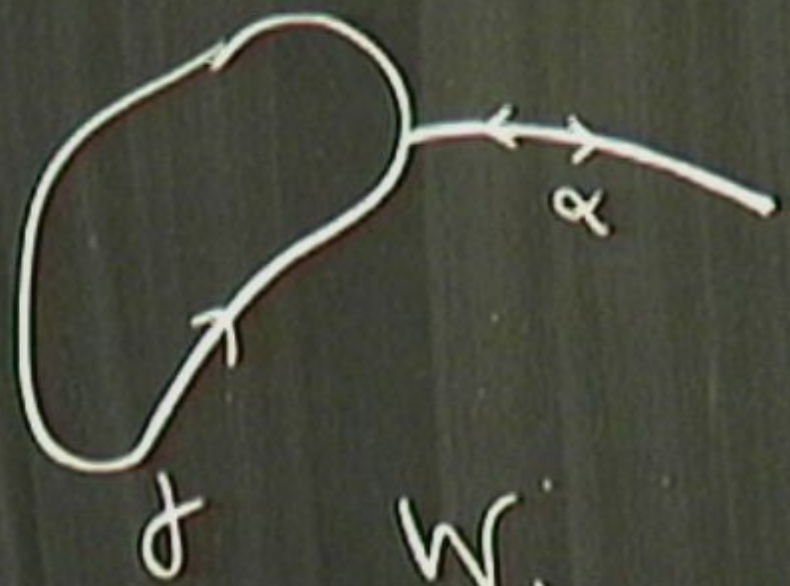
$J = 2j+1$

$m = \uparrow, \downarrow$

$= +, -$

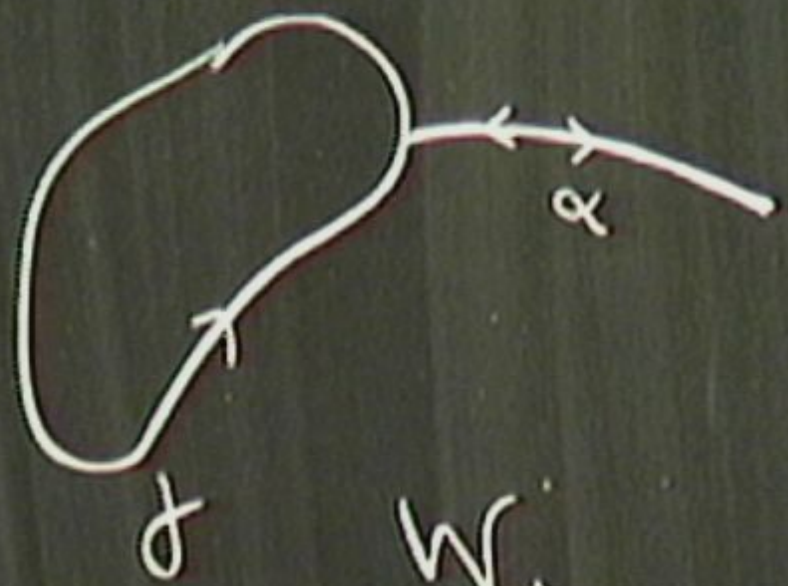
$= \tfrac{1}{2}$

$$W_{\gamma\cup\alpha\cup\alpha^{-1}}(A) = \mathrm{Tr}\left[U_\gamma{}^A{}_B\, U^B{}_\alpha{}_C\, (U_\alpha^{-1})^C{}_A\right]$$



$$W_{\gamma\cup\alpha\cup\alpha^{-1}}(A) = \left[U_{\gamma}{}^{A}{}_{B}\, U^{B}{}_{\alpha\, C} \left(U_{\alpha}^{-1}\right)^{C}{}_{A} \right]$$

$$= U_{\gamma}{}^{A}{}_{A} = W_{\gamma}(A)$$

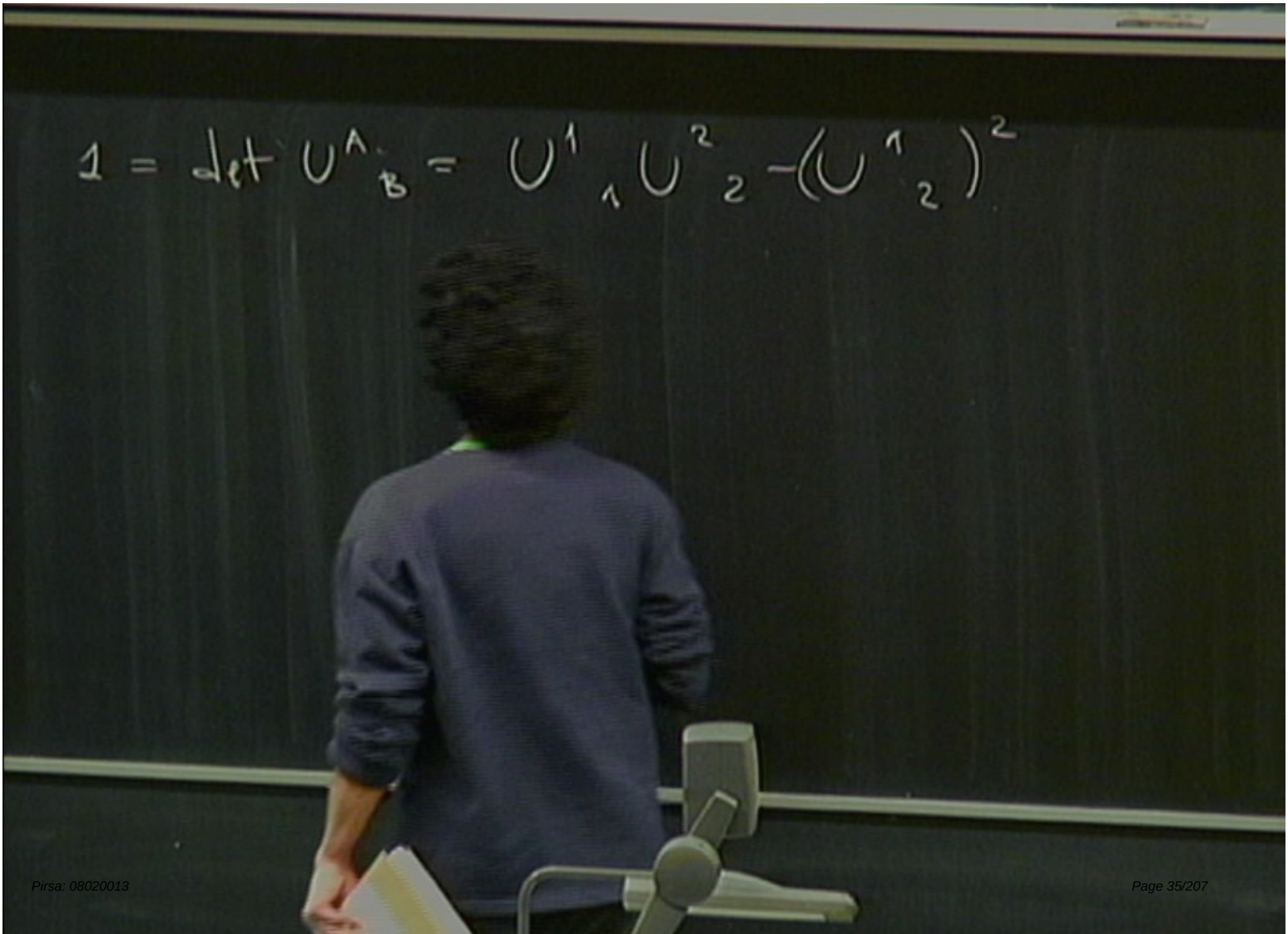


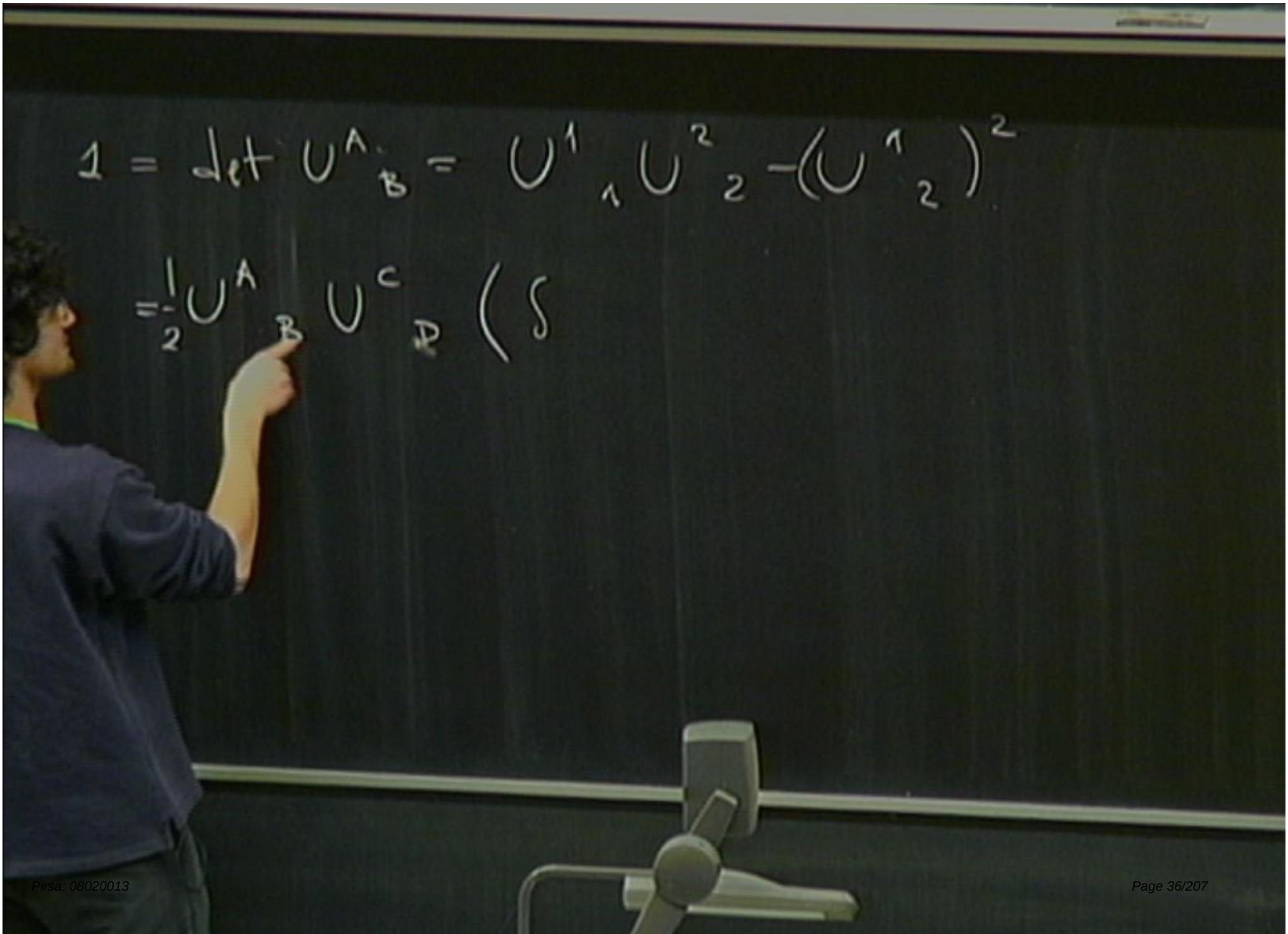
retracing

identity

$$W_{\gamma\cup\alpha\cup\alpha^{-1}}(A) = \left[U_\gamma{}^A{}_B\, U_\alpha{}^B{}_C \left(U_\alpha^{-1}\right)^C{}_A\right]$$

$$= U_\gamma{}^A{}_A = W_\gamma(A)$$


$1 = \det U^{A}{}_{B} = U^{1}{}_{1} U^{2}{}_{2} - (U^{1}{}_{2})^{2}$


1 = det U^A_B = U^1_1 U^2_2 - (U^1_2)^2
= 1/2 U^A_B U^C_D (S

$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

$$= \frac{1}{2} U^A{}_B U^C{}_D \left(\delta^B{}_A \delta^D{}_C - \delta_A{}^C \delta^D_B \right)$$

$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

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$$=$$

$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

$$= \frac{1}{2} U^A{}_B U^C{}_D \left(\delta^B{}_A \delta^D{}_C - \delta^C{}_A \delta^D{}_B \right)$$

$$= \frac{1}{2} \varepsilon$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

$$= \frac{1}{2} U^A{}_B U^C{}_D \left(\delta^B{}_A \delta^D{}_C - \delta_A{}^C \delta^D_B \right)$$

$$= \frac{1}{2} \varepsilon_{AC} \varepsilon^{BD} U^A{}_B U^C{}_D$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

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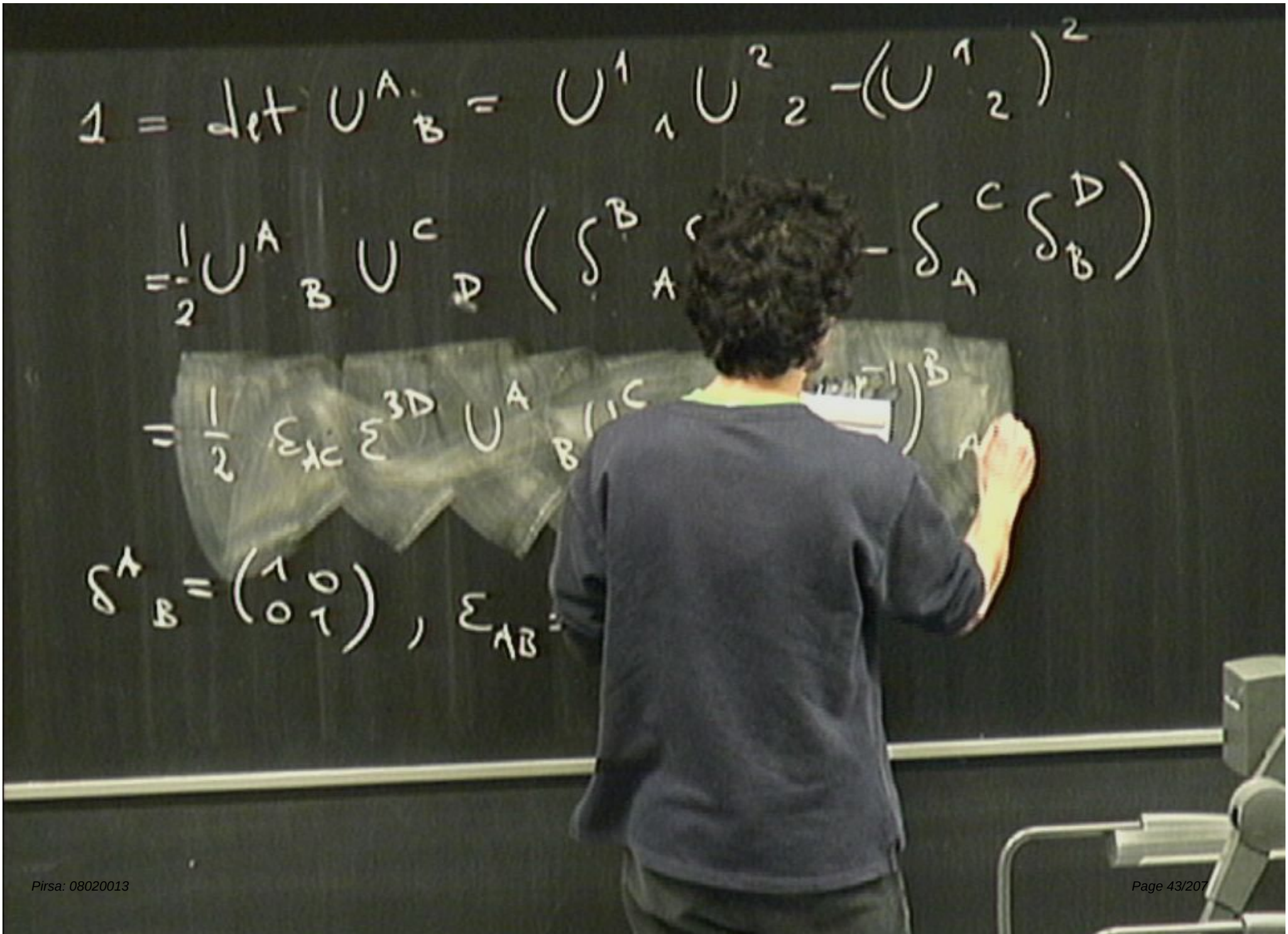
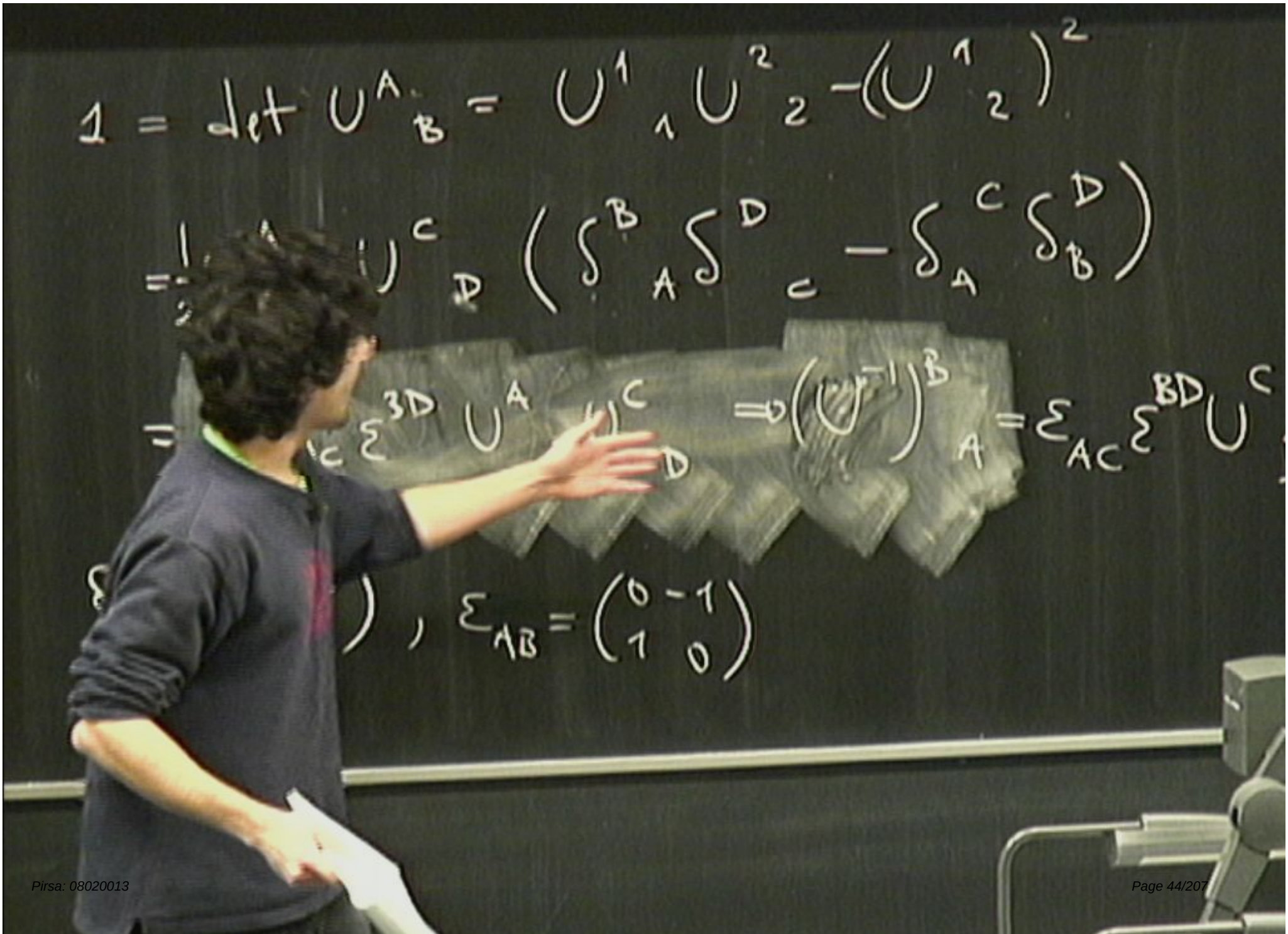
$$= \frac{1}{2} \varepsilon_{AC} \varepsilon^{BD} U^A{}_B U^C{}_D$$

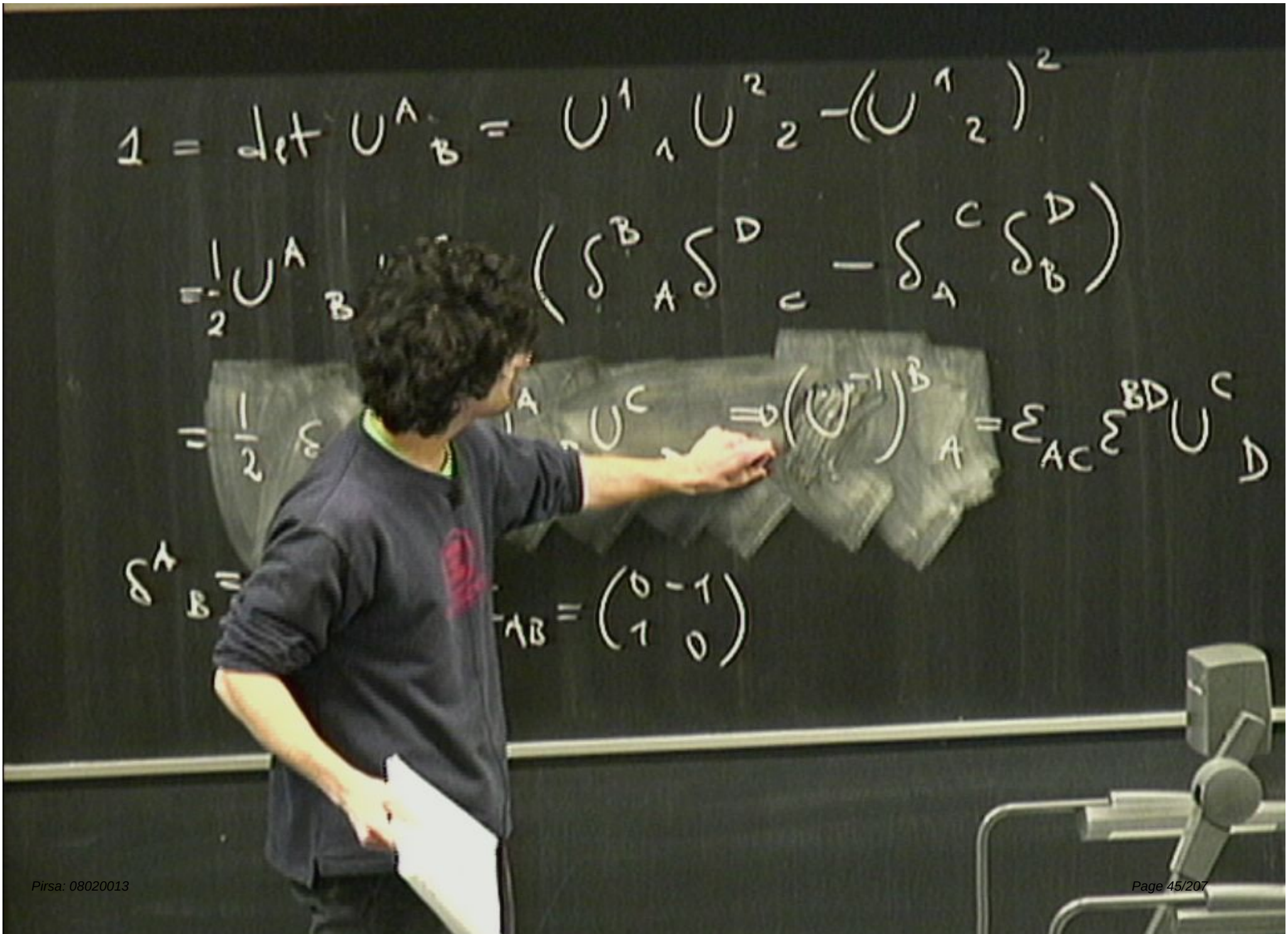
$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^C\,\delta_B{}^D$$

<u>spinorial identity</u>


$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$
$= \frac{1}{2} U^A{}_B U^C{}_D \left(\delta^B{}_A \delta^C{}_C - \delta_A{}^C \delta_B^D \right)$
$= \frac{1}{2} \varepsilon_{AC} \varepsilon^{BD} U^A{}_B$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $\varepsilon_{AB} =$


$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$
$= \frac{1}{2} \varepsilon^{AC} U^B{}_D \left(\delta^B{}_A \delta^D{}_C - \delta_A{}^C \delta^D_B \right)$
$= \varepsilon_{AC} \varepsilon^{BD} U^A{}_B U^C{}_D \Rightarrow (U^{-1})^B{}_A = \varepsilon_{AC} \varepsilon^{BD} U^C$
$\varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$


$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$
$= \frac{1}{2} U^A{}_B \left(\delta^B{}_A \delta^D{}_C - \delta_A{}^C \delta^D_B \right)$
$= \frac{1}{2} \varepsilon$ U^A U^C $= (U^{-1})^B{}_A = \varepsilon_{AC} \varepsilon^{BD} U^C{}_D$
$\delta^A{}_B =$
$AB = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$

$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

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$$= \frac{1}{2} \varepsilon_{AC} \varepsilon^{BD} U^A{}_B U^C{}_D \Rightarrow \left(U^{-1}\right)^B{}_A = \varepsilon_{AC} \varepsilon^{BD} U^C{}_D$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

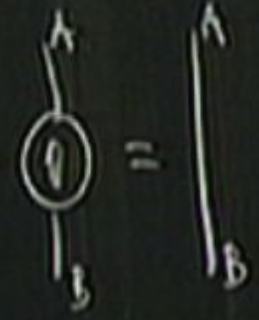
$$\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^C\,\delta_B{}^D$$

<u>spinorial identity</u>

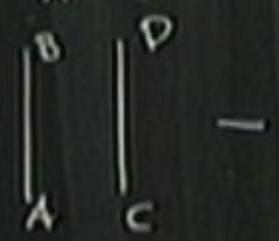
$$\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^C\,\delta_B{}^D$$

<u>spinorial identity</u>

$U^A{}_B \longrightarrow$

; $\delta^A{}_B \longrightarrow$ 

$$\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^C\,\delta_B{}^D$$



<u>spinorial identity</u>

$U^A{}_B \longrightarrow$

; $\delta^A{}_B \longrightarrow$

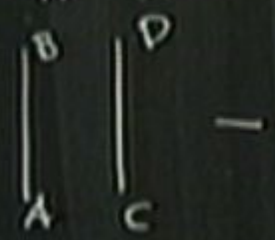
$$1 = \det U^A{}_B = U^1{}_1 U^2{}_2 - (U^1{}_2)^2$$

$$= \frac{1}{2} U^A{}_B U^C{}_D \left(\delta^B{}_A \delta^D{}_C - \delta^D{}_A \delta^B{}_C \right)$$

$$= \frac{1}{2} \varepsilon_{AC} \varepsilon^{BD} U^A{}_B U^C{}_D \Rightarrow (U^{-1})^B{}_A = \varepsilon_{AC} \varepsilon^{BD} U^C{}_D$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

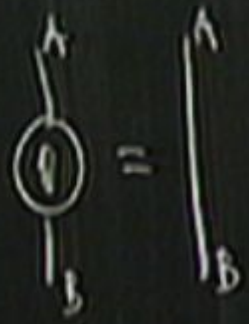
$$\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^D\,\delta_C{}^B$$



spinorial identity

$U^A{}_B \longrightarrow$

; $\delta^A{}_B \longrightarrow$



$$\boxed{\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^D\,\delta_C{}^B}$$

spinorial identity

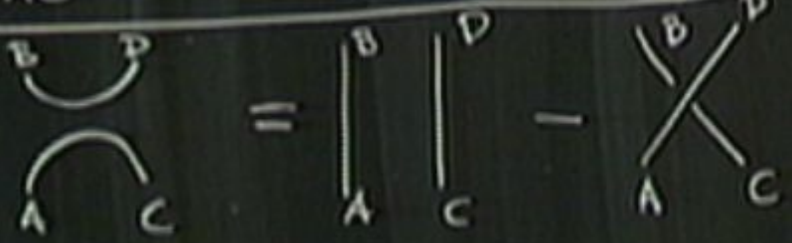
$U^A{}_B \longrightarrow$

; $\delta^A{}_B \longrightarrow$

=

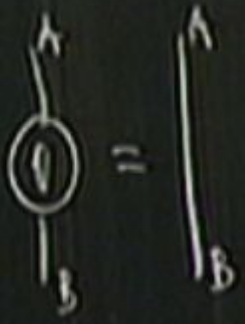
$$\boxed{\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^D\,\delta_C{}^B}$$

spinorial identity

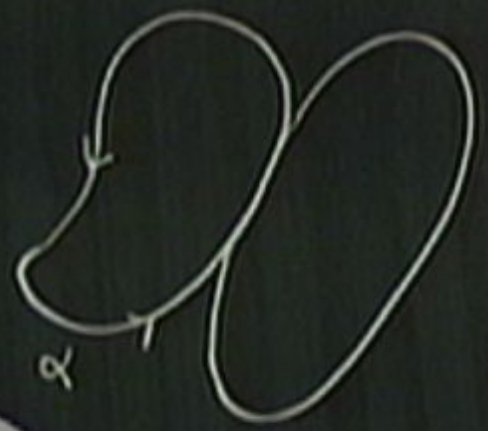


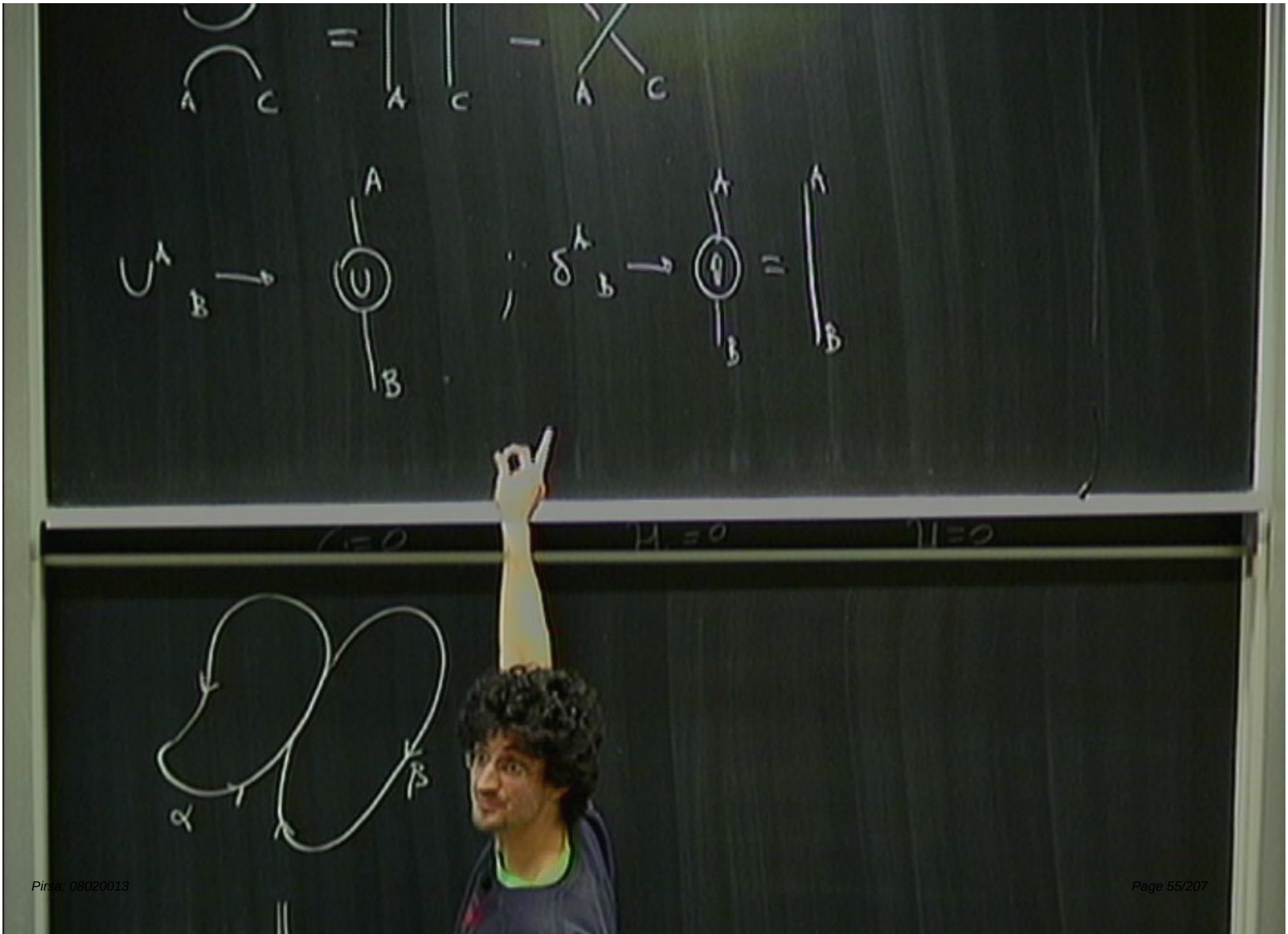
$U^A{}_B \longrightarrow$

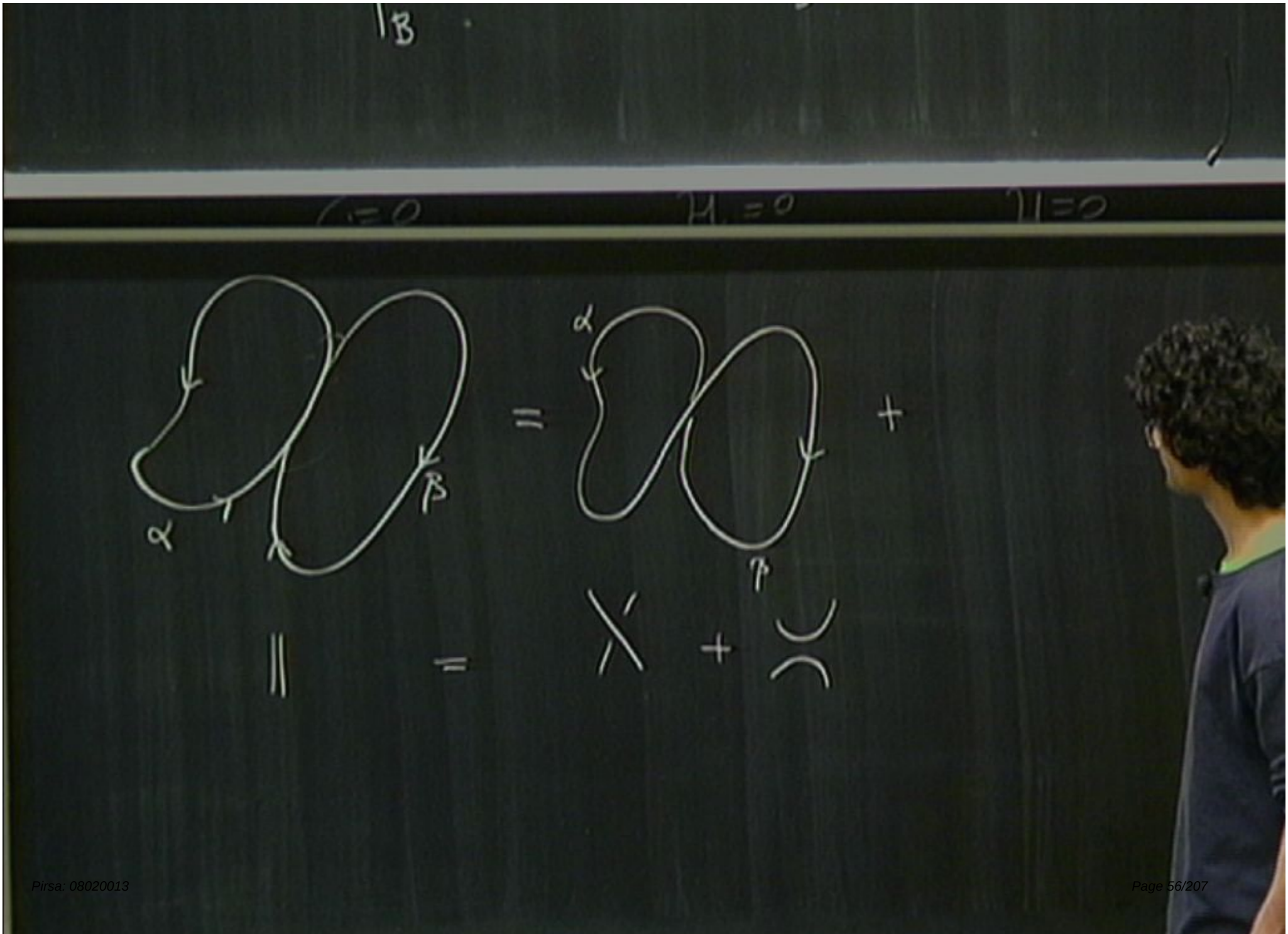
; $\delta^A{}_B \longrightarrow$

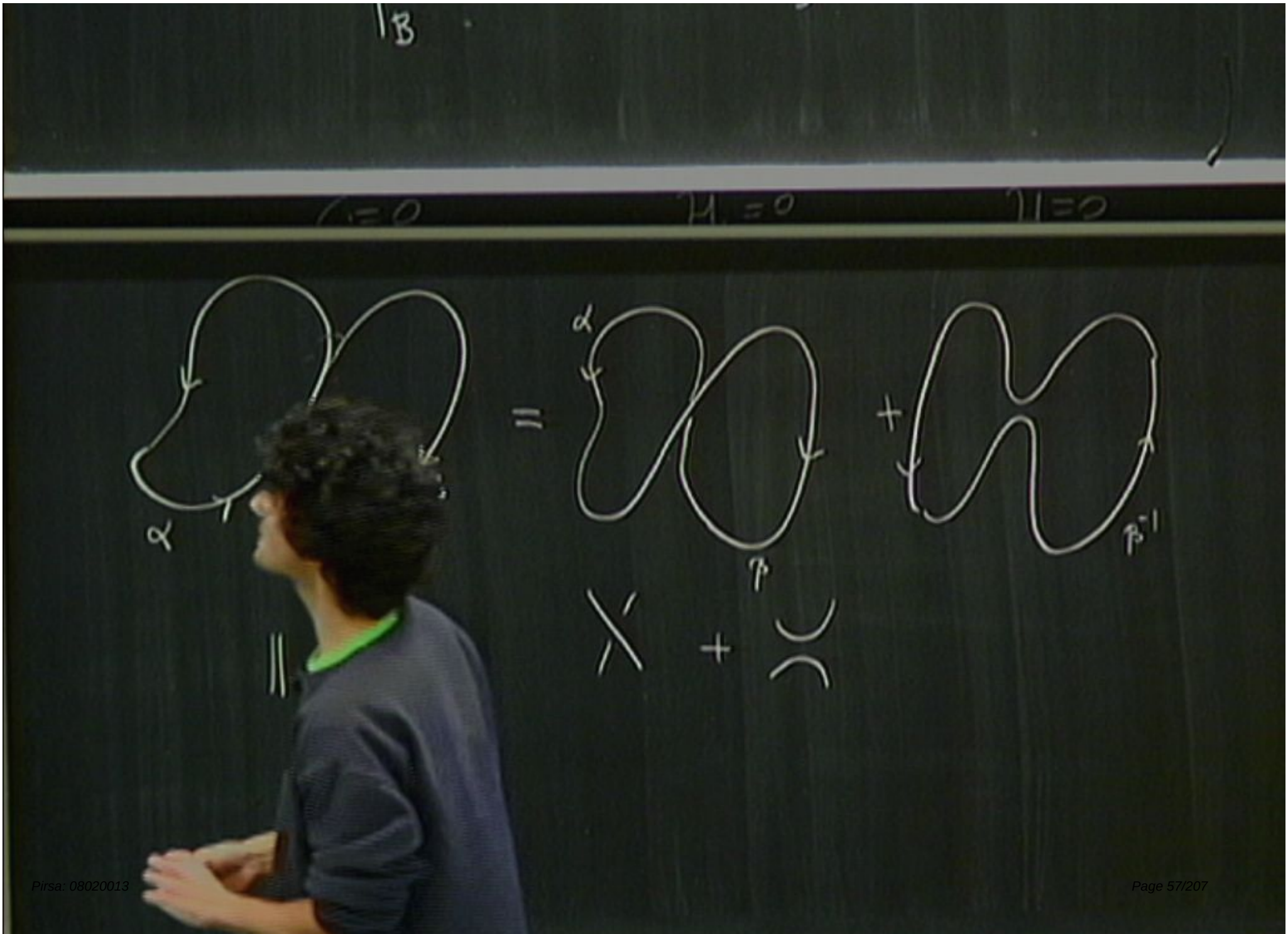


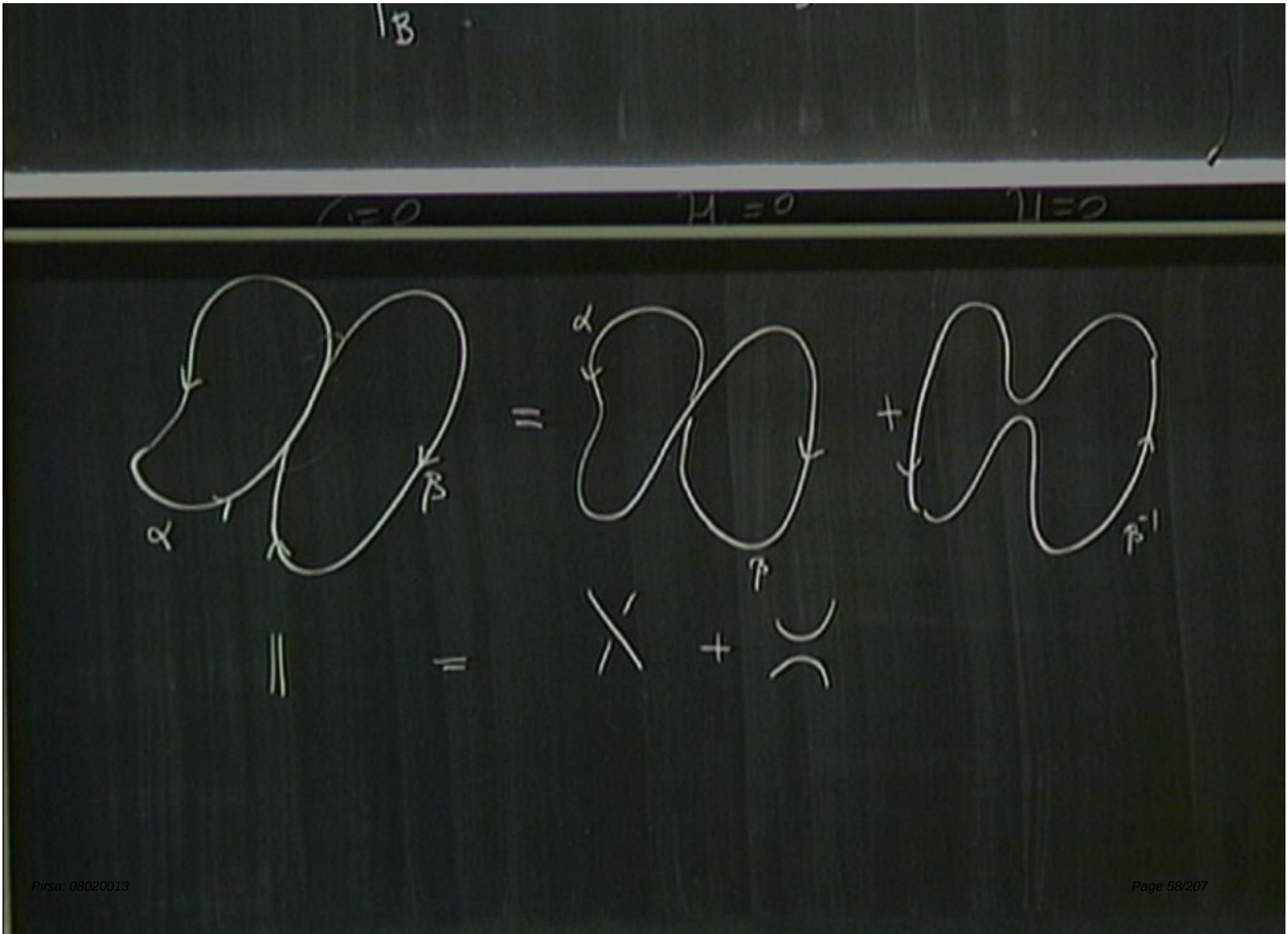
$C=0$ $\qquad$ $\mu^a=0$ $\qquad$ $\eta=0$

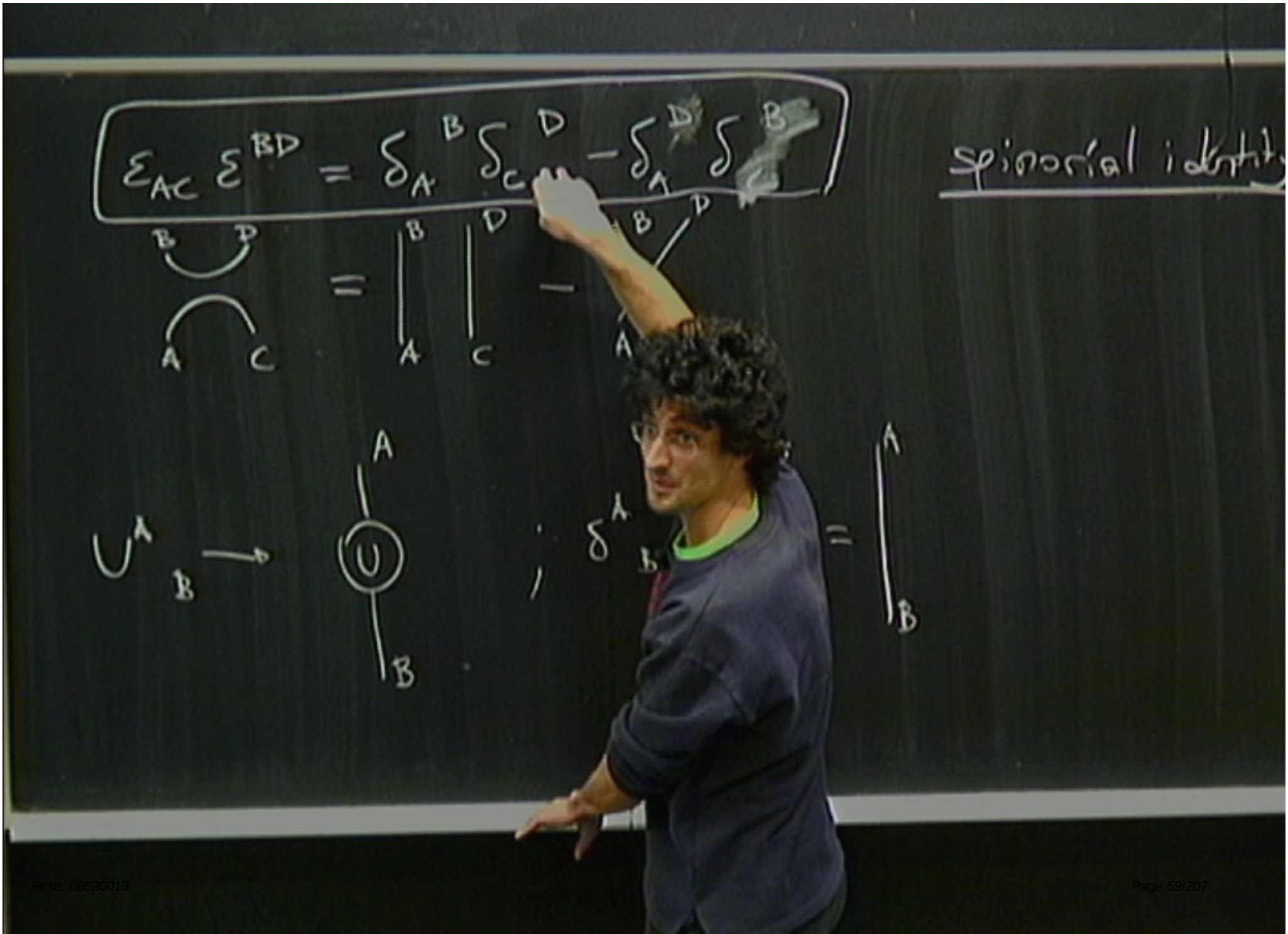


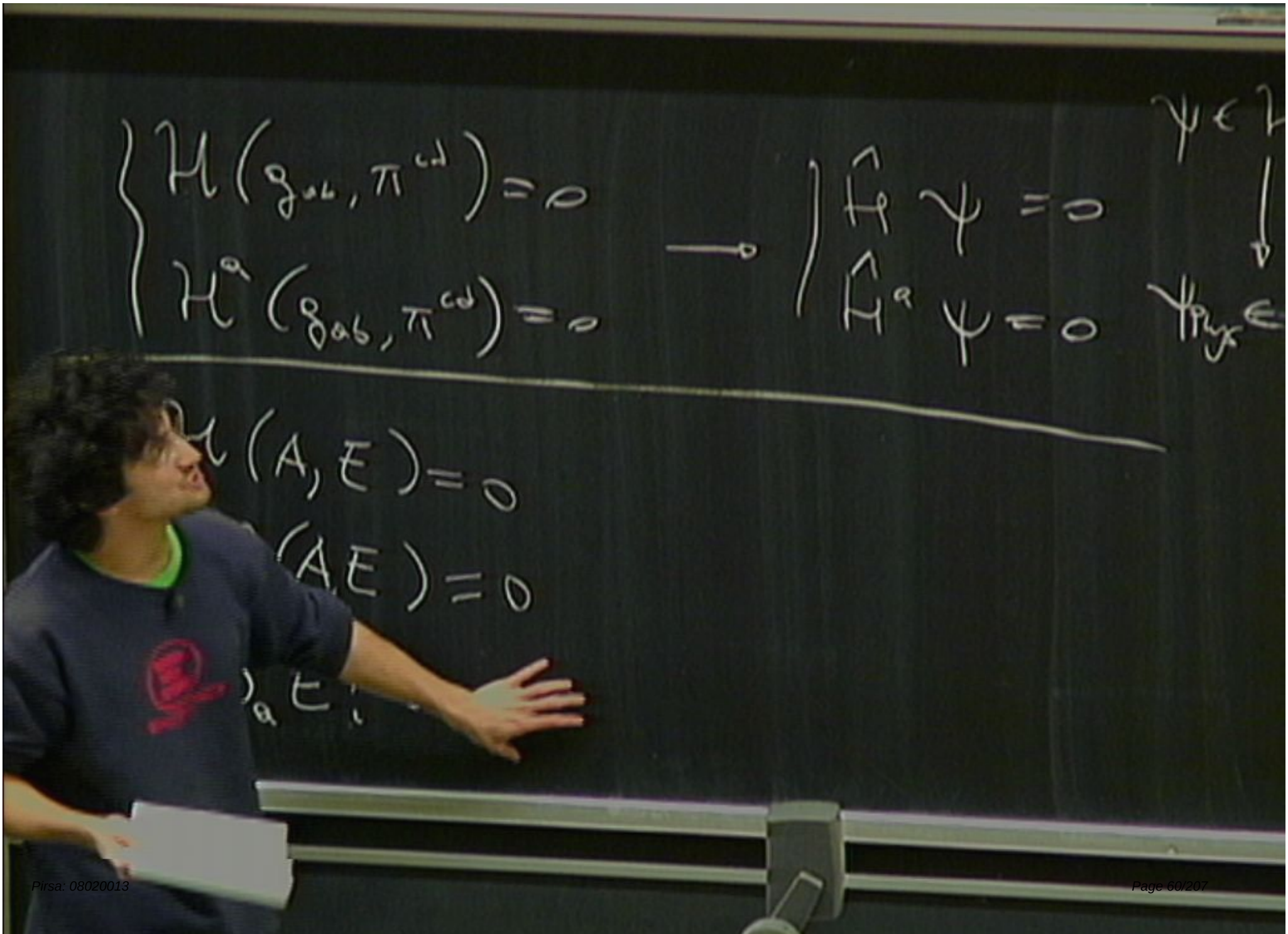

A C
= A C − A C
$U^A{}_B \to$ A U B ; $\delta^A{}_B \to$ A B = A B
α
β


B
α
β
α
β
+


B
α
α
β
β⁻¹


α
β
$=$
α
β
$+$
β^{-1}
$=$
$+$


$\varepsilon_{AC}\,\varepsilon^{BD} = \delta_A{}^B\,\delta_C{}^D - \delta_A{}^D\,\delta_C{}^B$
spinorial identity
$U^A{}_B$
$\delta^A{}_B$


$\mathcal{H}(g_{ab}, \pi^{cd}) = 0$
$\mathcal{H}^a(g_{ab}, \pi^{cd}) = 0$
$\hat{\mathcal{H}}\psi = 0$
$\hat{\mathcal{H}}^a\psi = 0$
$\mathcal{H}(A, E) = 0$
$(A, E) = 0$

$$\begin{cases} \mathcal{H}(g_{ab}, \pi^{cd}) = 0 \\ \mathcal{H}^a(g_{ab}, \pi^{cd}) = 0 \end{cases} \longrightarrow \begin{cases} \hat{\mathcal{H}}\psi = 0 \\ \hat{\mathcal{H}}^a\psi = 0 \end{cases}$$

$\psi \in \mathcal{H}$

$\psi_{phys} \in$

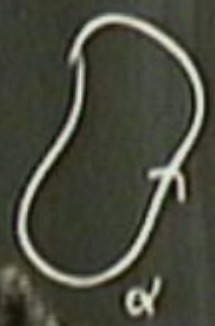
$$\begin{cases} \mathcal{H}(A, E) = 0 \\ \mathcal{H}^a(A, E) = 0 \\ D_a E^a_i = 0 \end{cases}$$

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$

$$W_\gamma(A) = \mathrm{Tr}\, e^{\oint_\alpha A}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A}$$

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$



$$W_\gamma(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

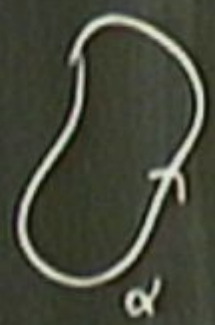
$$\mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}}$$

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$

$$W(\alpha)(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

$$W \quad e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(e^{\oint_\alpha A}\right)\right)$$

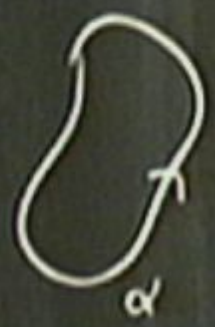
$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$



$$W_\alpha(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

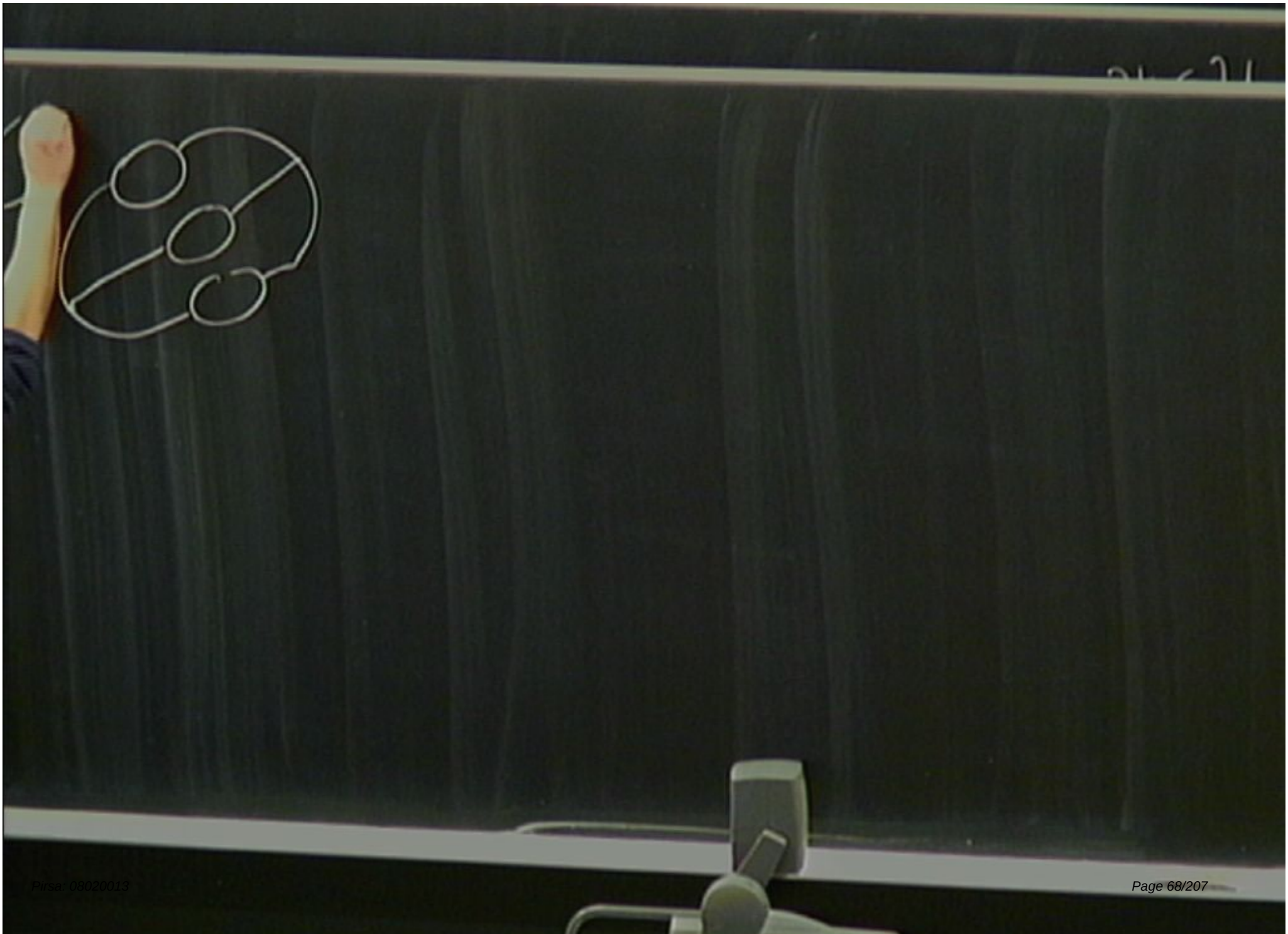
$$W_{\alpha(j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(e^{\oint_\alpha A}\right)\right)$$

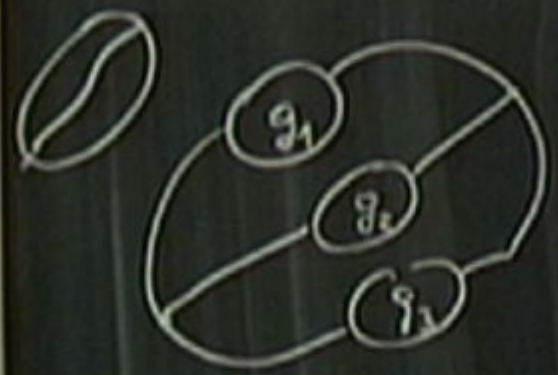
$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$

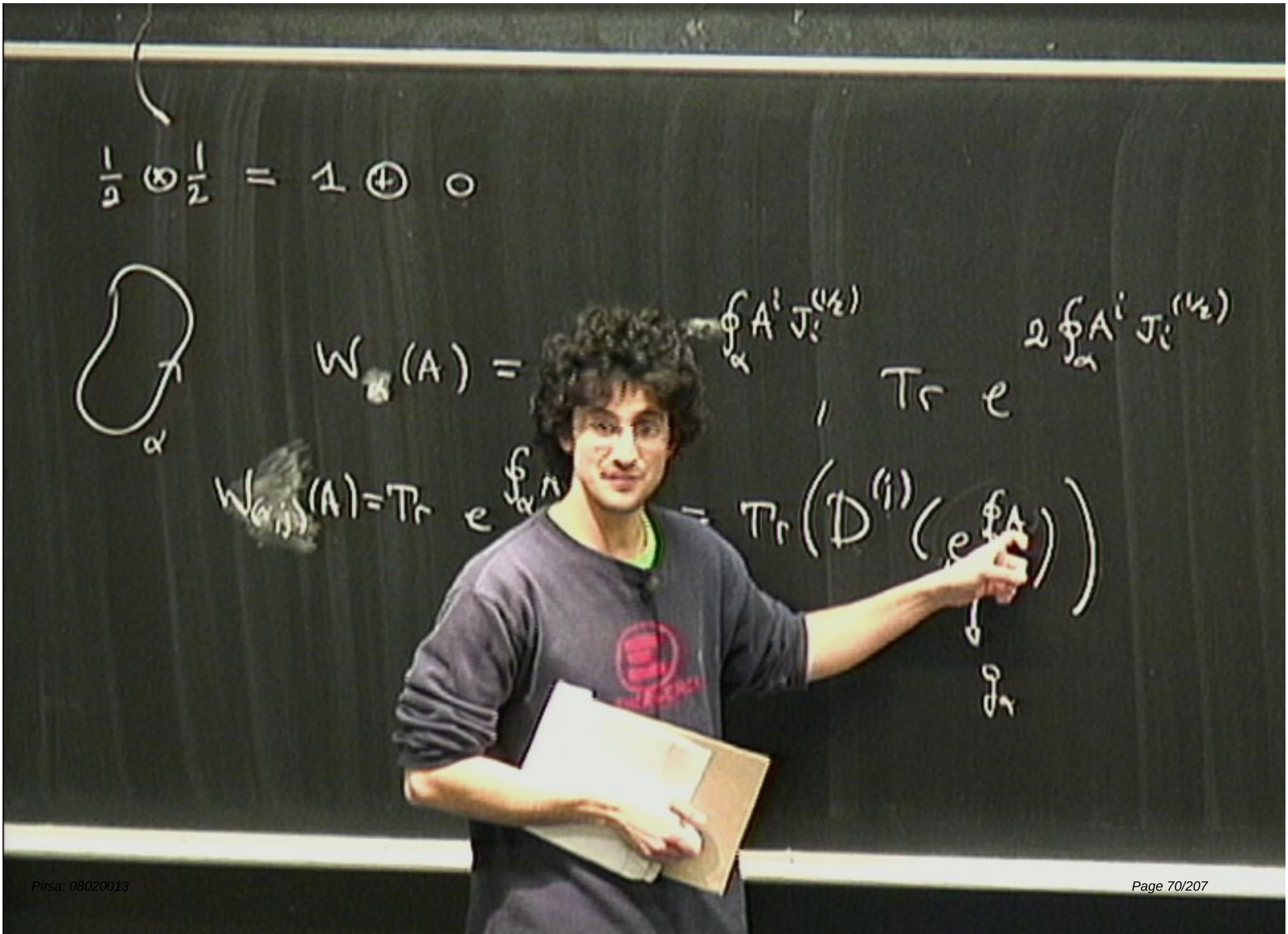


$$W_\alpha(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}} \,, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

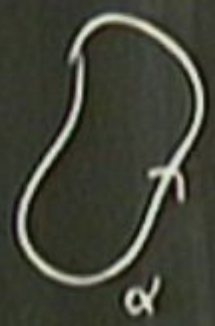
$$W_{\alpha(j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(\underbrace{e^{\oint_\alpha A}}_{g_\alpha}\right)\right)$$




g_1
g_2
g_3


$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$
α
$W_\alpha(A) = \quad , \ \mathrm{Tr}\, e^{2 \oint_\alpha A^i J_i^{(1/2)}}$
$W_{\alpha(j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A} = \mathrm{Tr}\left(D^{(j)}(e^{\oint A})\right)$
g_α

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$



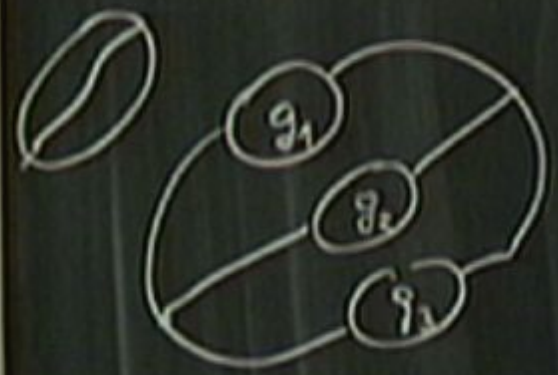
$$W_\alpha(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

$$W_{\alpha(j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(\underbrace{e^{\oint_\alpha A}}_{g_\alpha}\right)\right)$$

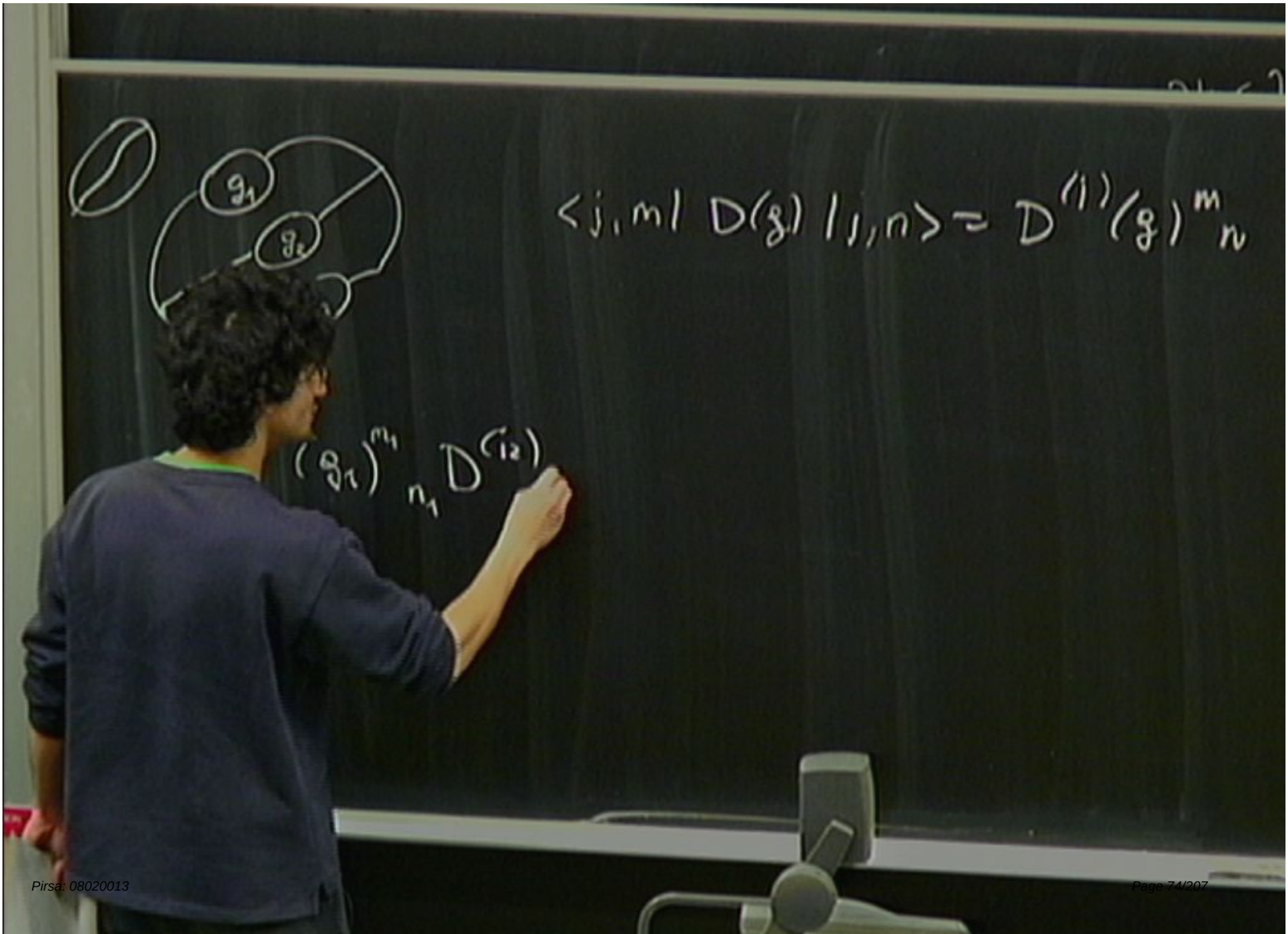
$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$

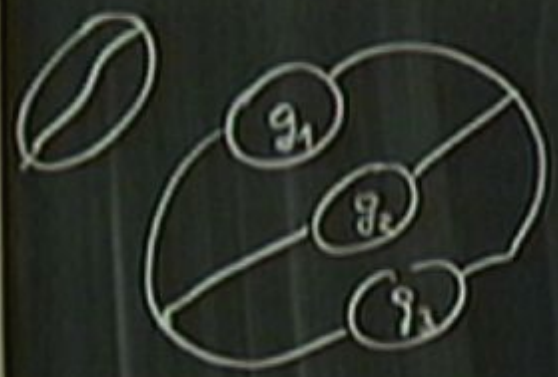
$$W_\alpha(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

$$W_{\alpha(j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(\underbrace{e^{\oint_\alpha A}}_{g_\alpha}\right)\right)$$



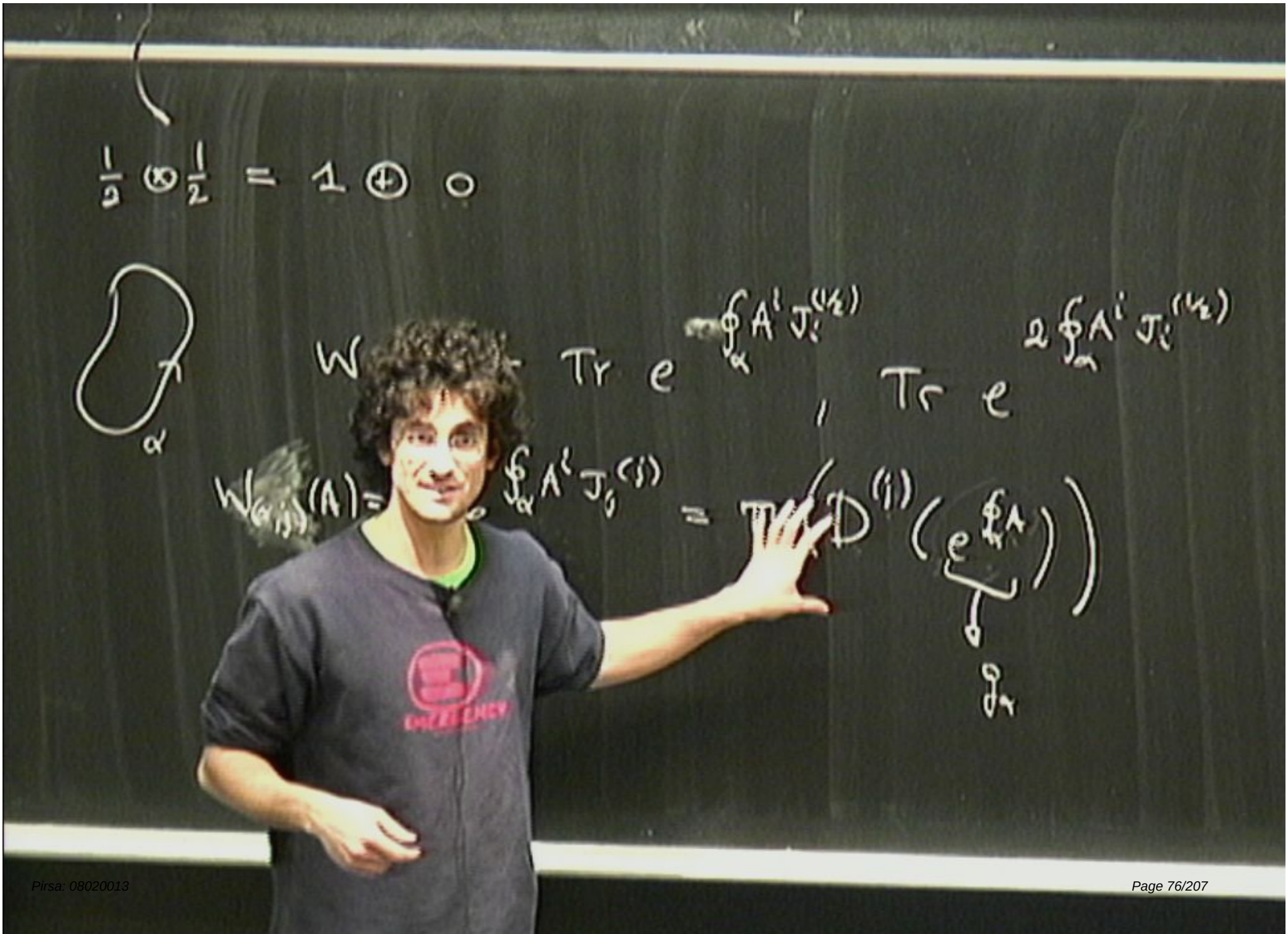
$D^{(n)}$


g_1
g_2
$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^m{}_n$
$(g_1)^{m_1}{}_{n_1} D^{(j_2)}$

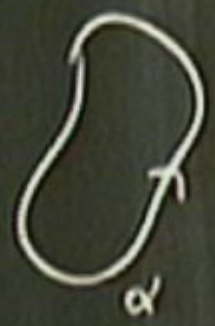


$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

$$D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3}$$

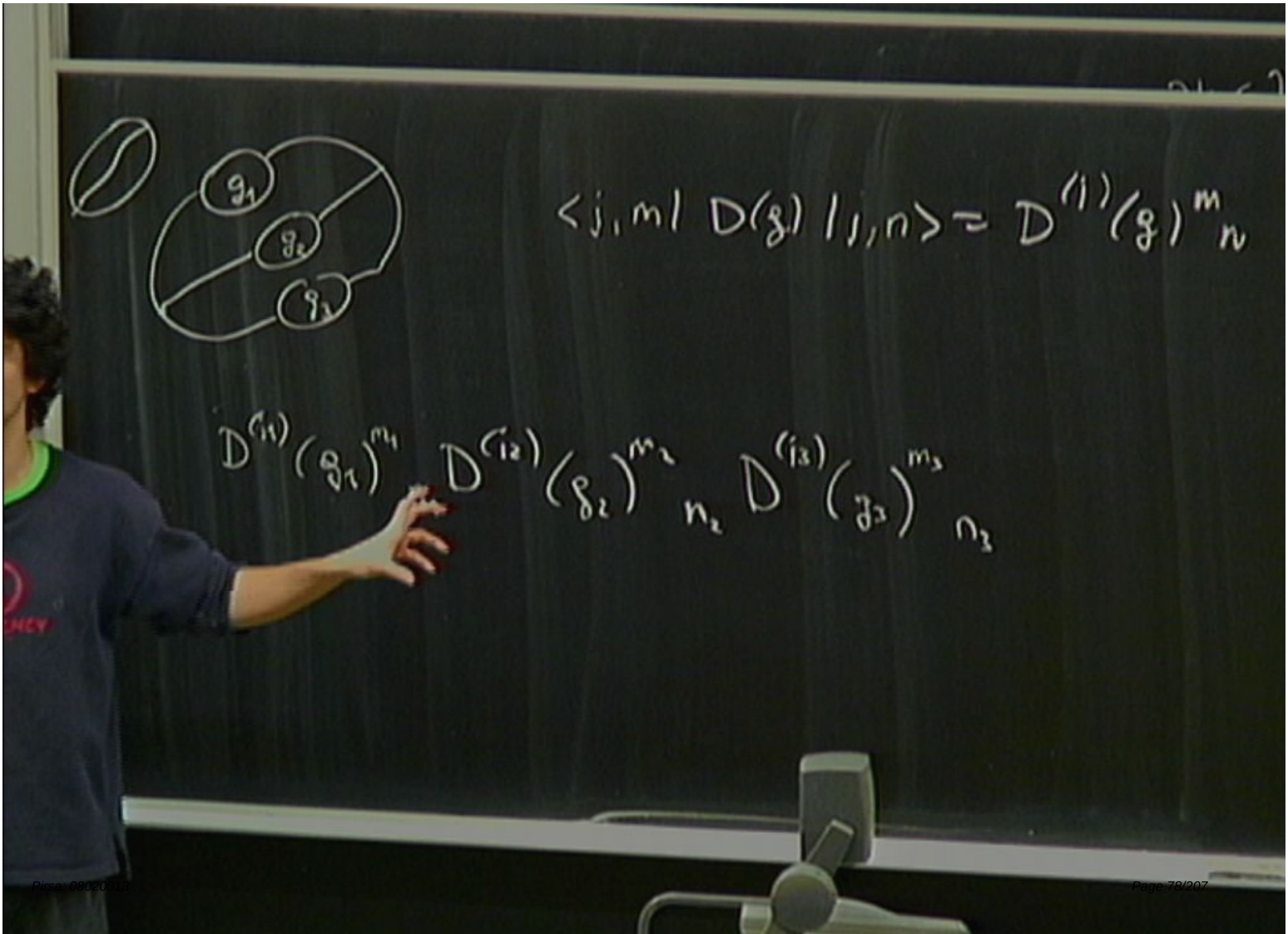

$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$
α
$W = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2 \oint_\alpha A^i J_i^{(1/2)}}$
$W_{(j)}(A) = e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(e^{\oint A}\right)\right)$
g_α

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$



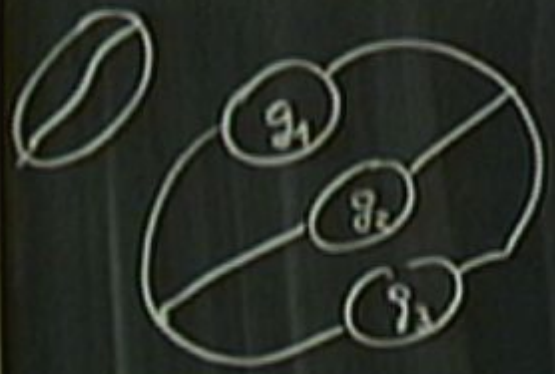
$$W_\alpha(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

$$W_{\alpha(j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(\underbrace{e^{\oint_\alpha A}}_{g_\alpha}\right)\right)$$


g_1
g_2
g_3
$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^m{}_n$
$D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3}$

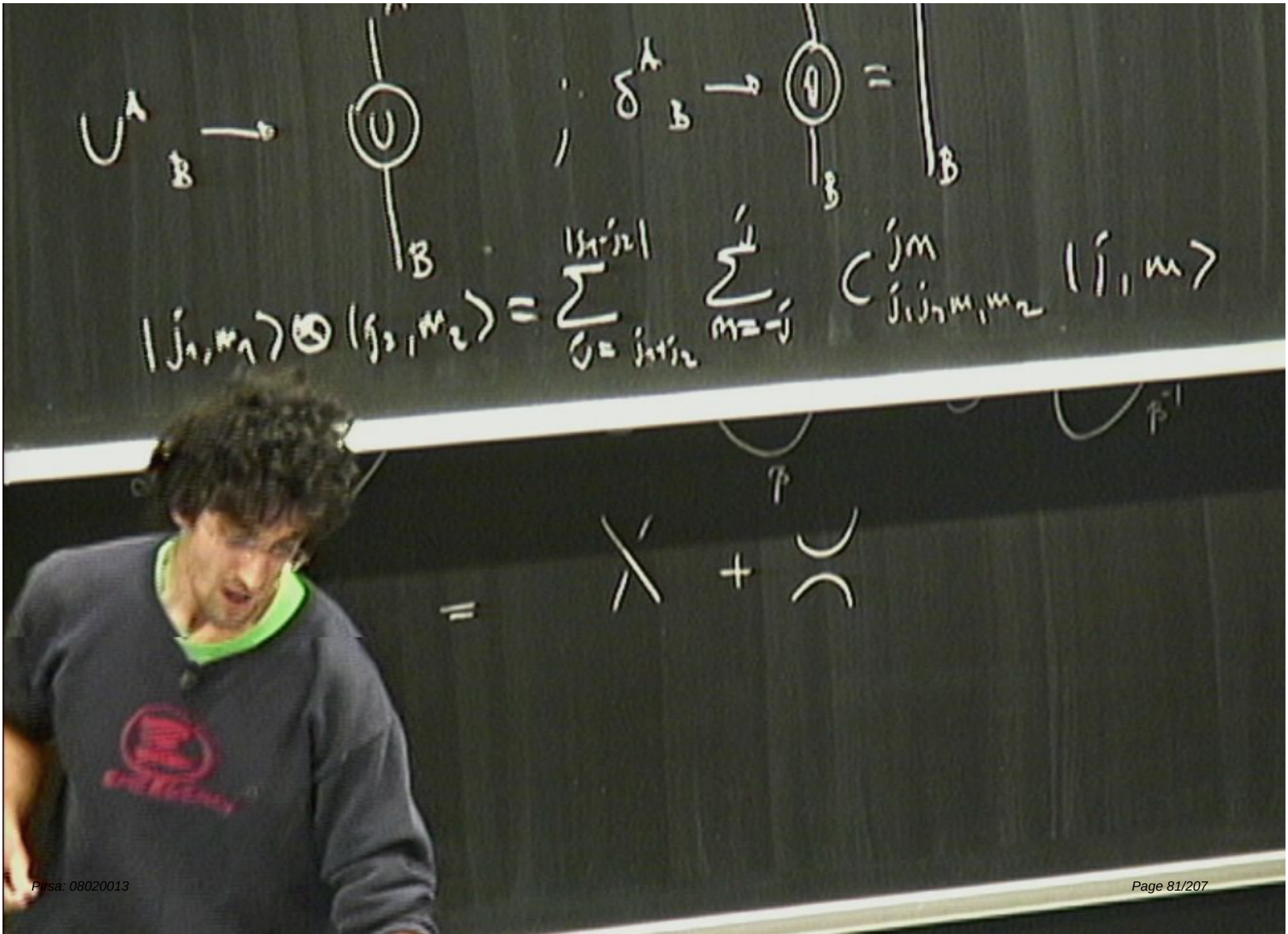
$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

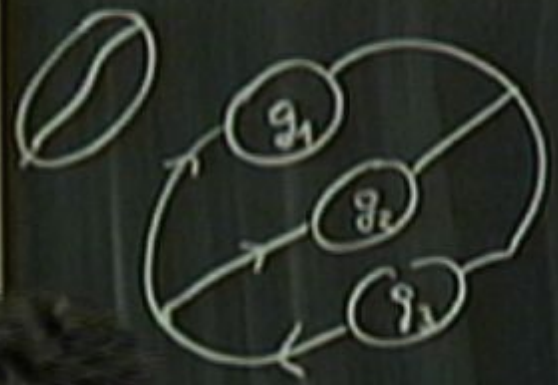
$$D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3}$$



$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

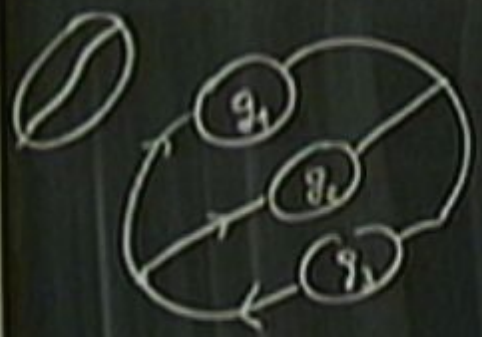
$$D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3}$$


$U^A{}_B \to$
$\delta^A{}_B \to$
$|j_1, m_1\rangle \otimes |j_2, m_2\rangle = \sum_{j=|j_1-j_2|}^{|j_1+j_2|} \sum_{m=-j}^{j} C^{jm}_{j_1 j_2 m_1 m_2} |j, m\rangle$



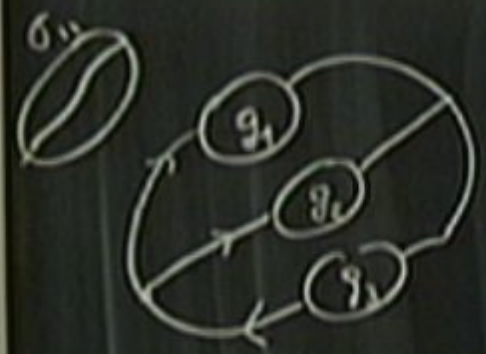
$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

$$D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3}$$



$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

$$\sum_{n_1 n_2 n_3} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

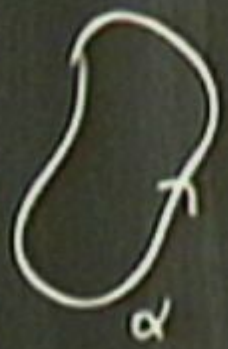


$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

$$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

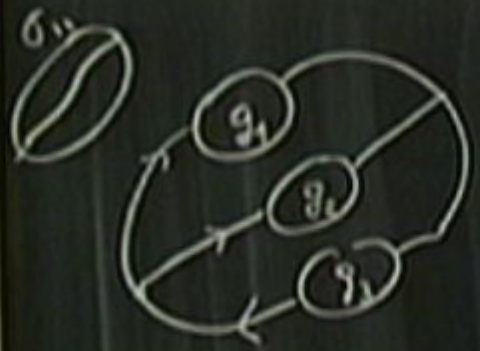
$$= \psi(r, j_1, j_2, j_3) C_0$$

$$\frac{1}{2} \otimes \frac{1}{2} = 1 \oplus 0$$



$$W_\alpha(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(1/2)}}, \quad \mathrm{Tr}\, e^{2\oint_\alpha A^i J_i^{(1/2)}}$$

$$W_{(\alpha,j)}(A) = \mathrm{Tr}\, e^{\oint_\alpha A^i J_i^{(j)}} = \mathrm{Tr}\left(D^{(j)}\left(\underbrace{e^{\oint_\alpha A}}_{g_\alpha}\right)\right)$$



$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

$$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

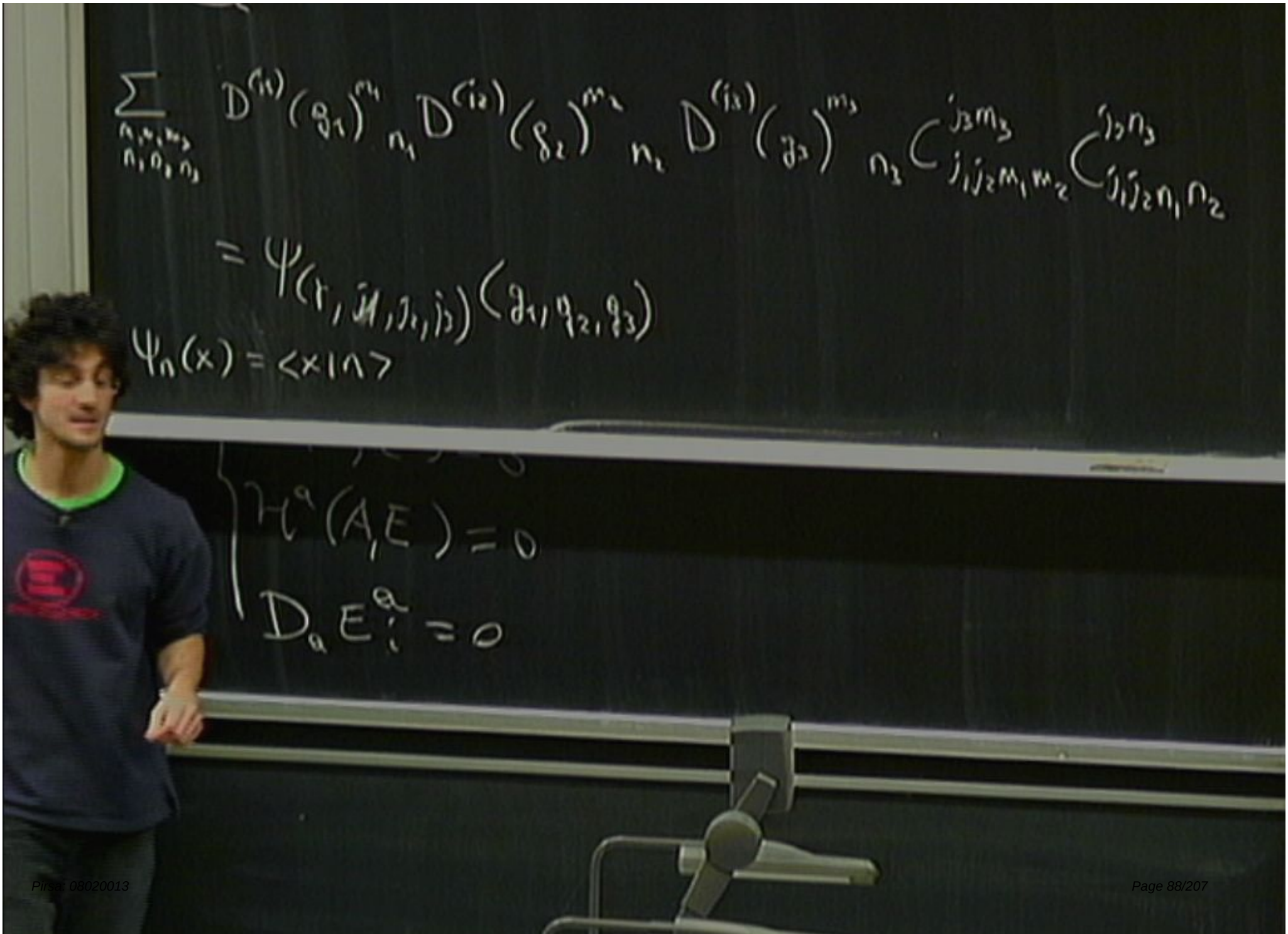
$$= \psi_{(r, j_1, j_2, j_3)}(g_1, g_2, g_3)$$

$$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

$$= \psi_{(r, \mu, j_1, j_3)}(g_1, g_2, g_3)$$

$$\psi_n(x) = \langle x | n \rangle$$

$$\begin{cases} \mathcal{H}^a(A, E) = 0 \\ D_a E^a_i = 0 \end{cases}$$

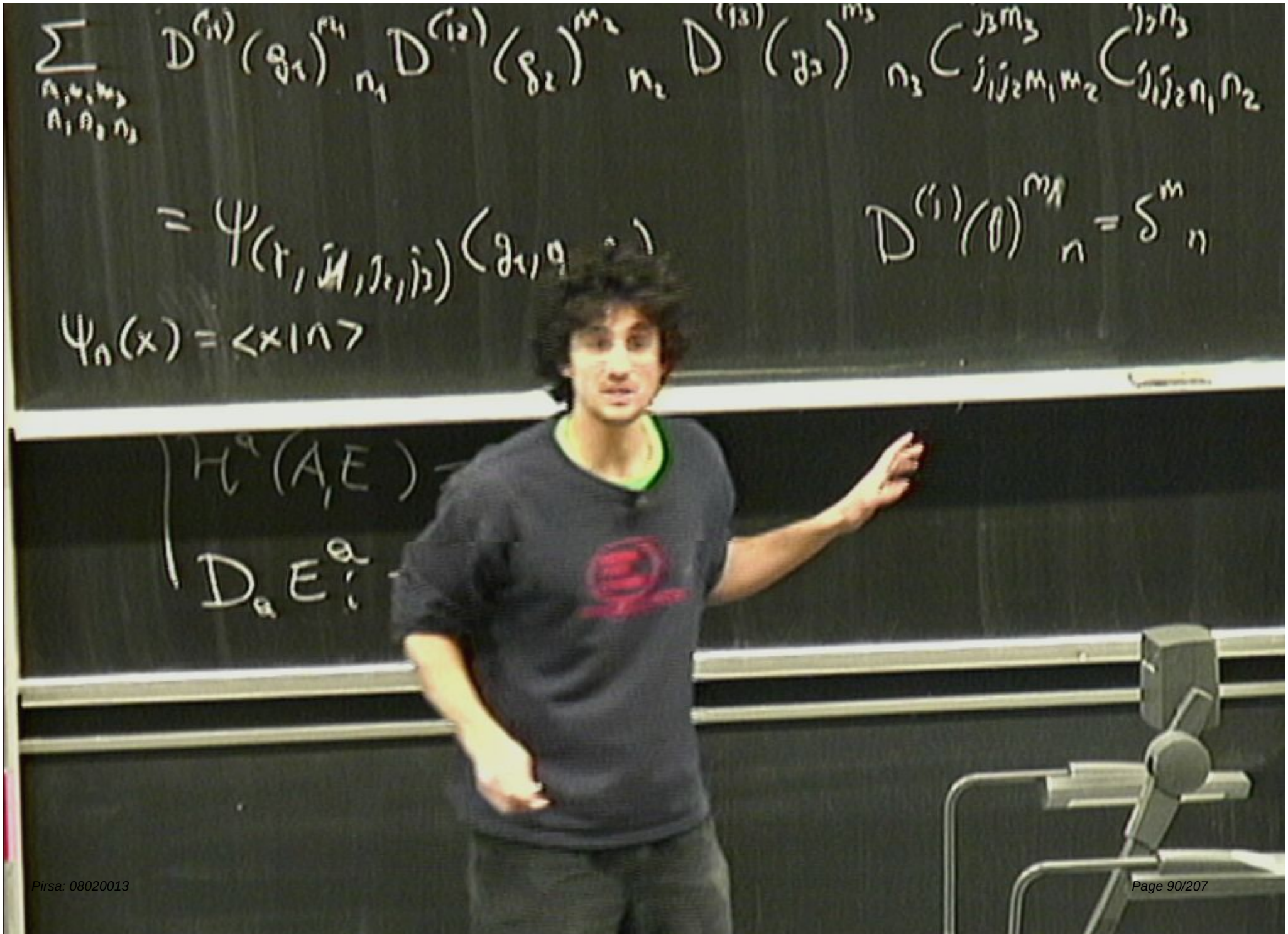

$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$
$= \Psi_{(r, \mu, j_1, j_3)}(g_1, g_2, g_3)$
$\Psi_n(x) = \langle x | n \rangle$
$\mathcal{H}^a(A, E) = 0$
$D_a E^a_i = 0$

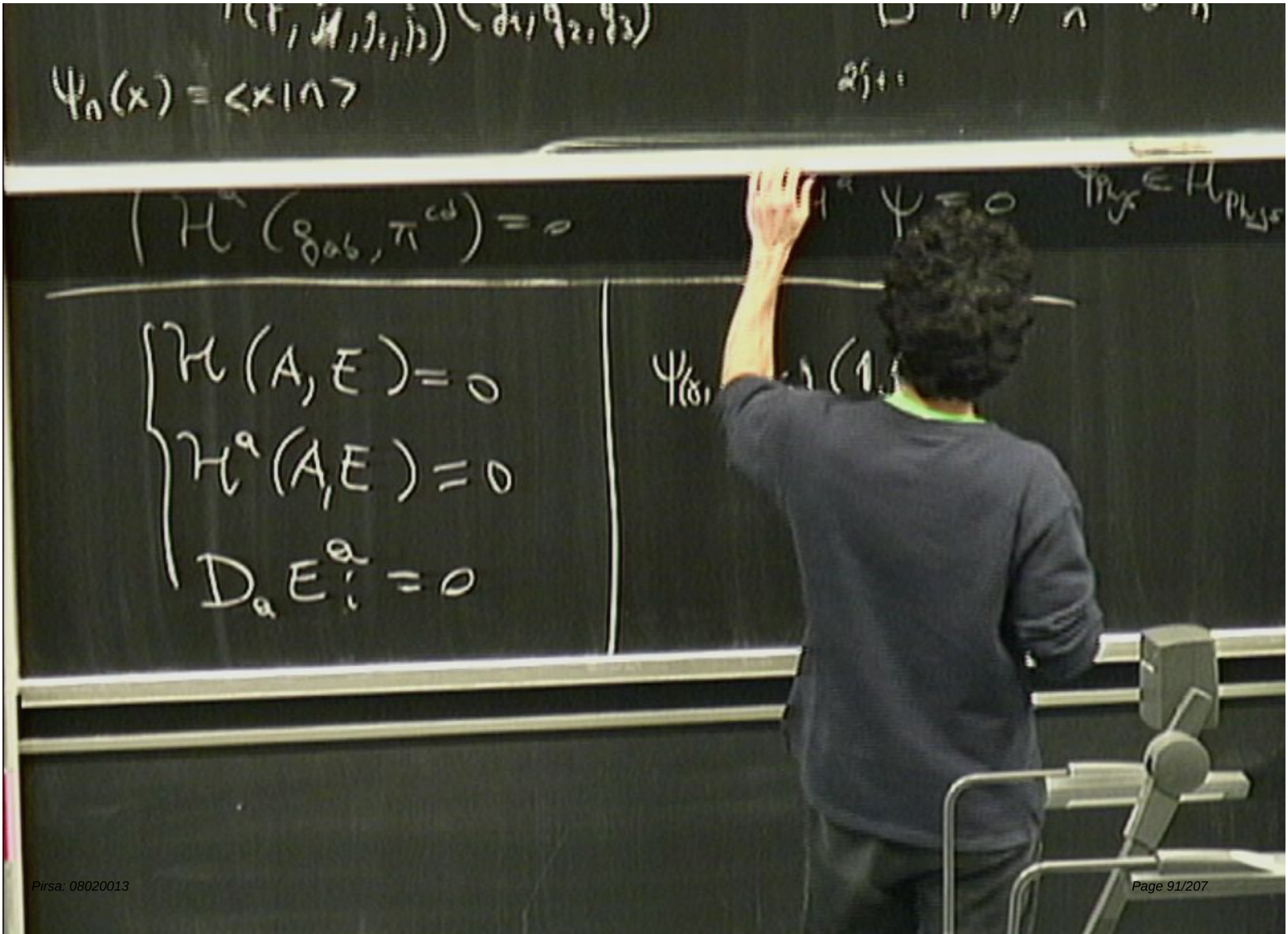
$$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

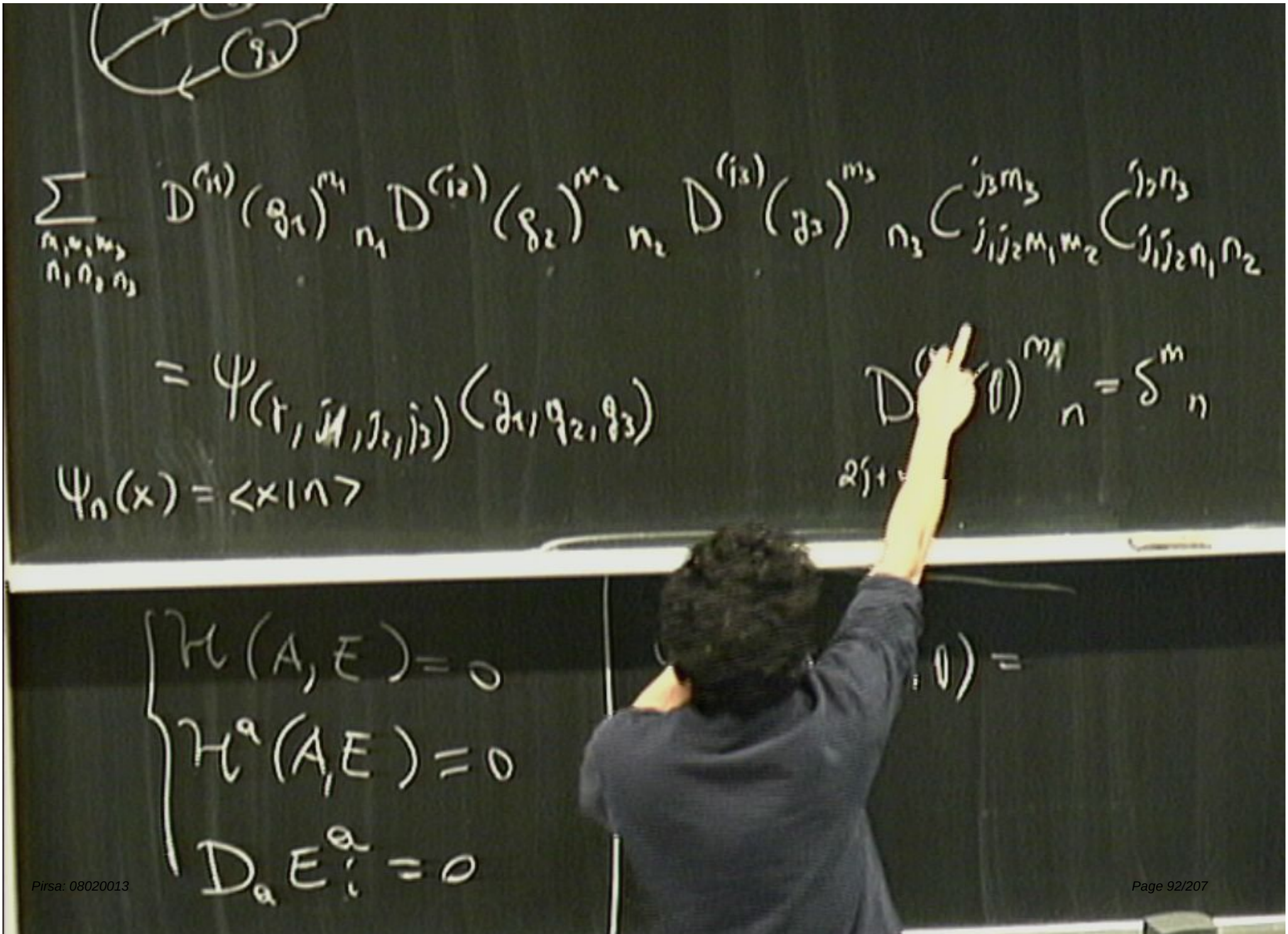
$$= \psi_{(r, \vec{M}, j_1, j_3)}(g_1, g_2, g_3)$$

$$\psi_n(x) = \langle x | n \rangle$$

$$\begin{cases} \mathcal{H}^a(A, E) = 0 \\ D_a E^a_i = 0 \end{cases}$$


$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$
$= \Psi_{(r, j_1, j_2, j_3)}(g_1, g_2, g_3)$
$D^{(j)}(0)^{m}{}_{n} = \delta^{m}{}_{n}$
$\Psi_n(x) = \langle x | n \rangle$
$H^a(A, E)$
$D_a E^a_i$


$\psi_n(x) = \langle x | n \rangle$
$\mathcal{H}(g_{ab}, \pi^{cd}) = 0$
$\mathcal{H}(A, E) = 0$
$\mathcal{H}^a(A, E) = 0$
$D_a E^a_i = 0$


g_3
$\sum_{\substack{m_1,m_2,m_3\\ n_1,n_2,n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$
$= \Psi_{(r, j_1, j_2, j_3)}(g_1, g_2, g_3)$
$D^{(0)}(0)^{m}{}_{n} = \delta^{m}{}_{n}$
$\Psi_n(x) = \langle x | n \rangle$
$\mathcal{H}(A, E) = 0$
$\mathcal{H}^a(A, E) = 0$
$D_a E^a_i = 0$

$$\sum_{\substack{m_1,m_2,m_3\\ n_1,n_2,n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

$$= \Psi_{(r,j_1,j_2,j_3)}(g_1,g_2,g_3)$$

$$D^{(j)}(0)^{m}{}_{n} = \delta^{m}{}_{n}$$

$$\Psi_n(x) = \langle x | n \rangle$$

$$\mathcal{H}(g_{ab}, \pi^{ab}) \qquad \mathcal{H}^a \psi = 0 \qquad \psi_{Phys} \in \mathcal{H}_{Phys}$$

$$\begin{cases} \mathcal{H}(A,E) = \\ \mathcal{H}^a(A \\ D_a E \end{cases}$$

$$\Psi_{(0,j_1,j_2,j_3)}(1,1,1) = \sum_{\substack{m_1,m_2\\ m_3}} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 m_3}_{j_1 j_2 m_1 m_2}$$

$$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

$$= \Psi_{(r, j_1, j_2, j_3)}(g_1, g_2, g_3)$$

$$D^{(j_1)}(0)^{m_1}{}_{n} = \delta^{m}{}_{n}$$

$2j+1$

$$\psi_n(x) = \langle x | n \rangle$$

$$\mathcal{H}(g_{ab}, \pi^{cd}) = 0 \qquad H^{\alpha} \psi = 0 \qquad \psi_{Phys} \in \mathcal{H}_{Phys}$$

$$\left\{ \begin{array}{l} \mathcal{H}(\quad) = 0 \\ \mathcal{H}(\quad) = 0 \end{array} \right.$$

$$\Psi_{(r, j_1, j_2, j_3)}(1, 1, 1) = \sum_{m_1 m_2 m_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 m_3}_{j_1 j_2 m_1 m_2}$$

$$\sum_{\substack{m_1,m_2,m_3\\ n_1,n_2,n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

$$= \Psi_{(j_1, j_2, j_3)}(g_1, g_2, g_3)$$

$$D^{(j_1)}(0)^{m}{}_{n} = \delta^{m}{}_{n}$$

$$\Psi_n(x) = \langle x | n \rangle$$

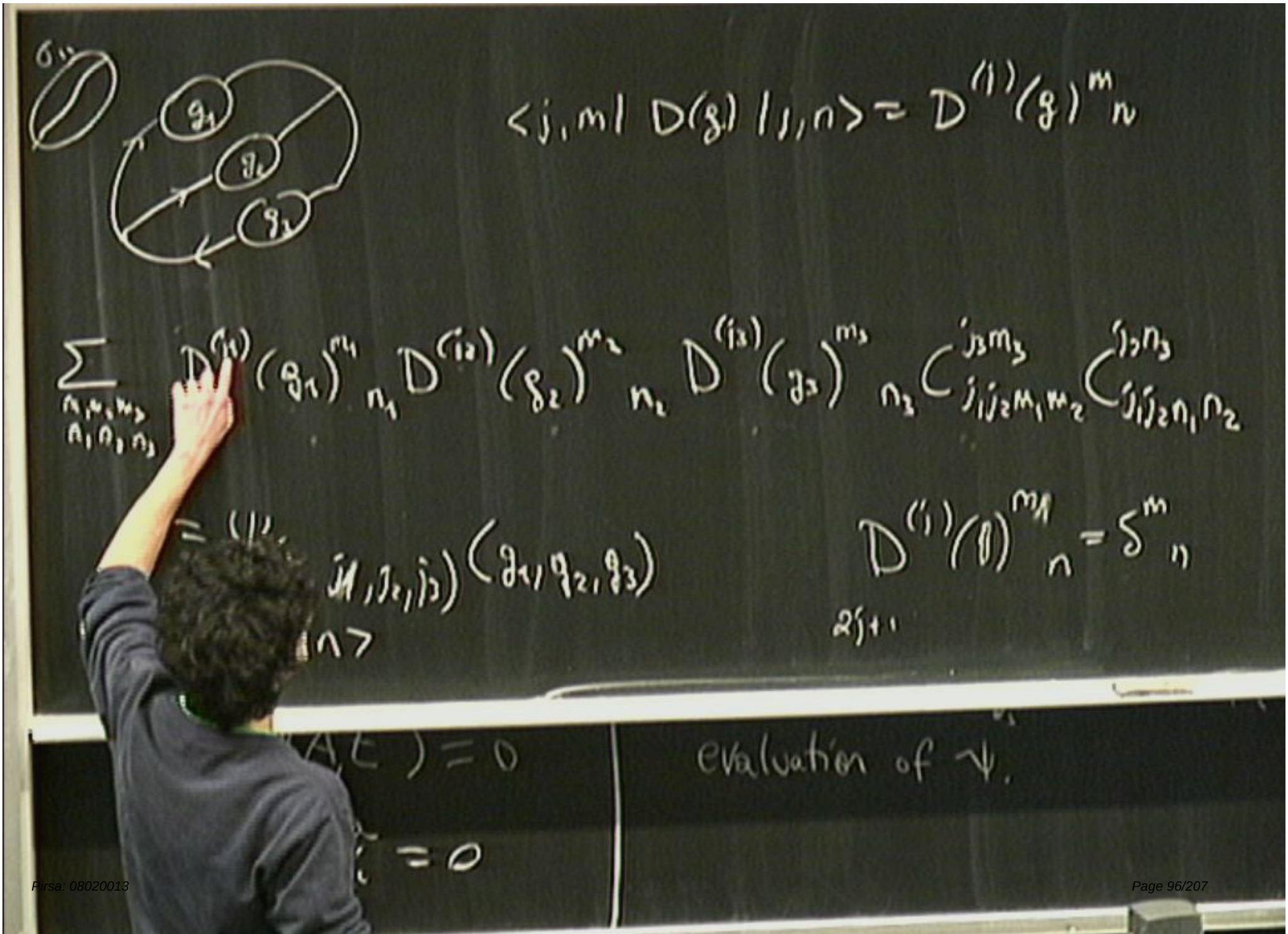
$2j+1$

$$\mathcal{H}(g_{ab}, \pi^{cd}) = 0 \qquad \mathcal{H}^a \psi = 0 \qquad \psi_{Phys} \in \mathcal{H}_{Phys}$$

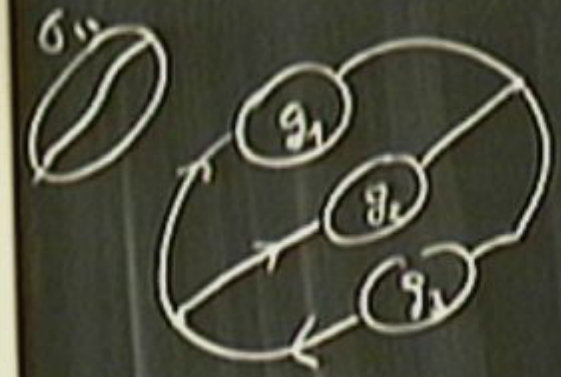
$$\begin{cases} \mathcal{H}(A, E) = 0 \\ \mathcal{H}^a(A, E) = 0 \\ D_a E^a_i = 0 \end{cases}$$

$$\Psi_{(j_1, j_2, j_3)}(1, 1, 1) = \sum_{\substack{m_1, m_2\\ m_3}} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 m_3}_{j_1 j_2 m_1 m_2}$$

evaluation of ψ.


$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^m{}_n$
$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$
$D^{(j)}(\mathbb{1})^m{}_n = \delta^m{}_n$
$2j+1$
evaluation of ψ.

$$\begin{tikzcd}
\mathcal{H} \arrow[r, "G_i=0"] & \mathcal{H}_0 \arrow[r, "\mathcal{H}^a=0"] & \mathcal{H}_D \arrow[r, "\mathcal{H}=0"] & \mathcal{H}_{Phys} \\
\psi(A) \arrow[u, phantom, "\in"] & W_\gamma(A) \arrow[u, phantom, "\in"] \arrow[d] & & \\
 & \psi_{(\gamma,\{x\})} & &
\end{tikzcd}$$



$$\langle j, m | D(g) | j, n \rangle = D^{(j)}(g)^{m}{}_{n}$$

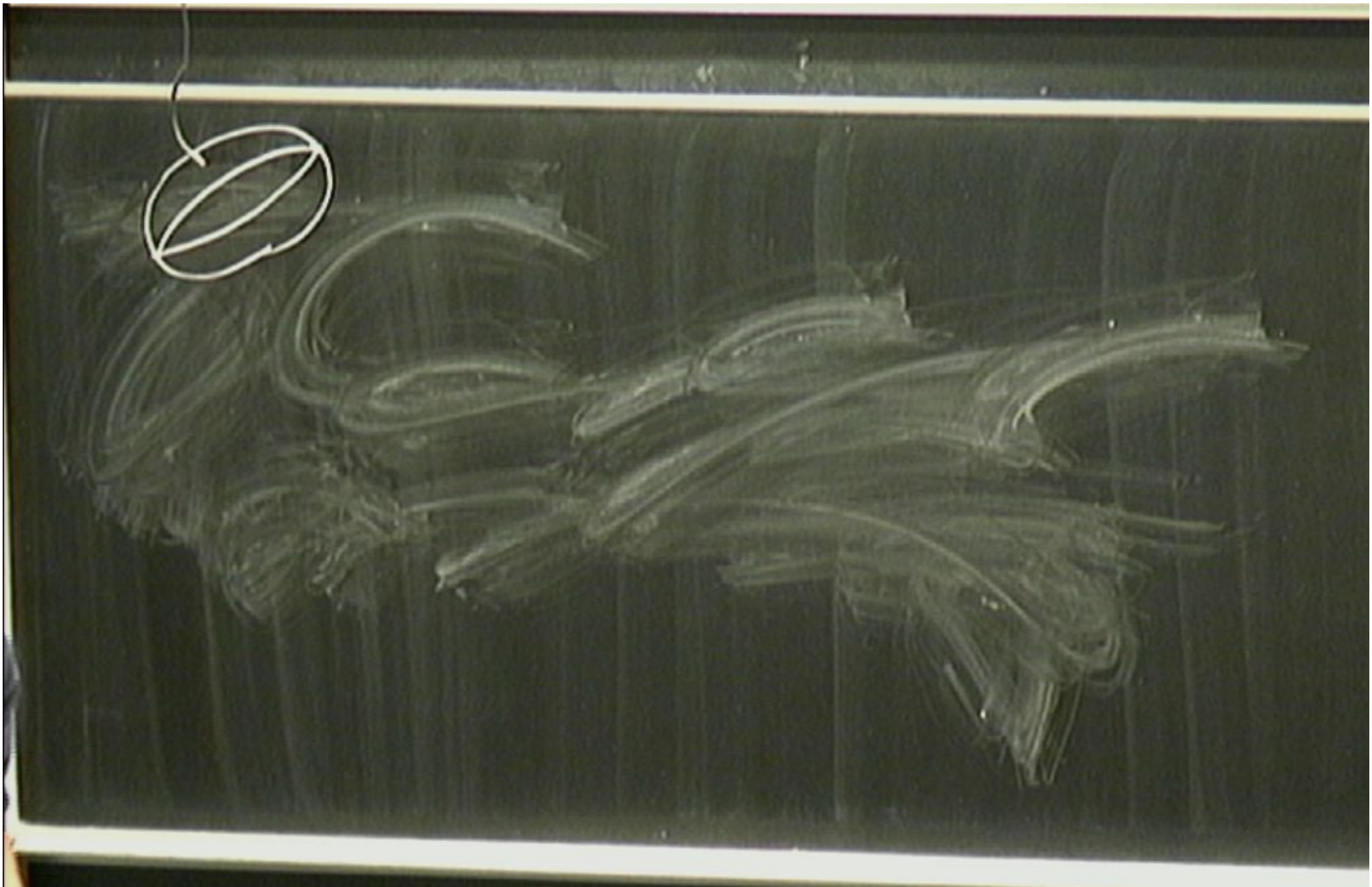
$$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

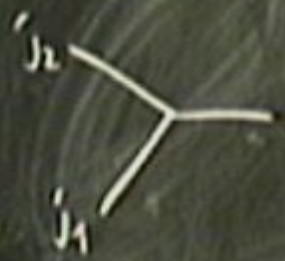
$$= \psi_{(r, j_1, j_2, j_3)}(g_1, g_2, g_3)$$

$$D^{(j)}(\mathbb{1})^{m}{}_{n} = \delta^{m}{}_{n}$$

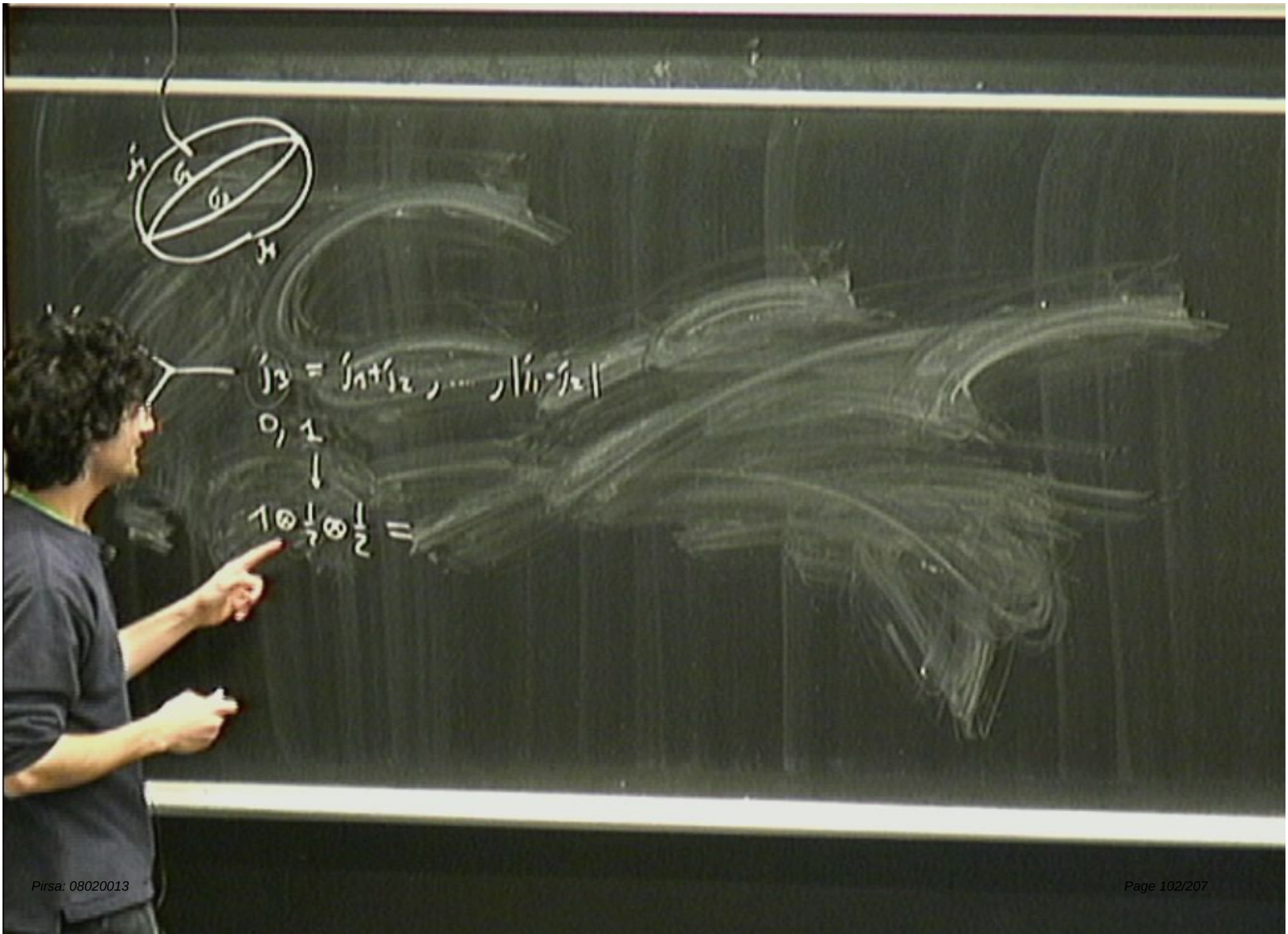
$2j+1$

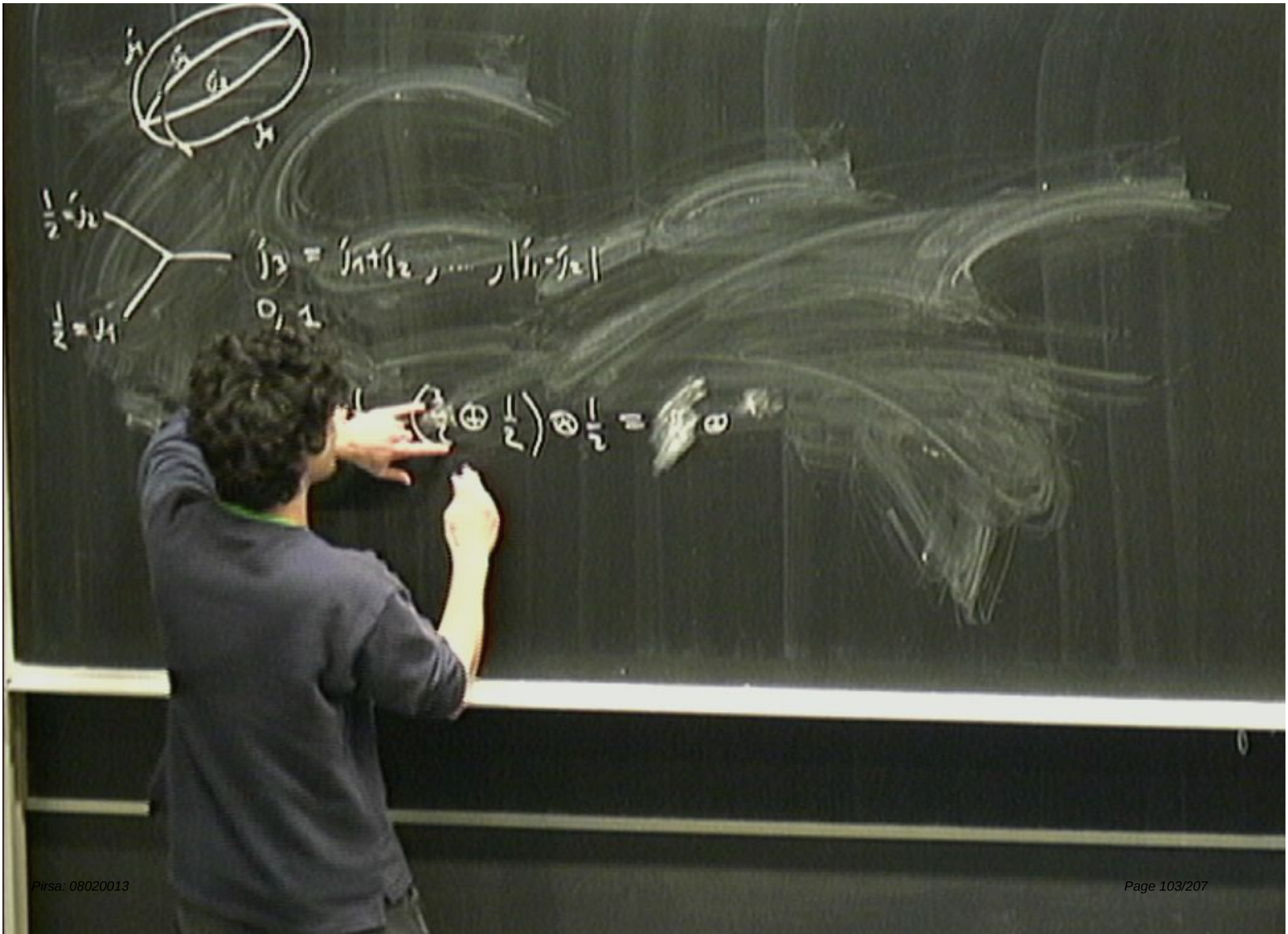
$$\psi_n(x) = \langle x | n \rangle$$



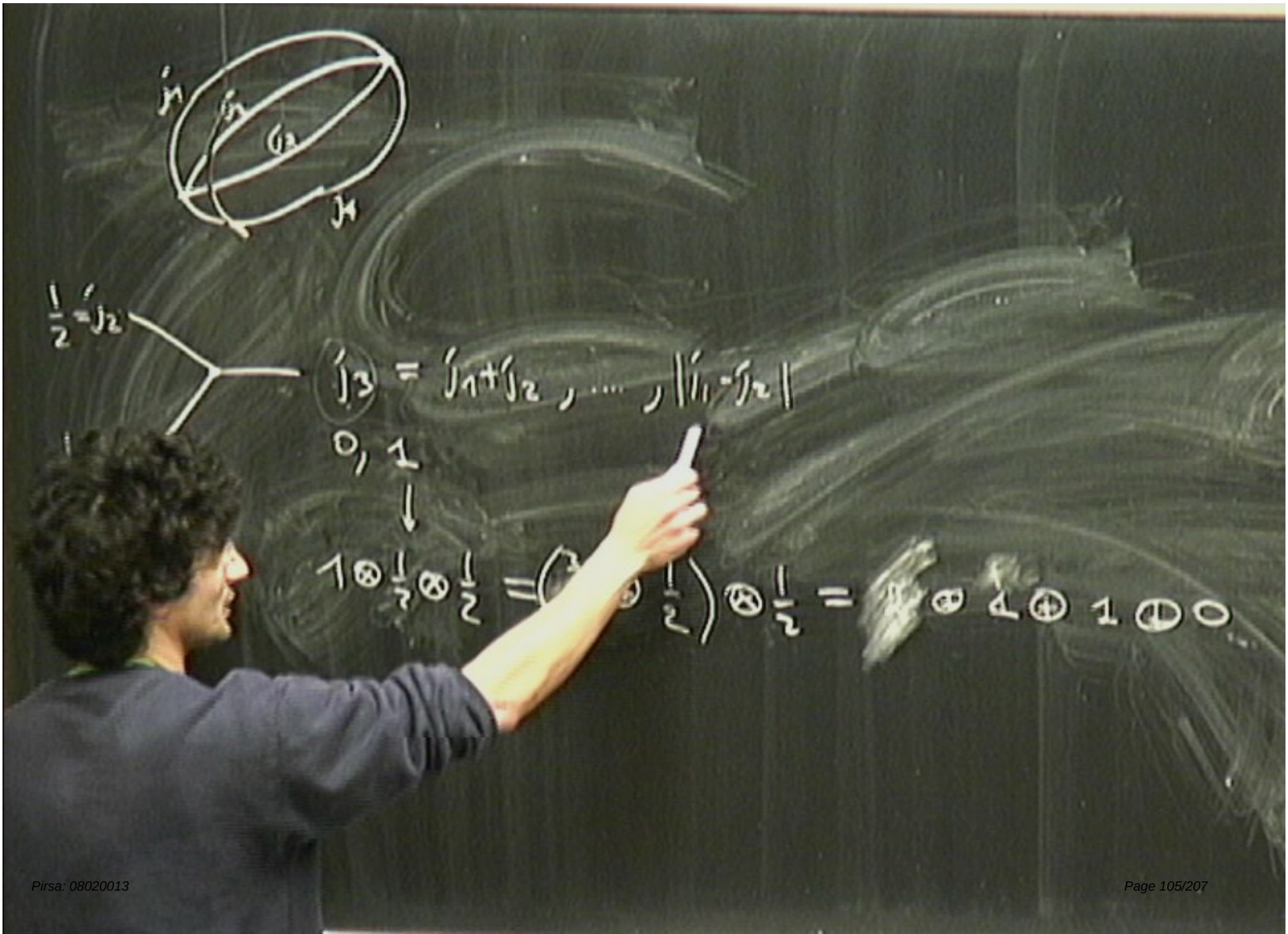


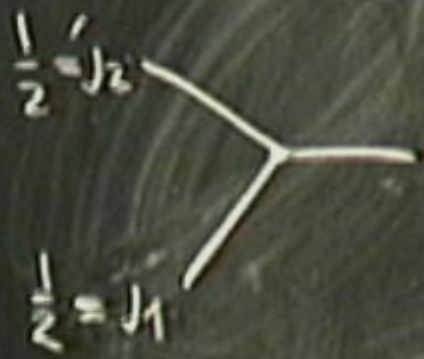
$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$


$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$
0, 1
$1 \otimes \frac{1}{2} \otimes \frac{1}{2} =$


$\frac{1}{2} = j_2$
$\frac{1}{2} = j_1$
$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$
0, 1

$\frac{1}{2} = j_2$
$\frac{1}{2} = j_1$
$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$
$0, 1$
$1 \otimes \frac{1}{2} \otimes \frac{1}{2} = \left(\frac{3}{2} \oplus \frac{1}{2}\right) \otimes \frac{1}{2} = \frac{3}{2} \oplus \frac{1}{2} \oplus 1 \oplus 0$


j1
j2
j3
j4
1/2 = j2
j3 = j1+j2 , ... , ||j1-j2||
0, 1
1 ⊗ 1/2 ⊗ 1/2 = (⊗ 1/2) ⊗ 1/2 = ⊕ 1 ⊕ 1 ⊕ 0

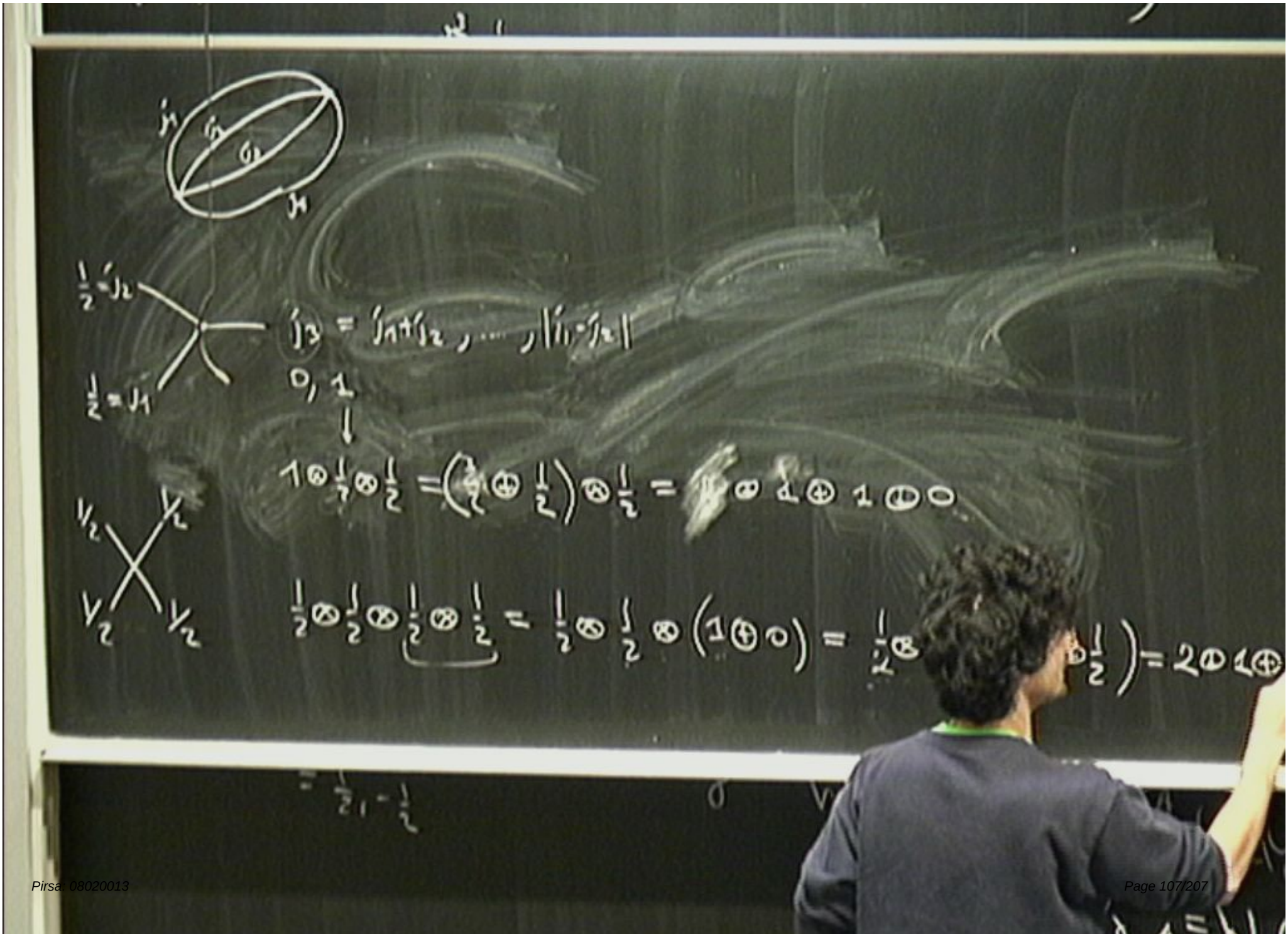


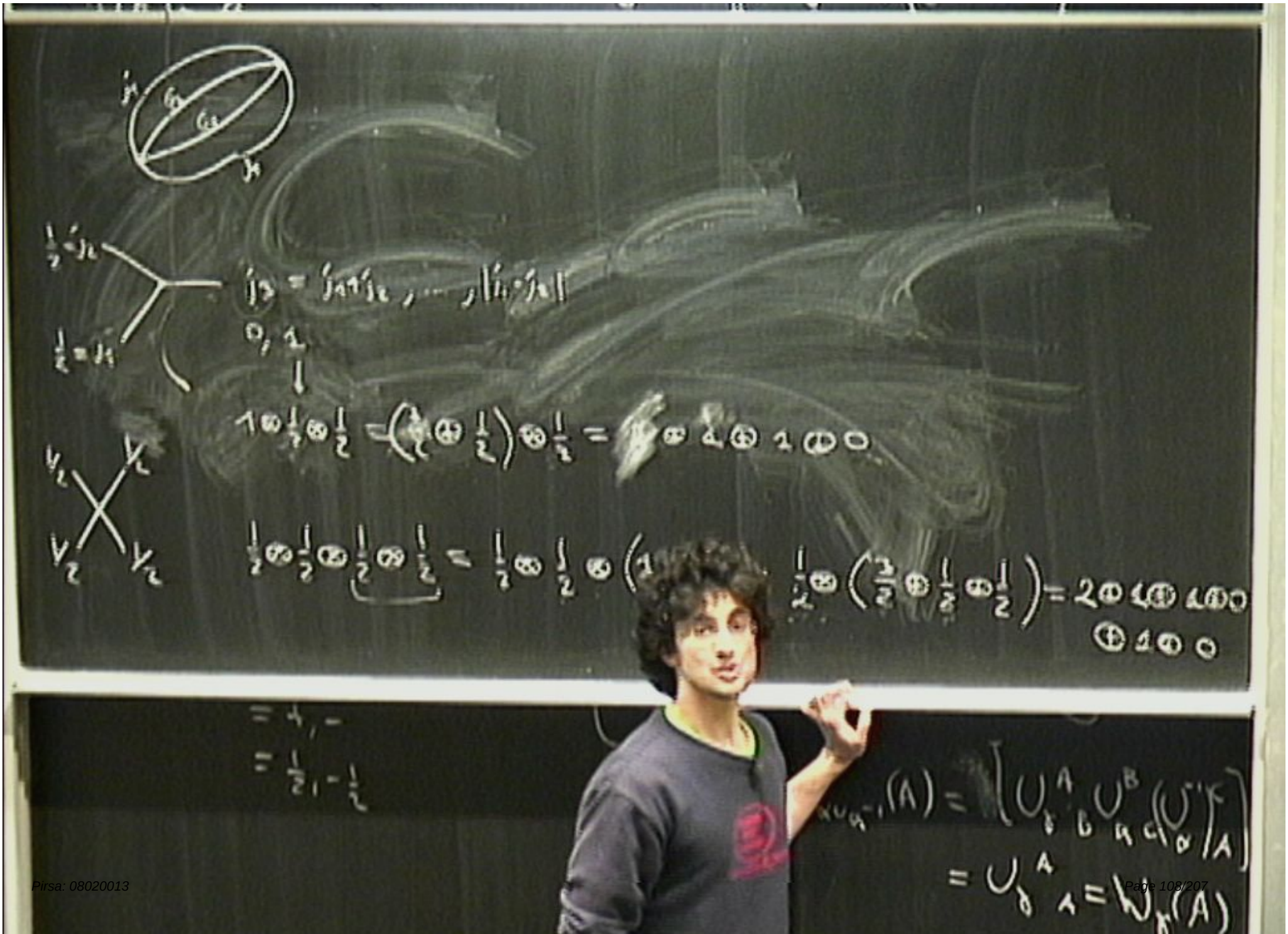
$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$

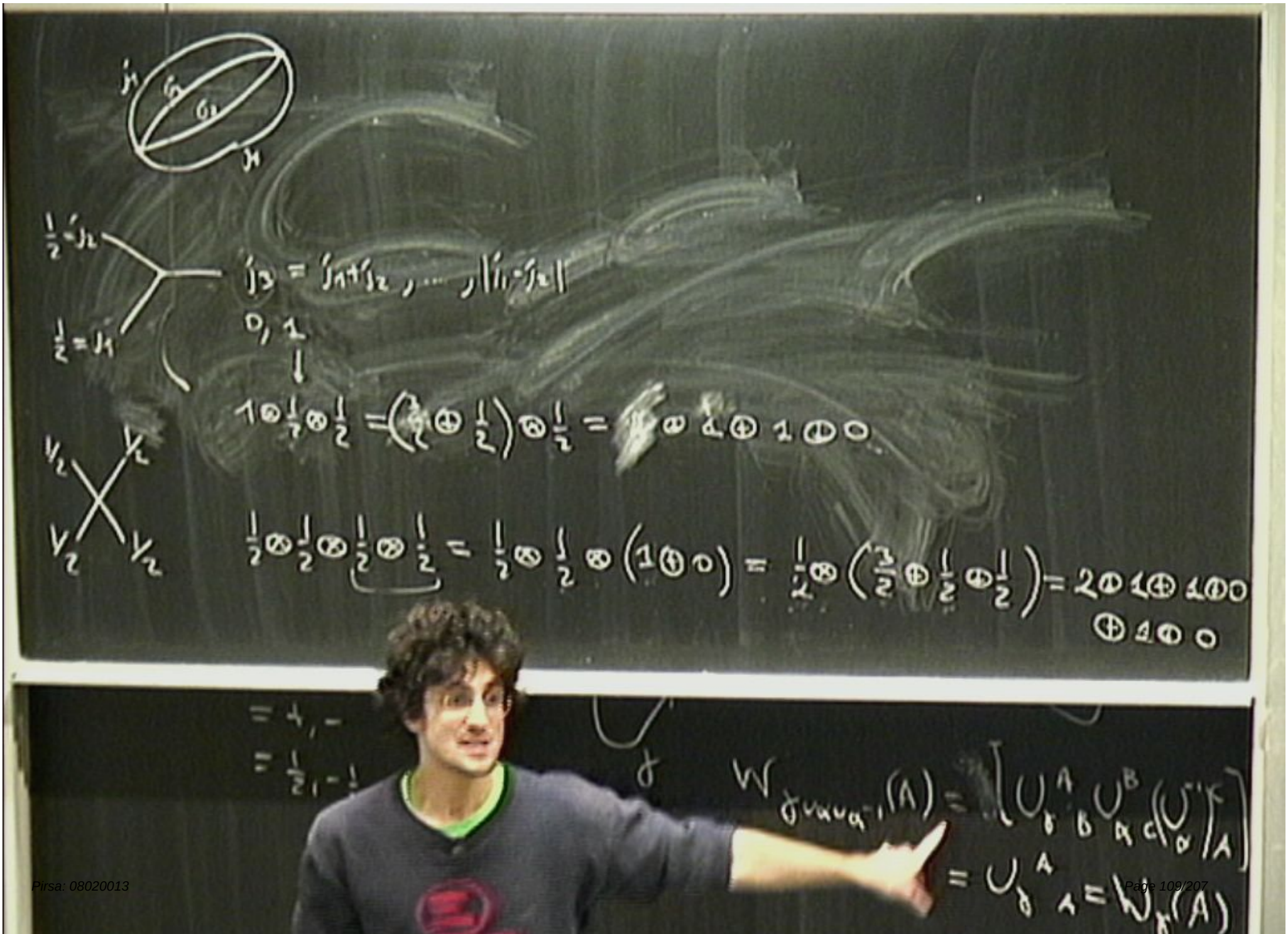
$0, 1$

$\downarrow$

$1 \otimes \frac{1}{2} \otimes \frac{1}{2} = \left(\frac{1}{2} \oplus \frac{1}{2}\right) \otimes \frac{1}{2} = \ldots \oplus 1 \oplus 1 \oplus 0 \ldots$


$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$
$0, 1$
$1 \otimes \frac{1}{2} \otimes \frac{1}{2} = \left(\frac{3}{2} \oplus \frac{1}{2}\right) \otimes \frac{1}{2} = \ldots \otimes 2 \oplus 1 \oplus 0$
$\frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} = \frac{1}{2} \otimes \frac{1}{2} \otimes (1 \oplus 0) = \frac{1}{2} \otimes \ldots \otimes \frac{1}{2}) = 2 \oplus 1 \oplus$


0, 1
1 ⊗ 1/2 ⊗ 1/2 = (1 ⊗ 1/2) ⊗ 1/2 = 2 ⊕ 1 ⊕ 0
1/2 ⊗ 1/2 ⊗ 1/2 ⊗ 1/2 = 1/2 ⊗ 1/2 ⊗ (1
1/2 ⊗ (3/2 ⊗ 1/2 ⊗ 1/2) = 2 ⊕ 1 ⊕ 1 ⊕ 0
⊕ 1 ⊕ 0


$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$
$0, 1$
$1 \otimes \frac{1}{2} \otimes \frac{1}{2} = \left(\frac{3}{2} \oplus \frac{1}{2}\right) \otimes \frac{1}{2} = \frac{3}{2} \oplus 2 \oplus 1 \oplus 0$
$\frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} = \frac{1}{2} \otimes \frac{1}{2} \otimes (1 \oplus 0) = \frac{1}{2} \otimes \left(\frac{3}{2} \oplus \frac{1}{2} \oplus \frac{1}{2}\right) = 2 \oplus 1 \oplus 1 \oplus 0$
$\oplus 1 \oplus 0$

$$SU(2) \ni g = e^{\sum_{i=1}^{3} \alpha^i J_i}$$

$$A^i J_i$$

$$\prod_{\ell=1}^{4} D^{(j_\ell)}(g_\ell)^{m_\ell}{}_{n_\ell}$$

$$\frac{1}{2} = j_2 \qquad \frac{1}{2} = j_1$$

$$j_3 = j_1 + \ldots - j_2 \,|$$

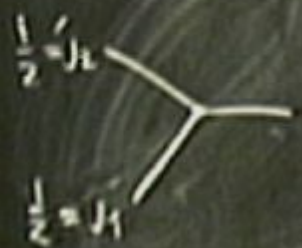
$$0, 1$$

$$1 \otimes \frac{1}{2} \ldots \frac{1}{2}) \otimes \frac{1}{2} = \ldots \oplus 2 \oplus 1 \oplus 0$$

$$SU(2) \ni g = e^{\sum_{i=1}^{3} \alpha^i J_i}$$

$$A^i J_i$$

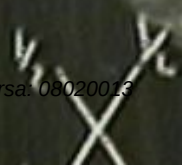
$$\prod_{\ell=1}^{q} D^{(j_\ell)}(g_\ell)^{m_\ell} \quad n_\ell \quad \prod_{n=1}^{2} C_{m_n n}$$



$$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$$

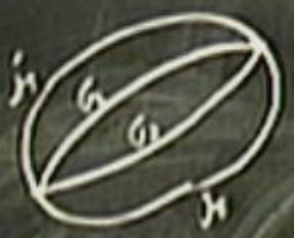
$$0, 1$$

$$1 \otimes \frac{1}{2} \otimes \frac{1}{2} = \left(\frac{1}{2} \oplus \frac{1}{2}\right) \otimes \frac{1}{2} = \frac{1}{2} \otimes \frac{1}{2} \oplus 1$$

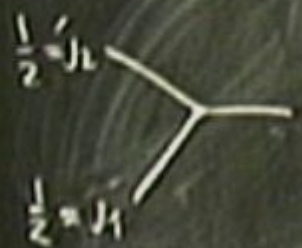


$$SU(2) \ni g = e^{\sum_{i=1}^{3} \alpha^i J_i}$$

$$A^i J_i$$



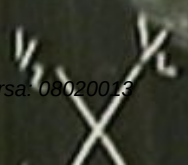
$$\prod_{\ell=1}^{q} D^{(j_\ell)}(g_\ell)^{m_\ell} \quad n_\ell \quad \prod_{n=1}^{2} C^{(j_n)}_{m_n n_n}$$

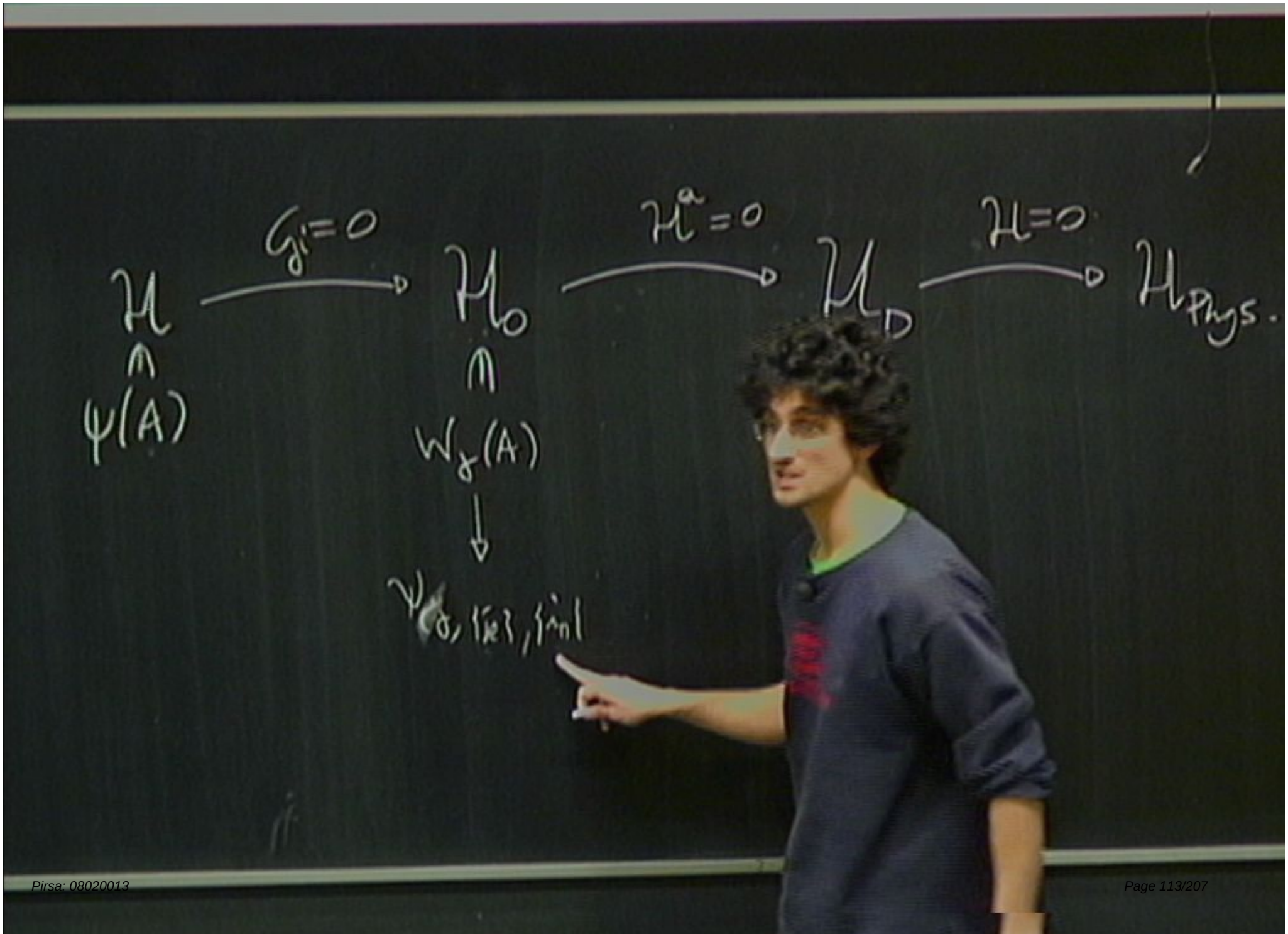


$$j_3 = j_1 + j_2, \ldots, |j_1 - j_2|$$

$$0, 1$$

$$1 \otimes \tfrac{1}{2} \otimes \tfrac{1}{2} = \left(\tfrac{1}{2} \oplus \tfrac{1}{2}\right) \otimes \tfrac{1}{2} = \ldots \otimes 2 \oplus 1 \oplus 0$$




$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys.}$
$\psi(A) \in \mathcal{H}$
$W_\gamma(A) \in \mathcal{H}_0$

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

$$\mathcal{H} \ni \psi(A)$$

$$\mathcal{H}_0 \ni W_\gamma(A)$$

$$W_\gamma(A) \longrightarrow \underbrace{\Psi(\gamma, \{k_e\}, \{j_{mn}\})}_{} \quad (\{g_e\})$$

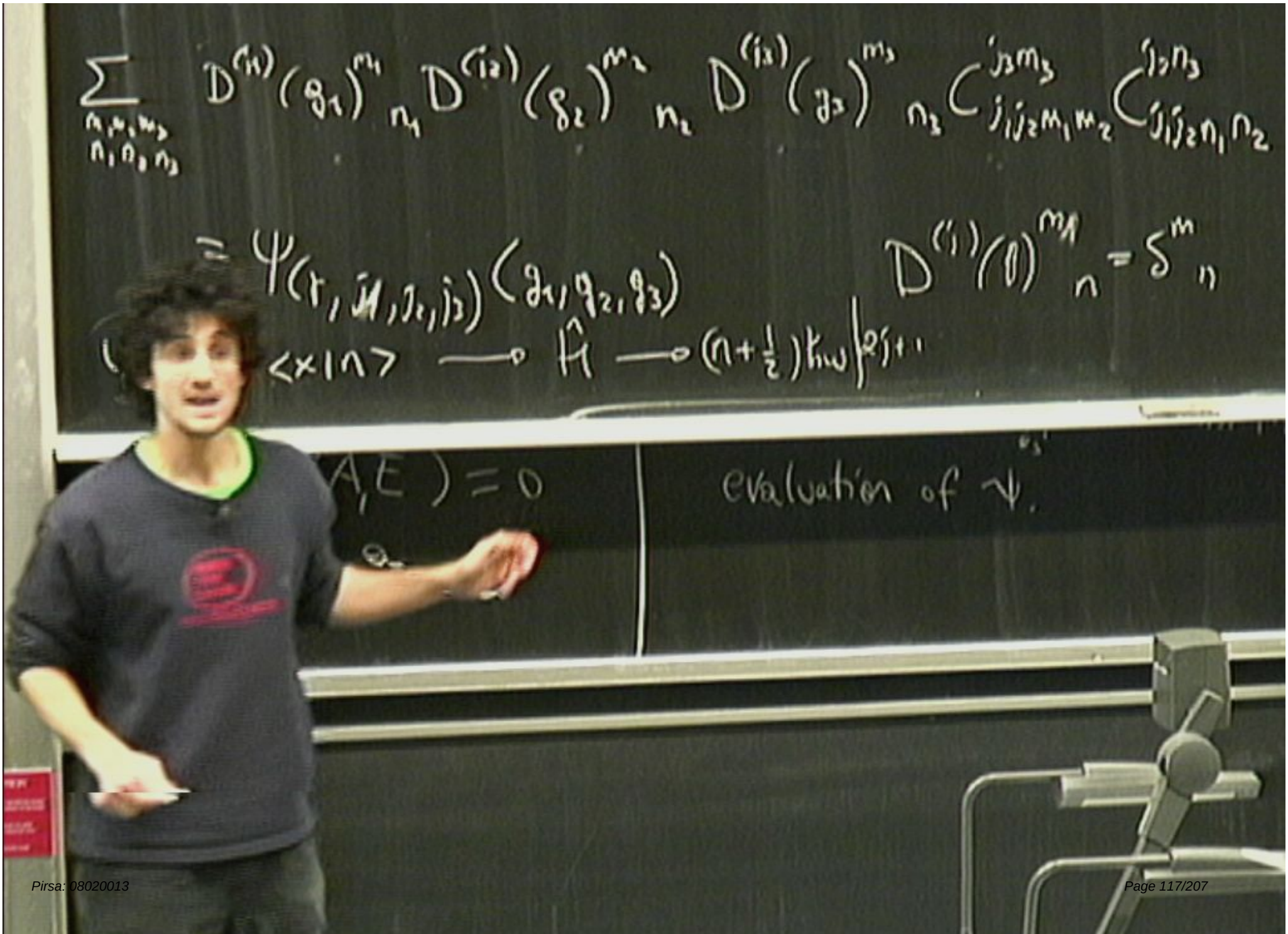
$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

$$\mathcal{H} \ni \psi(A)$$

$$\mathcal{H}_0 \ni W_\gamma(A)$$

$$W_\gamma(A) \longrightarrow \psi(\gamma, \{i_e\}, \{j_{nl}\}) \quad (\{g_e\})$$

$$\begin{tikzcd}
\mathcal{H} \arrow[r, "G_i=0"] & \mathcal{H}_0 \arrow[r, "\mathcal{H}^a=0"] & \mathcal{H}_D \arrow[r, "\mathcal{H}=0"] & \mathcal{H}_{Phys}. \\
\psi(A) \arrow[u, phantom, "\cap"] & W_\gamma(A) \arrow[u, phantom, "\cap"] \arrow[d] & & \\
& \psi(\sigma, \{k_e\}, \{i_n\}) \; (\{g_e\}) & &
\end{tikzcd}$$


$\sum_{\substack{m_1 m_2 m_3 \\ n_1 n_2 n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$
$= \Psi_{(r, j_1, j_2, j_3)}(g_1, g_2, g_3)$
$D^{(j)}(0)^{m}{}_{n} = \delta^{m}{}_{n}$
$\langle x | n \rangle \longrightarrow \hat{H} \longrightarrow (n + \frac{1}{2}) \hbar\omega |$
$A, E) = 0$
evaluation of Ψ.

$$\sum_{\substack{m_1,m_2,m_3\\ n_1,n_2,n_3}} D^{(j_1)}(g_1)^{m_1}{}_{n_1} D^{(j_2)}(g_2)^{m_2}{}_{n_2} D^{(j_3)}(g_3)^{m_3}{}_{n_3} C^{j_3 m_3}_{j_1 j_2 m_1 m_2} C^{j_3 n_3}_{j_1 j_2 n_1 n_2}$$

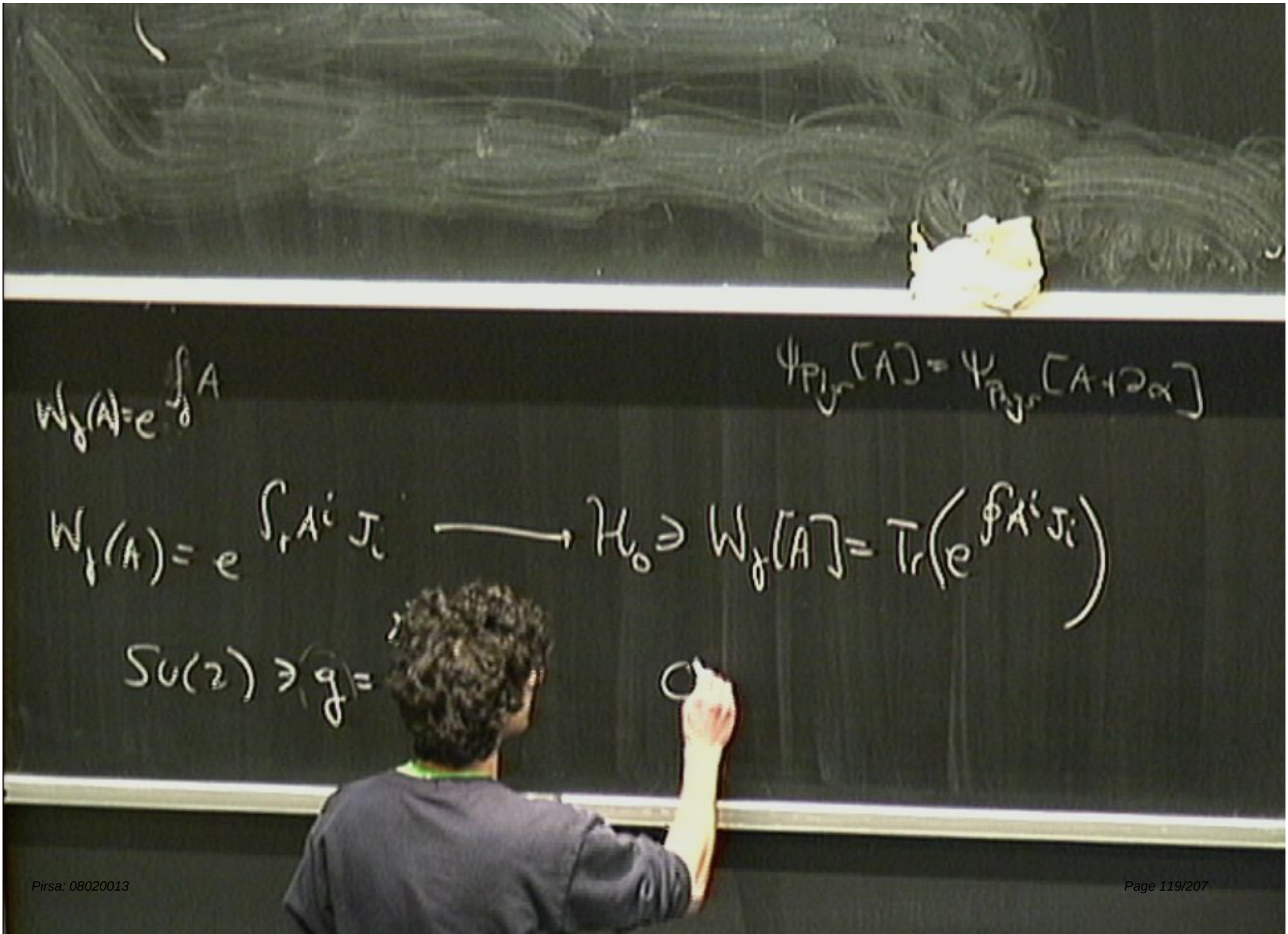
$$= \psi_{(j_1, j_2, j_3)}(g_1, g_2, g_3) \qquad D^{(j)}(0)^{m}{}_{n} = \delta^{m}{}_{n}$$

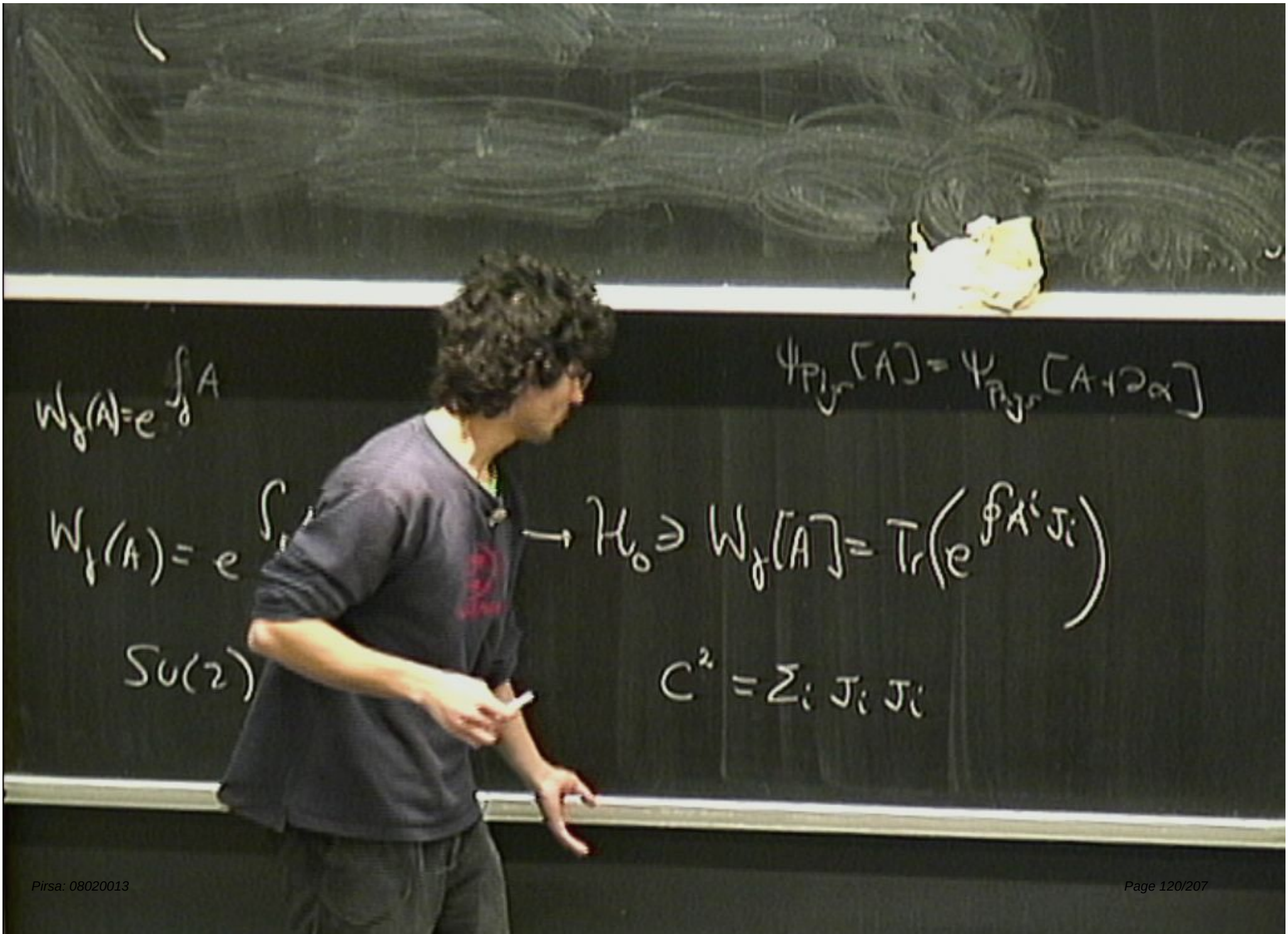
$$\psi_n(x) = \langle x | n \rangle \longrightarrow \hat{H} \longrightarrow (n+\tfrac{1}{2})\hbar\omega \,|\, \text{exp}\, j+1$$

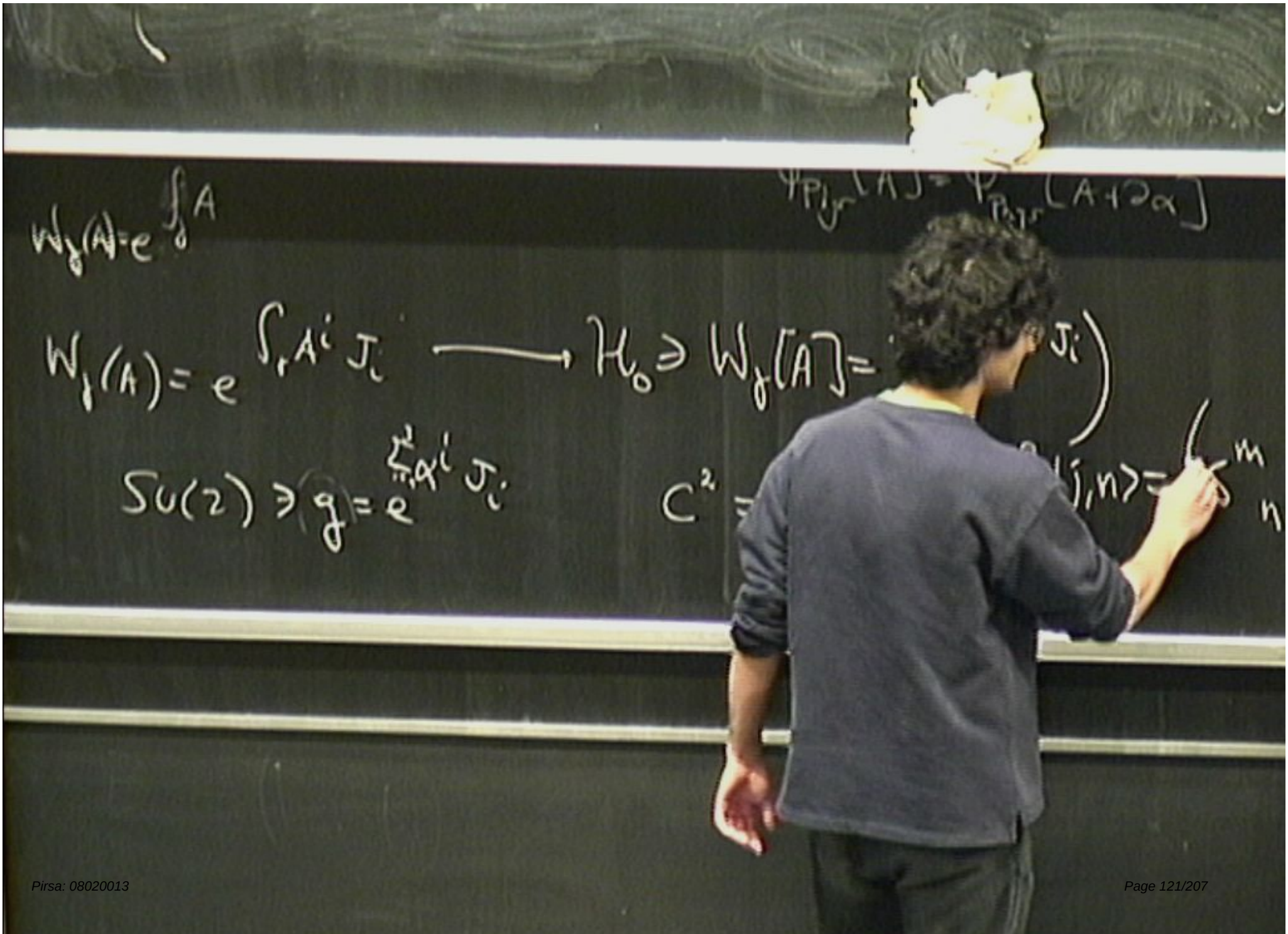
$$\mathcal{H}(A, E) = 0$$

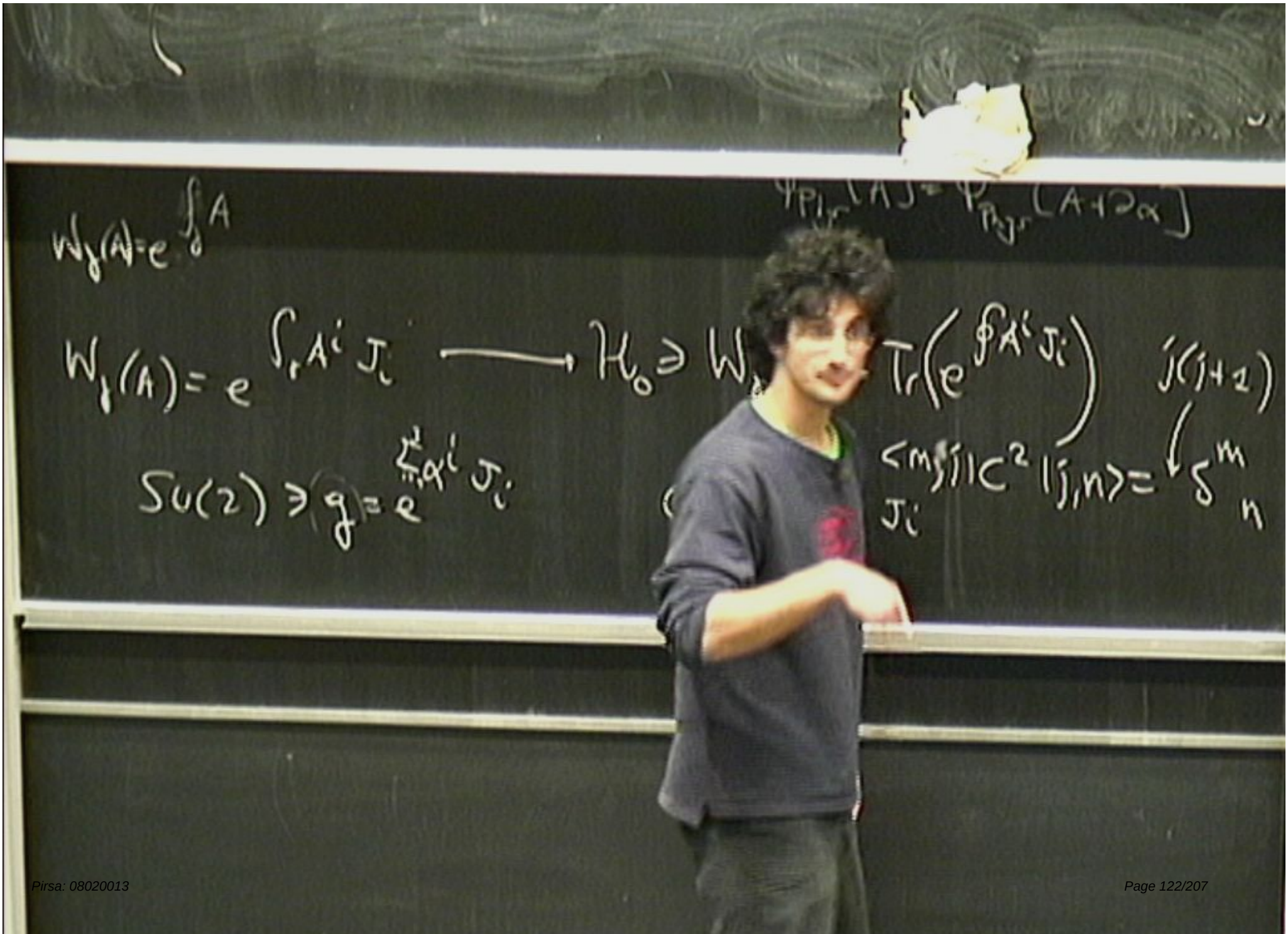
$$D_a E^a_i = 0$$

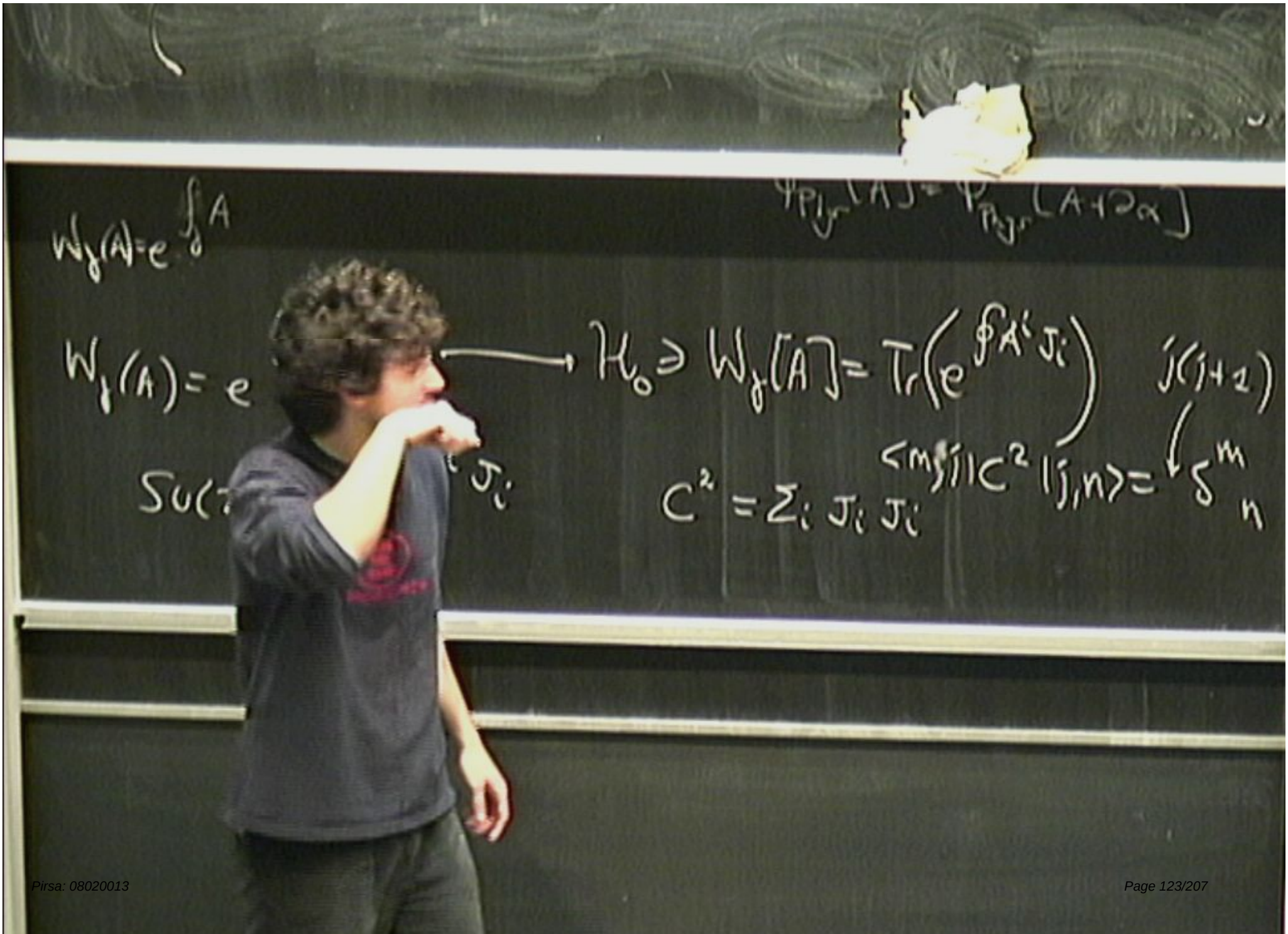
evaluation of ψ.


$W_\gamma(A) = e^{\int_\gamma A}$
$\psi_{P_{J_\gamma}}[A] = \psi_{P_{J_\gamma}}[A + \partial\alpha]$
$W_\gamma(A) = e^{\int_\gamma A^i J_i} \longrightarrow \mathcal{H}_0 \ni W_\gamma[A] = \mathrm{Tr}\left(e^{\oint A^i J_i}\right)$
$SU(2) \ni g =$


$W_\gamma(A) = e^{\int_\gamma A}$
$\psi_{P_{J_\gamma}}[A] = \psi_{P_{J_\gamma}}[A + \partial\alpha]$
$W_\gamma(A) = e^{\int_\gamma}$
$\to \mathcal{H}_0 \ni W_\gamma[A] = \mathrm{Tr}\left(e^{\oint A^i J_i}\right)$
$SU(2)$
$C^2 = \Sigma_i J_i J_i$


$W_\gamma(A) = e^{\oint_\gamma A}$
$W_\gamma(A) = e^{\int_\gamma A^i J_i} \longrightarrow \mathcal{H}_0 \ni W_\gamma[A] =$
$SU(2) \ni g = e^{\xi^i J_i}$


$W_\gamma(A) = e^{\oint_\gamma A}$
$W_\gamma(A) = e^{\int_\gamma A^i J_i} \longrightarrow \mathcal{H}_0 \ni W_\gamma$
$\mathrm{Tr}\left(e^{\oint A^i J_i}\right)$
$j(j+1)$
$SU(2) \ni g = e^{\xi^i_\gamma A^i J_i}$
$\langle m, j | C^2 | j, n \rangle = \delta^m_n$
J_i


$W_\gamma(A) = e^{\oint A}$
$W_\gamma(A) = e$
$\mathcal{H}_0 \ni W_\gamma[A] = \mathrm{Tr}\left(e^{\oint A^i J_i}\right)$
$j(j+1)$
$SU(2$
J_i
$C^2 = \Sigma_i J_i J_i$
$\langle m, j | C^2 | j, n \rangle = \delta^m_n$

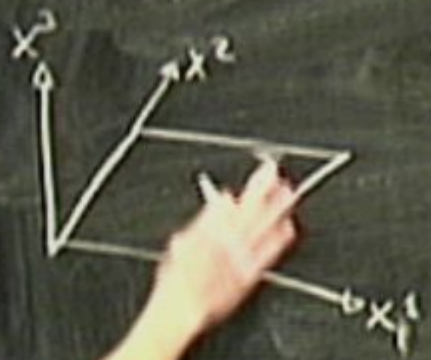
$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j\, \delta^b_a\, \delta^{(3)}(\vec{x}-\vec{y})$$

$$A_2 = \int d\sigma_1\, d\sigma_2\, \sqrt{\det {}^{(2)}g_{ij}}$$

$$= g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$$

$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j\, \delta^b_a\, \delta^{(3)}(\vec{x}-\vec{y})$$

$$A_2 = \int d\sigma_1\, d\sigma_2 \sqrt{\det {}^{(2)}g_{ij}}$$



$${}^{(2)}g_{ij} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$$

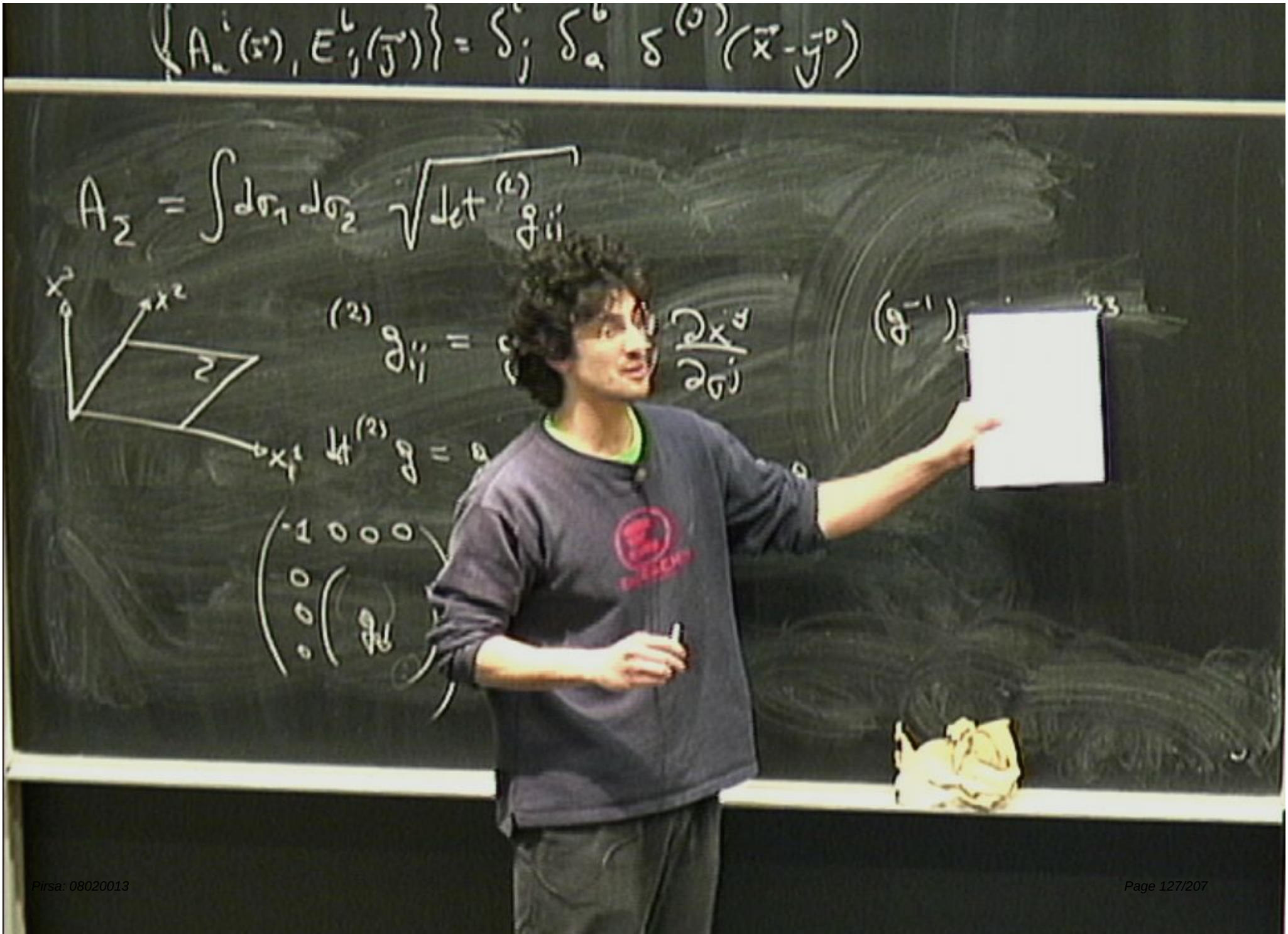
$$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j\, \delta^b_a\, \delta^{(3)}(\vec{x}-\vec{y})$$

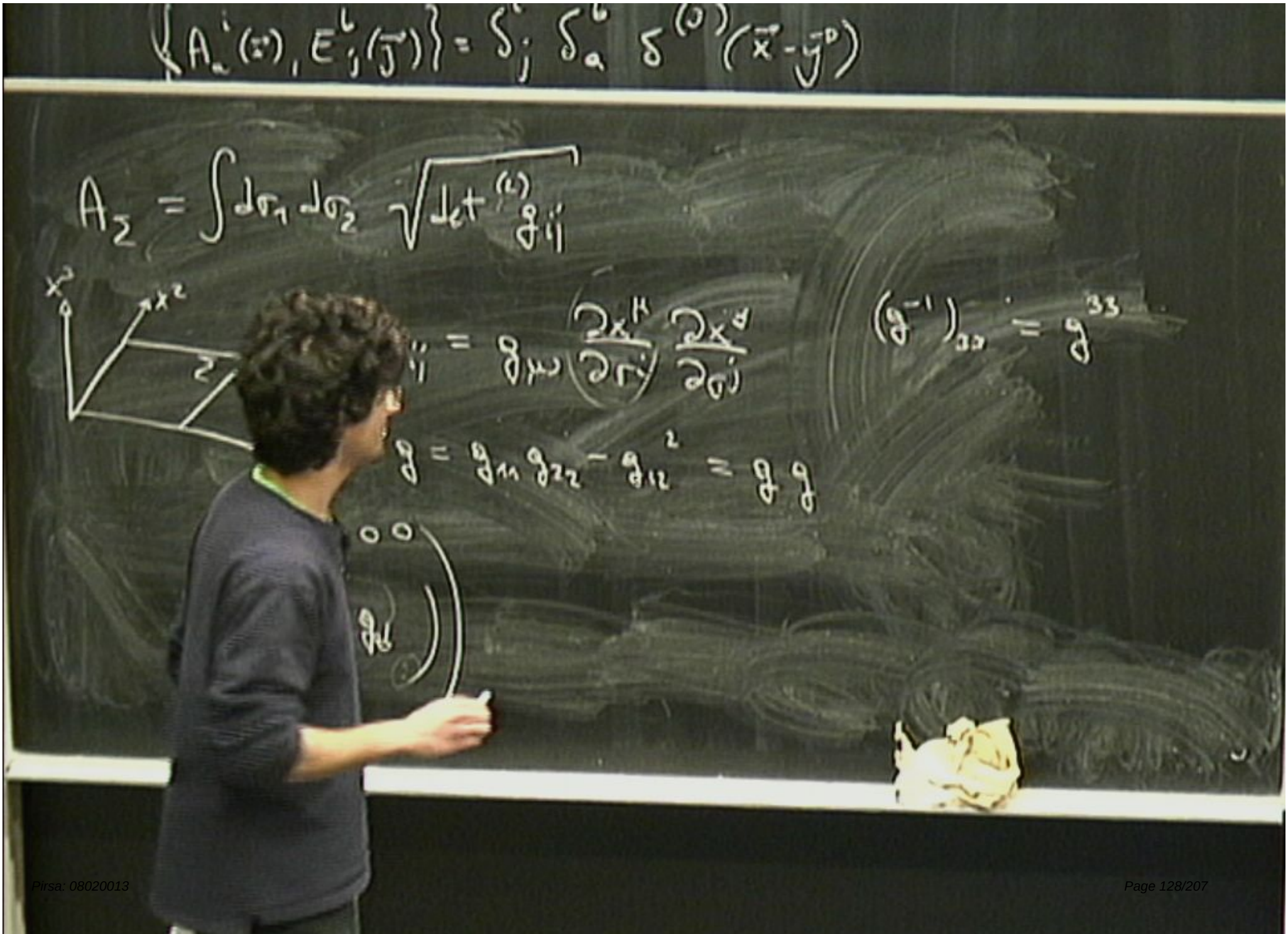
$$A_2 = \int d\sigma_1\, d\sigma_2 \sqrt{\det {}^{(2)}g_{ij}}$$

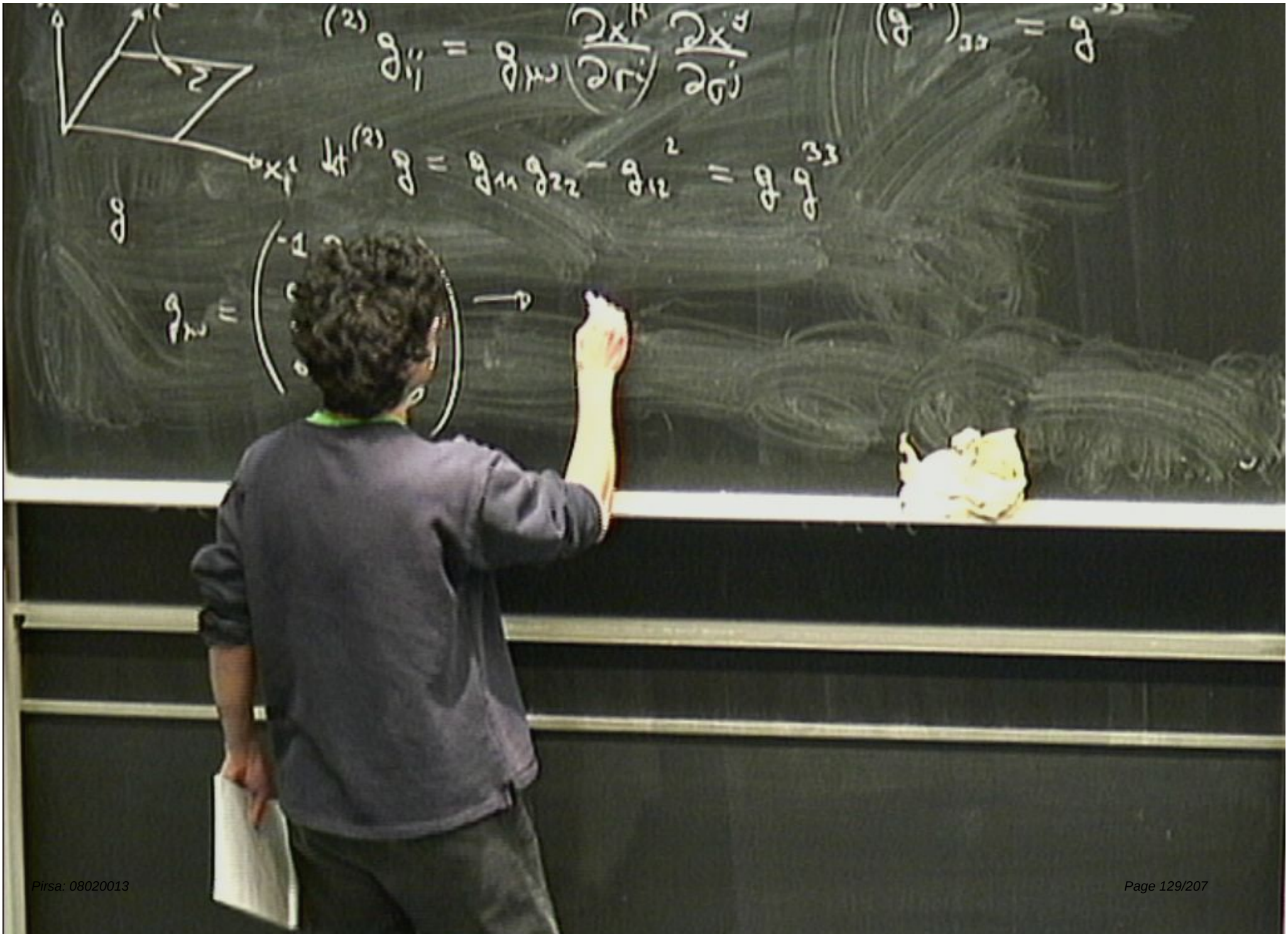
$$^{(2)}g_{ij} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$$

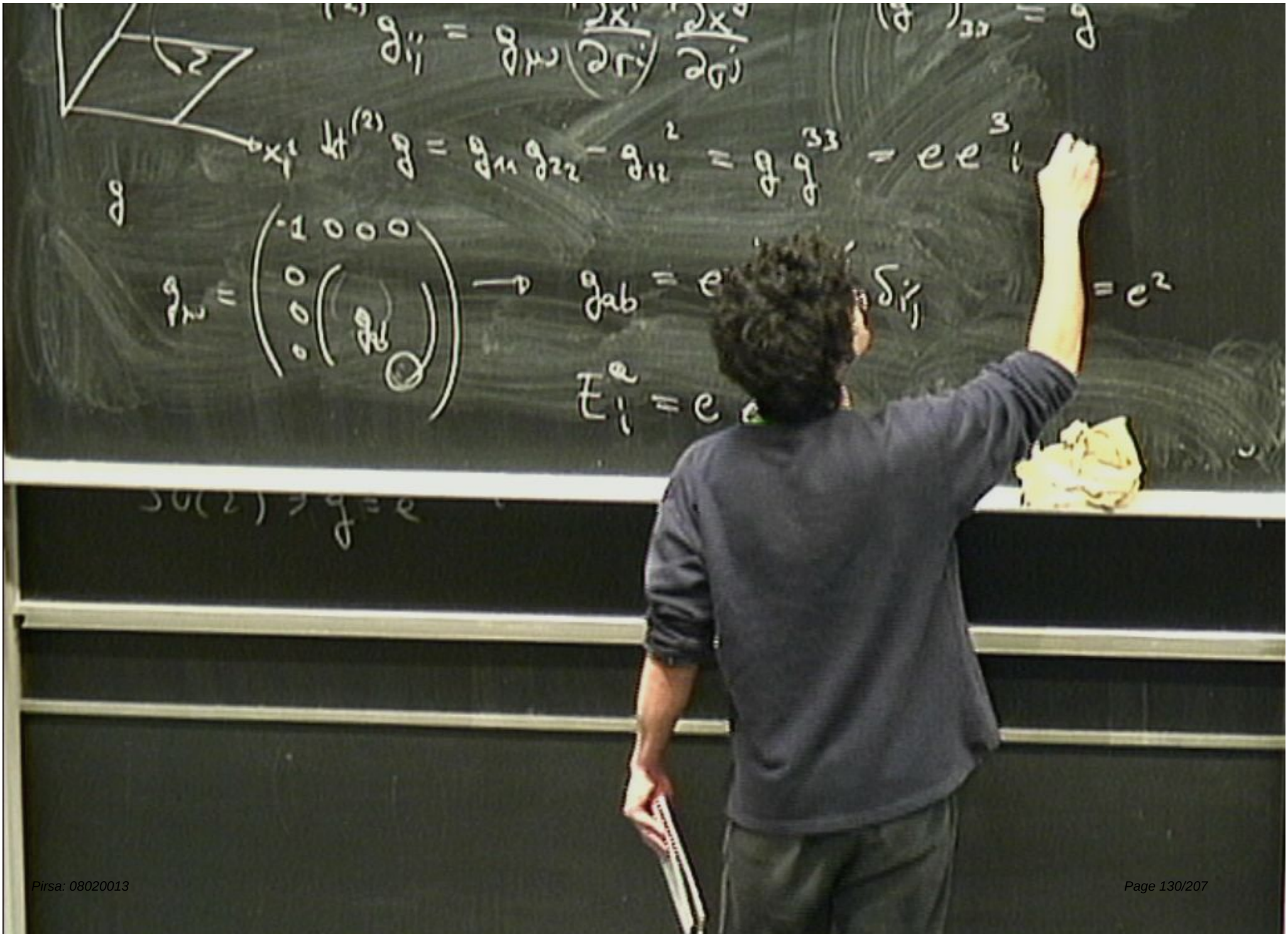
$$\det {}^{(2)}g = g_{11} g_{22} - g_{12}^2 =$$

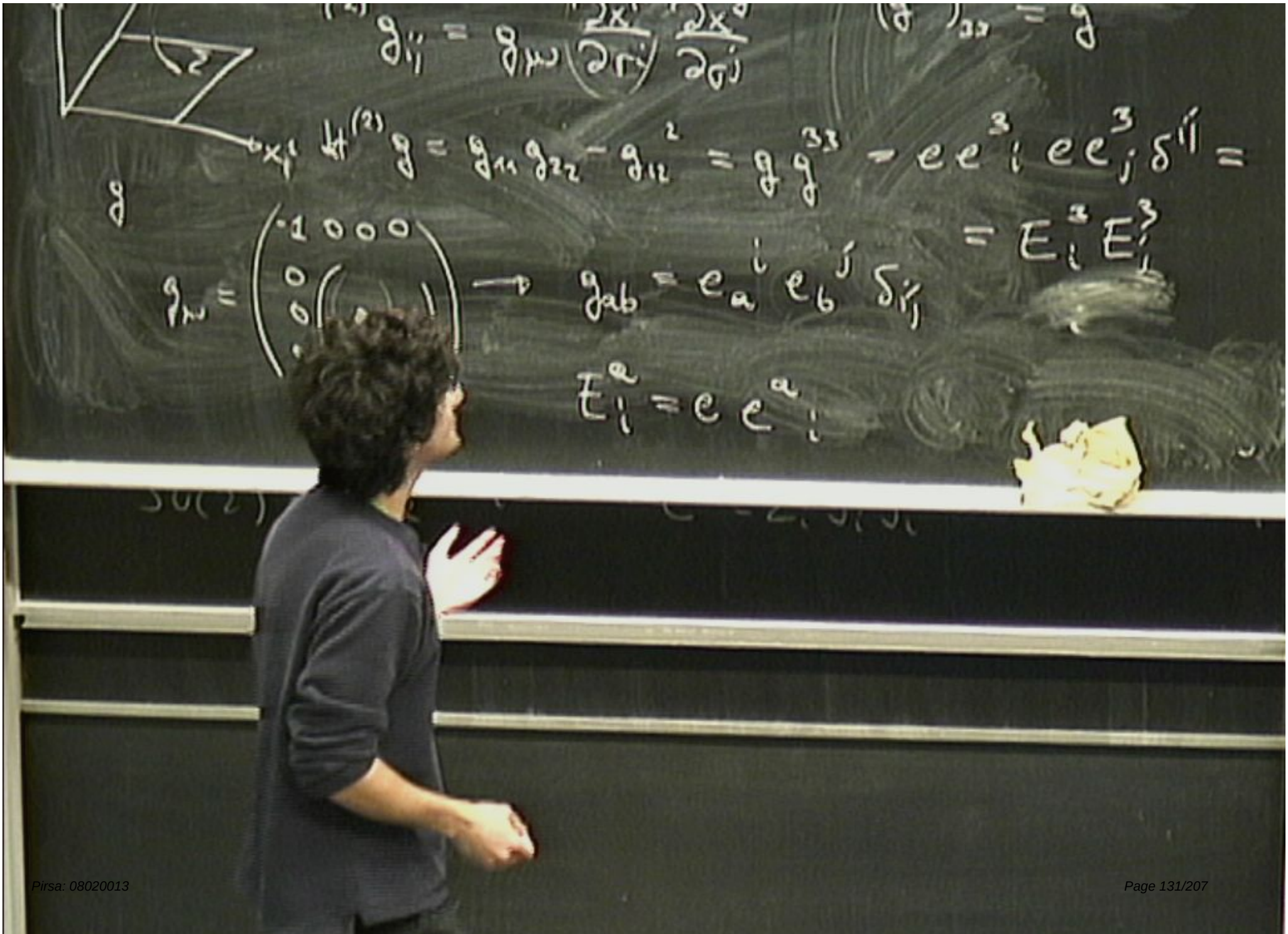
$$\begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & g_{ab} & \\ 0 & & & \end{pmatrix}$$


$\{A_a^i(\vec{x}), E^b_j(\vec{y})\} = \delta^i_j \, \delta^b_a \, \delta^{(3)}(\vec{x}-\vec{y})$
$A_2 = \int d\sigma_1 \, d\sigma_2 \sqrt{\det^{(2)} g_{ij}}$
x^3
x^2
x^1
Σ
$^{(2)} g_{ij} = \ldots \frac{\partial x^\mu}{\partial \sigma^j}$
$\det^{(2)} g = 0$
(g^{-1})


$\{A_a^i(\vec{x}), E_j^b(\vec{y})\} = \delta_j^i \delta_a^b \delta^{(3)}(\vec{x}-\vec{y})$
$A_2 = \int d\sigma_1 d\sigma_2 \sqrt{\det^{(2)} g_{ij}}$
x^3
x^2
$g_{ij} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$
$(g^{-1})_{33} = g^{33}$
$g = g_{11} g_{22} - g_{12}^2 = g\, g$


$g^{(2)}_{ij} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$
$\det{}^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33}$
$g_{\mu\nu} =$


$g_{ij} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$
$\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e\, e^3$
$g_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & g_{ab} & \\ 0 & & & \end{pmatrix} \longrightarrow g_{ab} = e$
δ_{ij}
$= e^2$
$E^a_i = e$


$g_{ij}^{(2)} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$
x_i^1
$\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$
$= E^3_i E^3_j$
$g_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & & \end{pmatrix} \longrightarrow g_{ab} = e_a^i e_b^j \delta_{ij}$
$E^a_i = e e^a_i$

$\psi \in \mathcal{H}$

$[\hat{A}, \hat{E}] = i\delta$

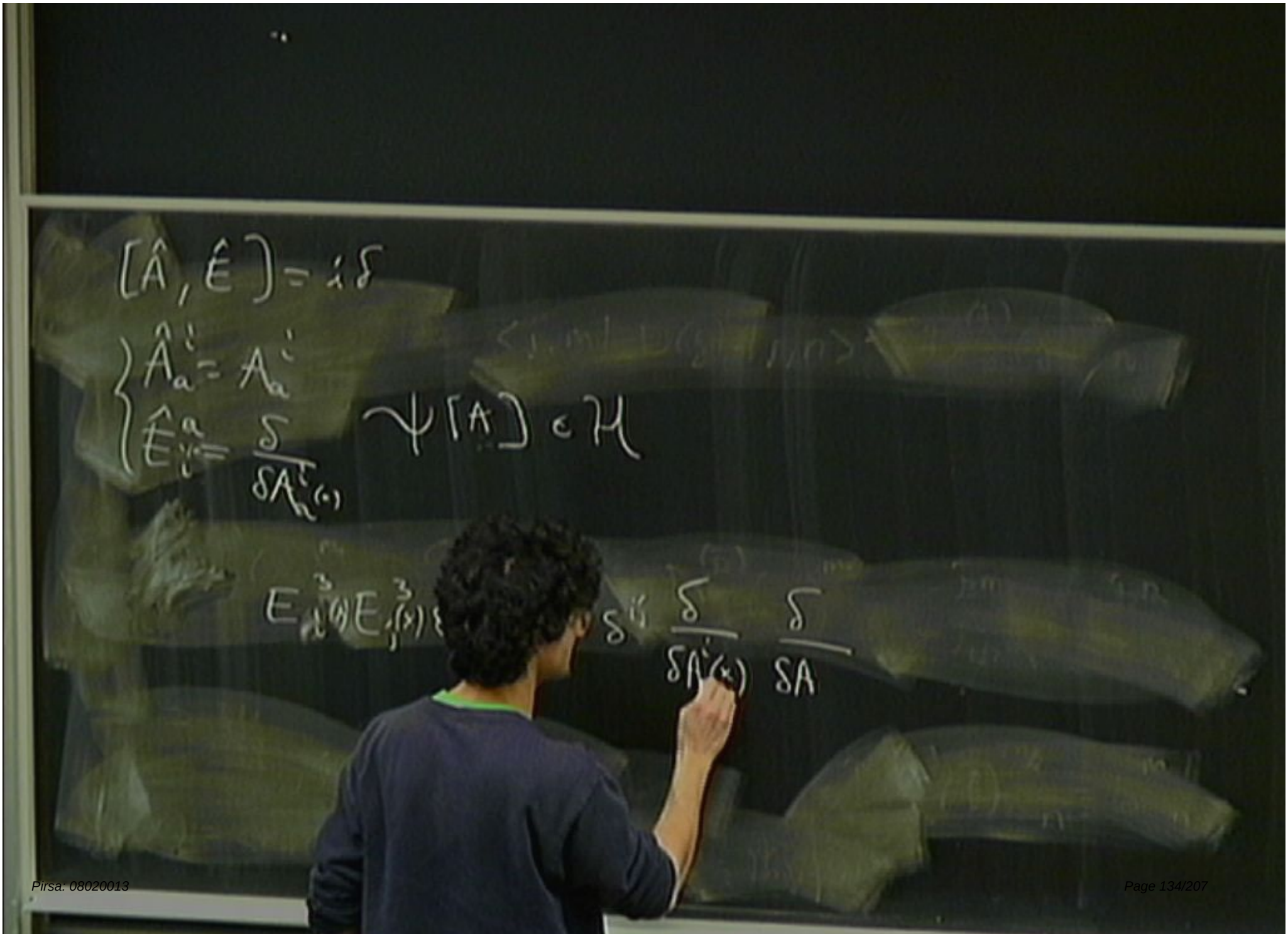
$\hat{A} = A$

$\hat{E} = \frac{\delta}{\delta A}$ $\quad \psi[A] \in \mathcal{H}$

$\psi \in \mathcal{H}$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(x)} \end{cases} \qquad \psi[A] \in \mathcal{H}$$


[Â, Ê] = iδ
Â = A
Ê = δ/δA
ψ[A] ∈ H

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(\cdot)} \end{cases} \qquad \psi[A] \in \mathcal{H}$$

$$E_i^3(x) E_j^3(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_i^i(x)} \frac{\delta}{\delta A_j^j(x)}$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(x)} \end{cases} \qquad \psi[A] \in \mathcal{H}$$

$$E_i^3(x) E_j^3(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_i^i(x)} \frac{\delta}{\delta A_j^j(x)}$$

$$= \int_0^L dx^1 dx^2$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(\cdot)} \end{cases} \qquad \psi[A] \in \mathcal{H}$$

$$E_i^3(x) E_j^3(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_i^i(x)} \frac{\delta}{\delta A_j^j(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(\cdot)} \end{cases}$$

$$\psi[A] \in \mathcal{H} \qquad \psi[A] = \ldots \; e^{\int_\ell A}$$

$$\ldots(x)\delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_a^i(x)} \frac{\delta}{\delta A_b^j(x)} = \hat{a}(x)$$

$$A \ldots \sqrt{\hat{a}(x,x')}$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(\cdot)} \end{cases}$$

$$\psi[A] \in \mathcal{H} \qquad \psi[A] = \ldots \; e^{\int_\Sigma A}$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots))$$

$$E_i^3(x) E_j^3(x) \delta^{ij} \mapsto \frac{\delta}{\delta A_3^j(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\ldots}$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(x)} \end{cases}$$

$$\psi[A] \in \mathcal{H} \qquad \psi[A] = \dots e^{\int_\ell A}$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$$

$$E_i^3(x) E_j^3(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_3^i(x)} \frac{\delta}{\delta A_3^j(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}^a_i = \dfrac{\delta}{\delta A_a^i(x)} \end{cases} \qquad \psi[A] \in \mathcal{H} \qquad \psi[A] = \dots e^{\int_\Sigma A}$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(x)} f(A(\overset{x}{\cdot})) = 0$$

$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}^a_i = \dfrac{\delta}{\delta A_a^i(\cdot)} \end{cases} \qquad \psi[A] \in \mathcal{H} \qquad \psi[A] = \ldots \; e^{\int_\ell A}$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ell)) = 0$$

$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_i^3(x)} \frac{\delta}{\delta A_j^3(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^1 dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$D_a E^a_i = 0$$

$$E_{i}(x)E_{j}(x)\delta^{ij} \longmapsto \delta^{ij}\frac{\delta}{\delta A_{i}^{a}(x)}\frac{\delta}{\delta A_{j}^{a}(x)} = \hat{a}(x)$$

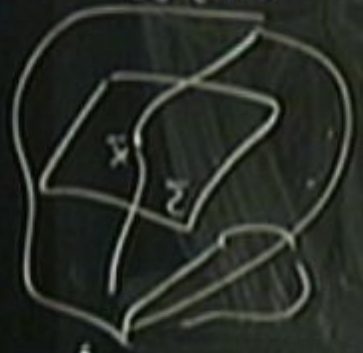
$$A_{\Sigma} = \int_{0}^{L} dx^{1}dx^{2}\sqrt{\hat{a}(x^{1},x^{2})}$$

$$_{B} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$E_{i}(x)E_{j}(x)\delta^{ij} \longmapsto \delta^{ij}\frac{\delta}{\delta A^{i}_{a}(x)}\frac{\delta}{\delta A^{j}_{b}(x)} = \hat{a}(\vec{x})$$

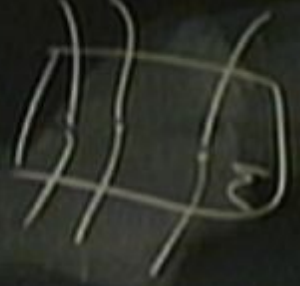
$$A_{\Sigma} = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

$\hat{a}(\vec{x})$

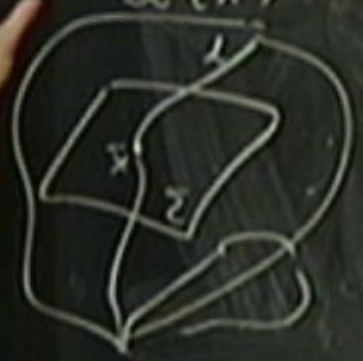


$$\delta^{A}{}_{B} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

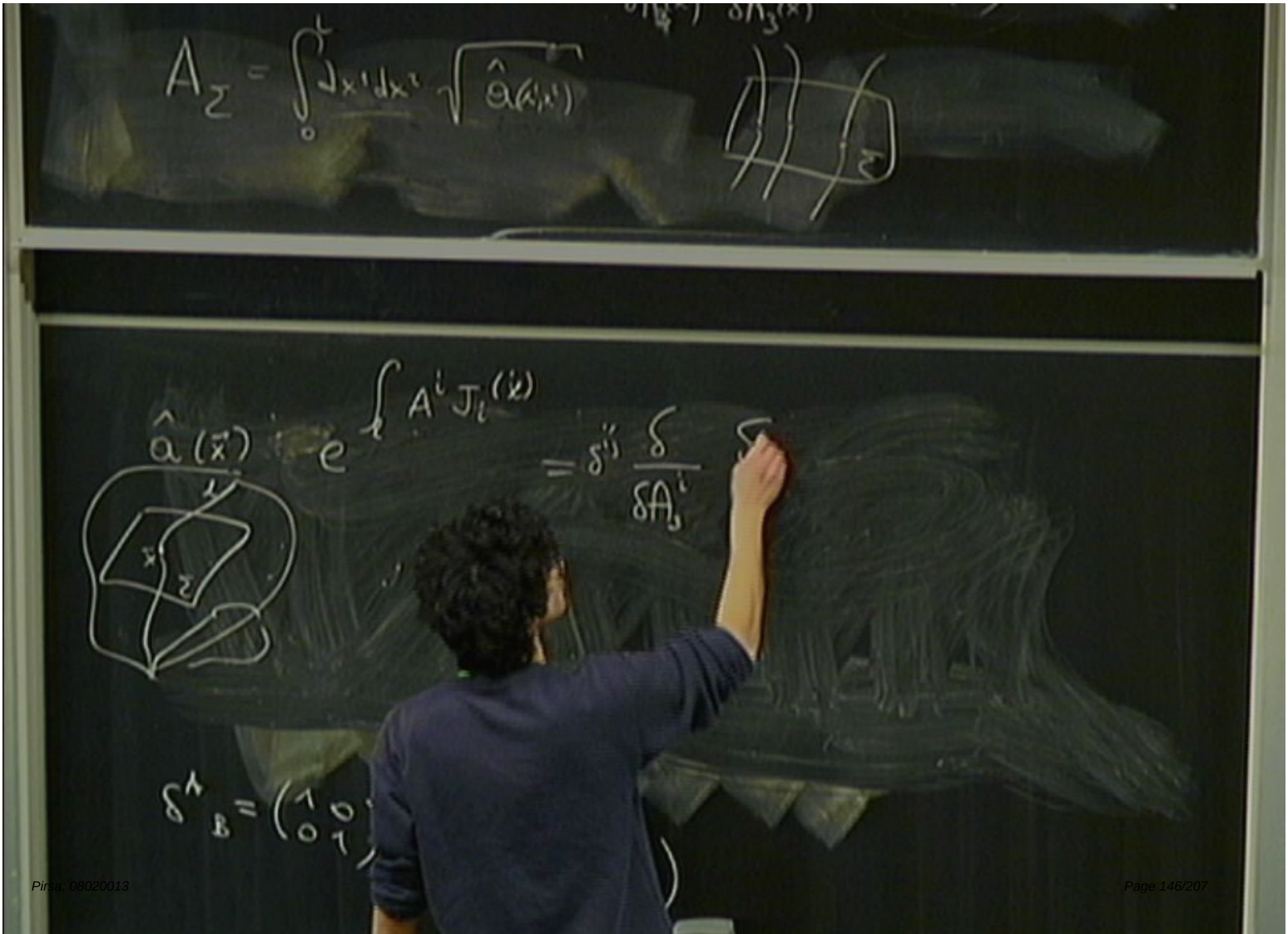
$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$



$$\hat{a}(\vec{x}) = e^{\int A^i J_i(x)}$$



$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

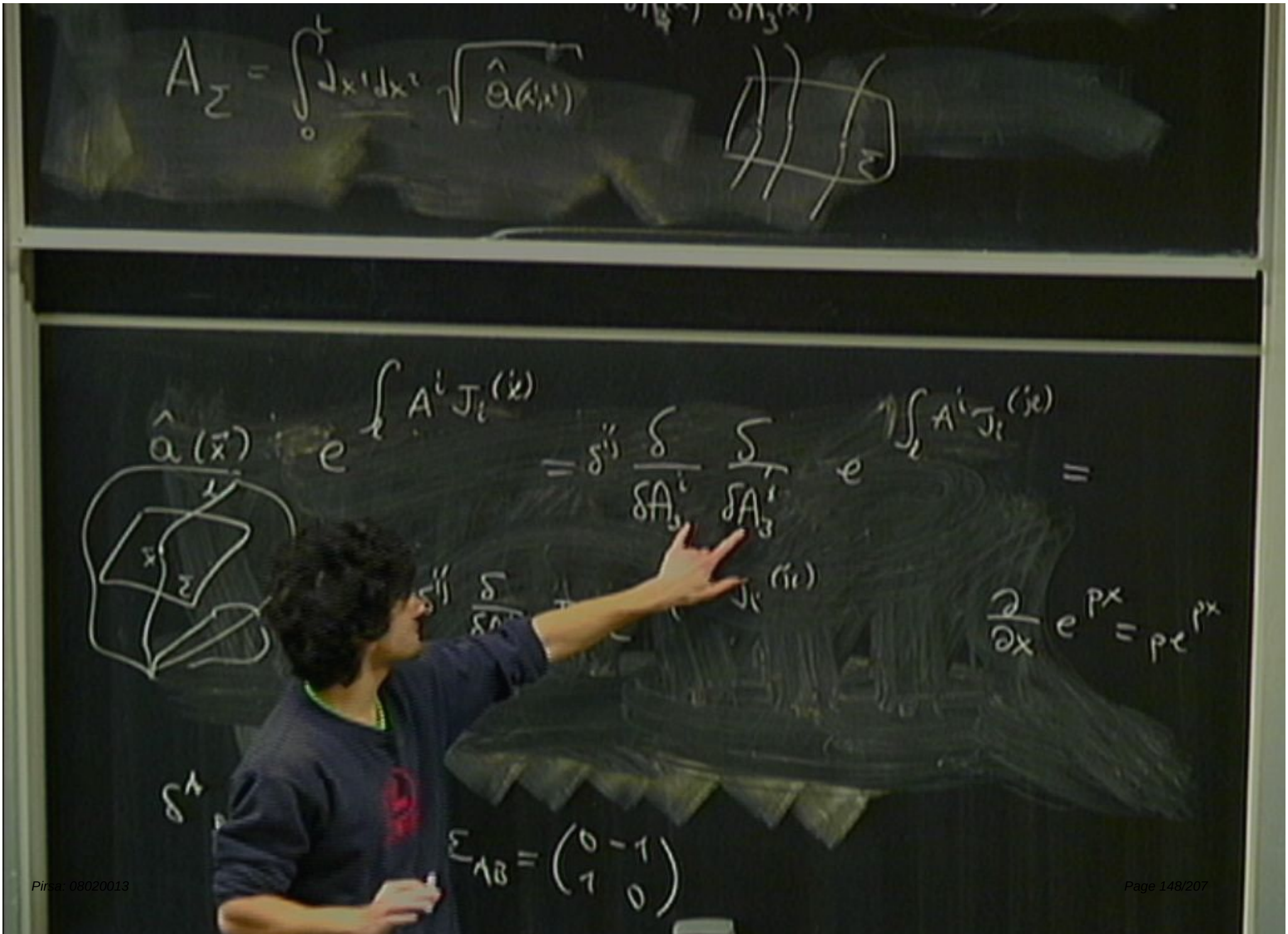

$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$
Σ
$\hat{a}(\vec{x}) = e^{\int A^i J_i(x)}$
$= \delta^{ij} \frac{\delta}{\delta A_j^i}$
Σ
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

$$\hat{a}(\vec{x})\, e^{i\int A^i J_i(x)} = \delta^{ij} \frac{\delta}{\delta A_3^i} \frac{\delta}{\delta A_3^j} e^{i\int A^i J_i(x)} =$$

$$= \qquad \frac{\partial}{\partial x} e^{px} = p e^{px}$$

$$\varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$


$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$
$\hat{a}(\vec{x}) = e^{\ell \int A^i J_i(\vec{x})}$
$= \delta^{ij} \frac{\delta}{\delta A_3^i} \frac{\delta}{\delta A_3^j} e^{\eta \int_\ell A^i J_i(\vec{x})} =$
$\frac{\partial}{\partial x} e^{px} = p e^{px}$
$\varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

$$\hat{a}(\vec{x})\, e^{\int A^i J_i(x)} = \delta^{ij} \frac{\delta}{\delta A_j^i} \frac{\delta}{\delta A_j^i} e^{\int A^i J_i(x)} =$$

$$= \delta^{ij} \frac{\delta}{\delta A_j^i} J_j\, e^{\int A^i J_i(x)}$$

$$\frac{\partial}{\partial x} e^{px} = p e^{px}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$A_\Sigma = \int_0^1 dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

$$\hat{a}(\vec{x})\, e^{\int A^i J_i^{(k)}} = \delta^{ij} \frac{\delta}{\delta A_3^i} \frac{\delta}{\delta A_3^j} e^{\int A^i J_i^{(k)}} =$$

$$= \delta^{ij} \frac{\delta}{\delta A_3^i} J_j\, e^{\int A^i J_i^{(k)}}$$

$$= \Sigma_i J$$

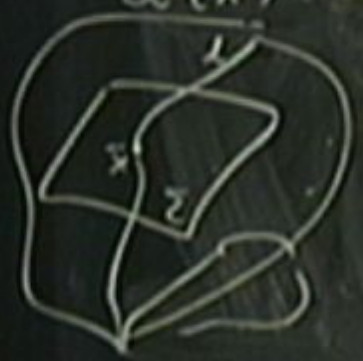
$$\frac{\partial}{\partial x^i} e^{p^i x_i} = p_i e^{p^i x_i}$$

$$\delta^{ij} \frac{\partial}{\partial x^i} \frac{\partial}{\partial x^j} e^{p^i x_i} = p^2 e^{p^i x_i}$$

$$, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

$$\hat{a}(\vec{x}) \; e^{\int_\ell A^i J_i^{(\ell)}} = \delta^{ij} \frac{\delta}{\delta A_j^i} \frac{\delta}{\delta A_j^i} e^{\int_\ell A^i J_i^{(\ell)}} =$$



$$= \delta^{ij} \frac{\delta}{\delta A_j^i} J_j \, e^{\int_\ell A^i J_i^{(\ell)}}$$

$$= \Sigma_i J_i J_i \, e^{\int_\ell A^i J_i^{(\ell)}}$$

$$\frac{\partial}{\partial x^i} e^{p^i x_i} = p_i e^{p^i x_i}$$

$$\delta^{ij} \frac{\partial}{\partial x^j} \frac{\partial}{\partial x^i} e^{p^i x_i} = p^2 e^{p^i x_i}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$\delta A_3^i(x)\,\delta A_3^j(x) = a(\vec{x})$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

$$\hat{a}(\vec{x})\, e^{\int A^i J_i(k)} = \delta^{ij} \frac{\delta}{\delta A_3^i} \frac{\delta}{\delta A_3^j} e^{\int A^i J_i(k)} =$$

$$= \delta^{ij} \frac{\delta}{\delta A_3^i} J_j\, e^{\int A^i J_i(k)}$$

$$\frac{\partial}{\partial x^i} e^{p^i x_i} = p_i e^{p^i x_i}$$

$$= \Sigma_i J_i J_i\, e^{\int A^i J_i(k)}$$

$$\delta^{ij} \frac{\partial}{\partial x^j} \frac{\partial}{\partial x^i} e^{p^i x_i} = p^2 e^{p^i x_i}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

x_i^1 $\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i\, e e^3_j\, \delta^{ij} =$

g

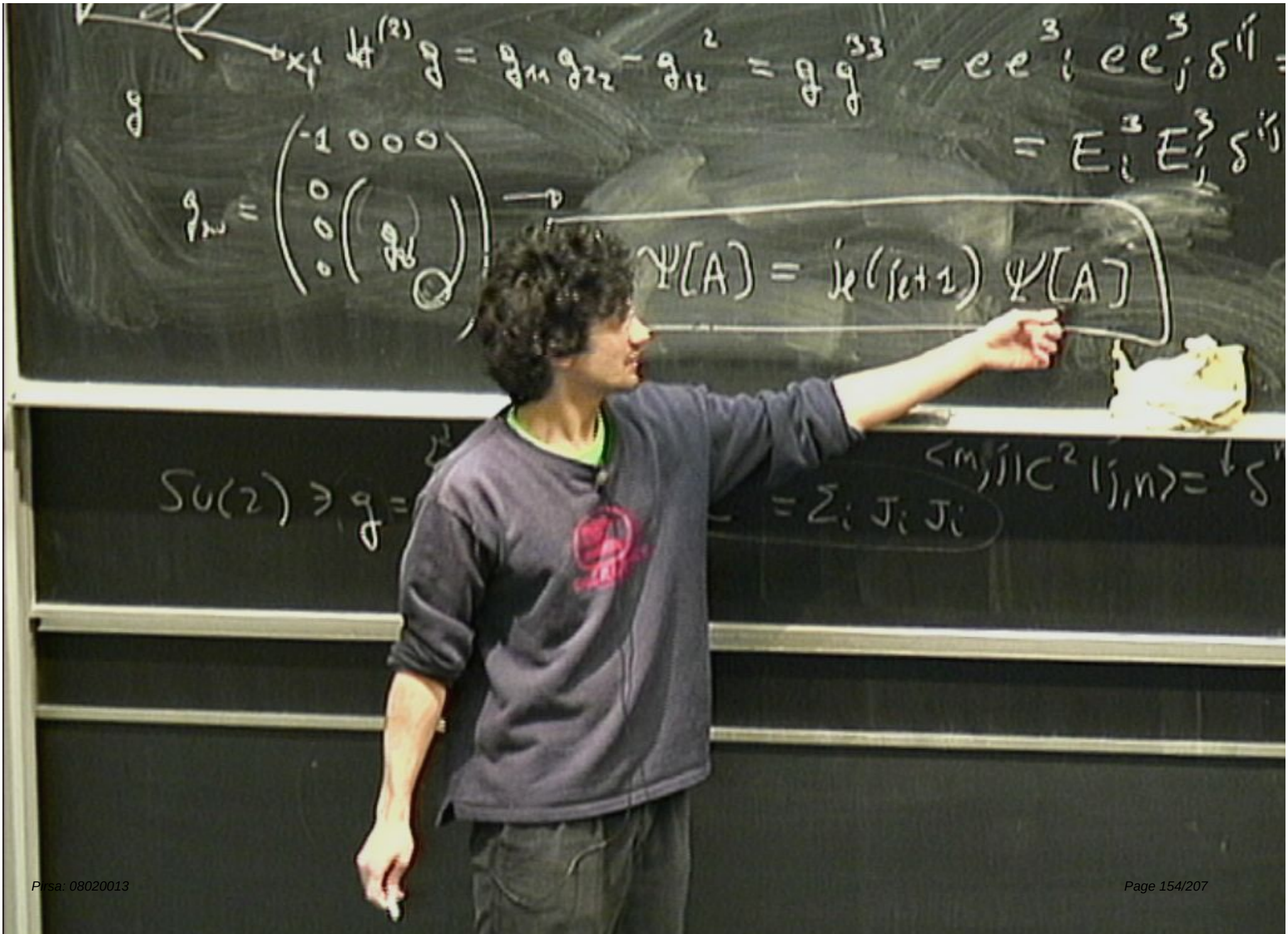
$= E^3_i E^3_j \delta^{ij}$

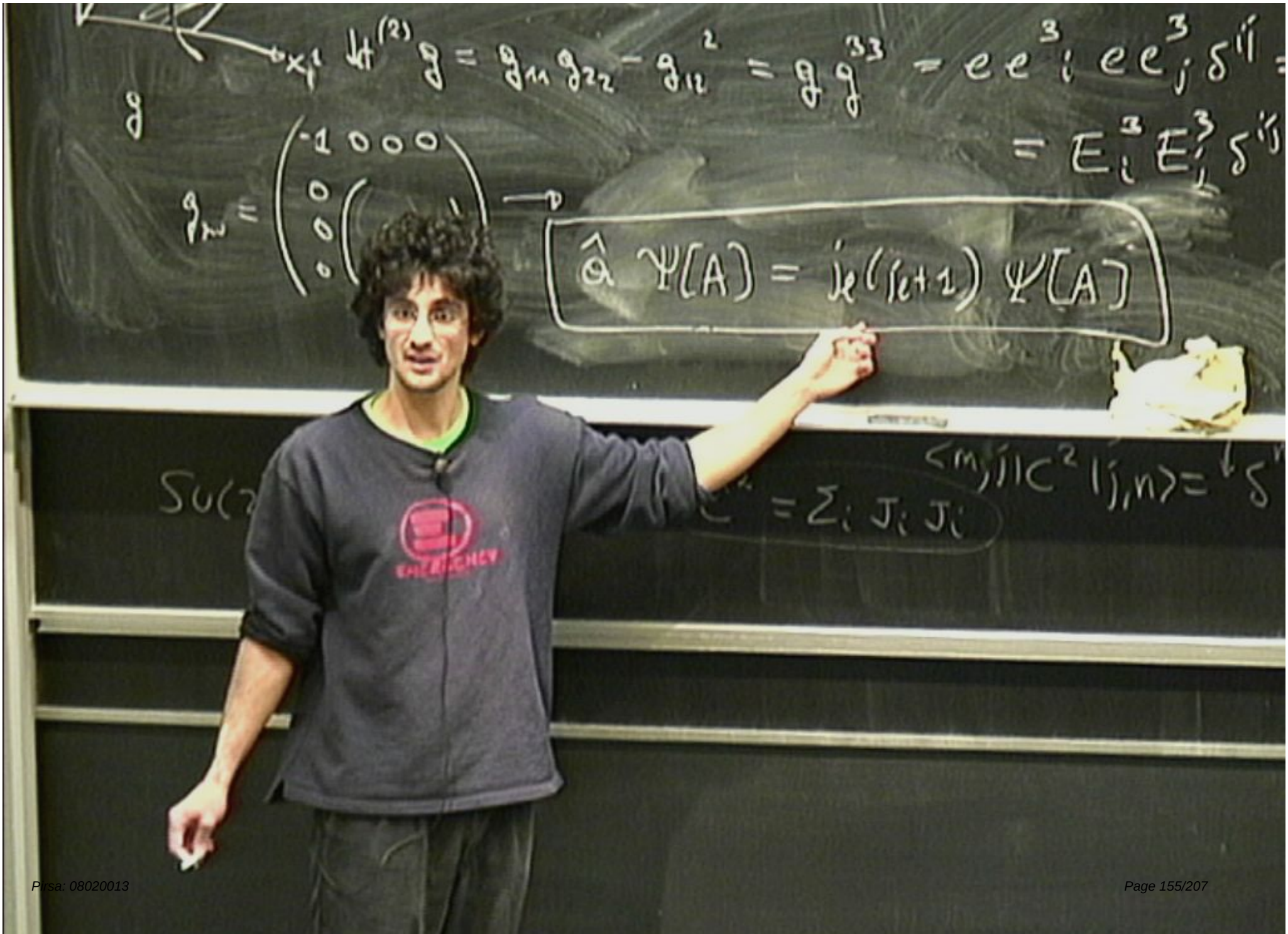
$$g_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & g_{ij} & \\ 0 & & & \end{pmatrix} \longrightarrow \hat{a}\, \Psi(A) =$$

$SU(2) \ni g = e^{\sum_i a^i J_i}$

$C^2 = \sum_i J_i J_i$

$\langle m, j | C^2 | j, n \rangle = \delta^{\ldots}$


Ψ[A] = ik(k+1) Ψ[A]
SU(2) ∋ g =
= Σ_i J_i J_i


$\hat{a}\,\Psi[A] = i\kappa(\kappa+1)\,\Psi[A]$
$= \Sigma_i J_i J_i$

$$\hat{a}(\vec{x}) : e^{\int_\ell A^i J_i(\dot{x})} = \delta^{ij} \frac{\delta}{\delta A_j^i} \frac{\delta}{\delta A_j^j} e^{\int_\ell A^i J_i(\dot{x})} =$$

$$= \delta^{ij} \frac{\delta}{\delta A_j^i} J_j e^{\int_\ell A^i J_i(\dot{x})}$$

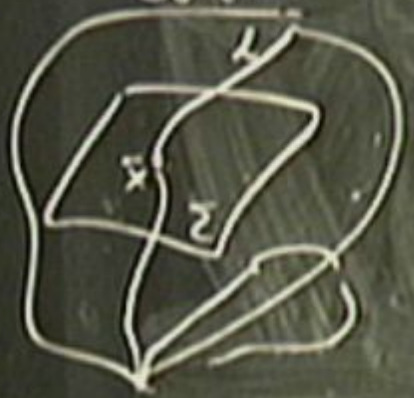
$$= \Sigma_i \underbrace{J_i J_i}_{\mathbb{1}(\dot{x}(k+1))} e^{\int_\ell A^i J_i(\dot{x})}$$

$$\frac{\partial}{\partial x^i} e^{p^i x}$$

$$\delta^i \frac{\partial}{\partial x^i} \frac{\partial}{\partial x^i} e^{p^i x}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$\hat{a}(\vec{x}) : e^{\int_\ell A^i J_i(\dot{x})} = \delta^{ij} \frac{\delta}{\delta A_j^i} \frac{\delta}{\delta A_j^j} e^{\int_\ell A^i J_i(\dot{x})} =$$



$$= \delta^{ij} \frac{\delta}{\delta A_j^i} J_j \, e^{\int_\ell A^i J_i(\dot{x})}$$

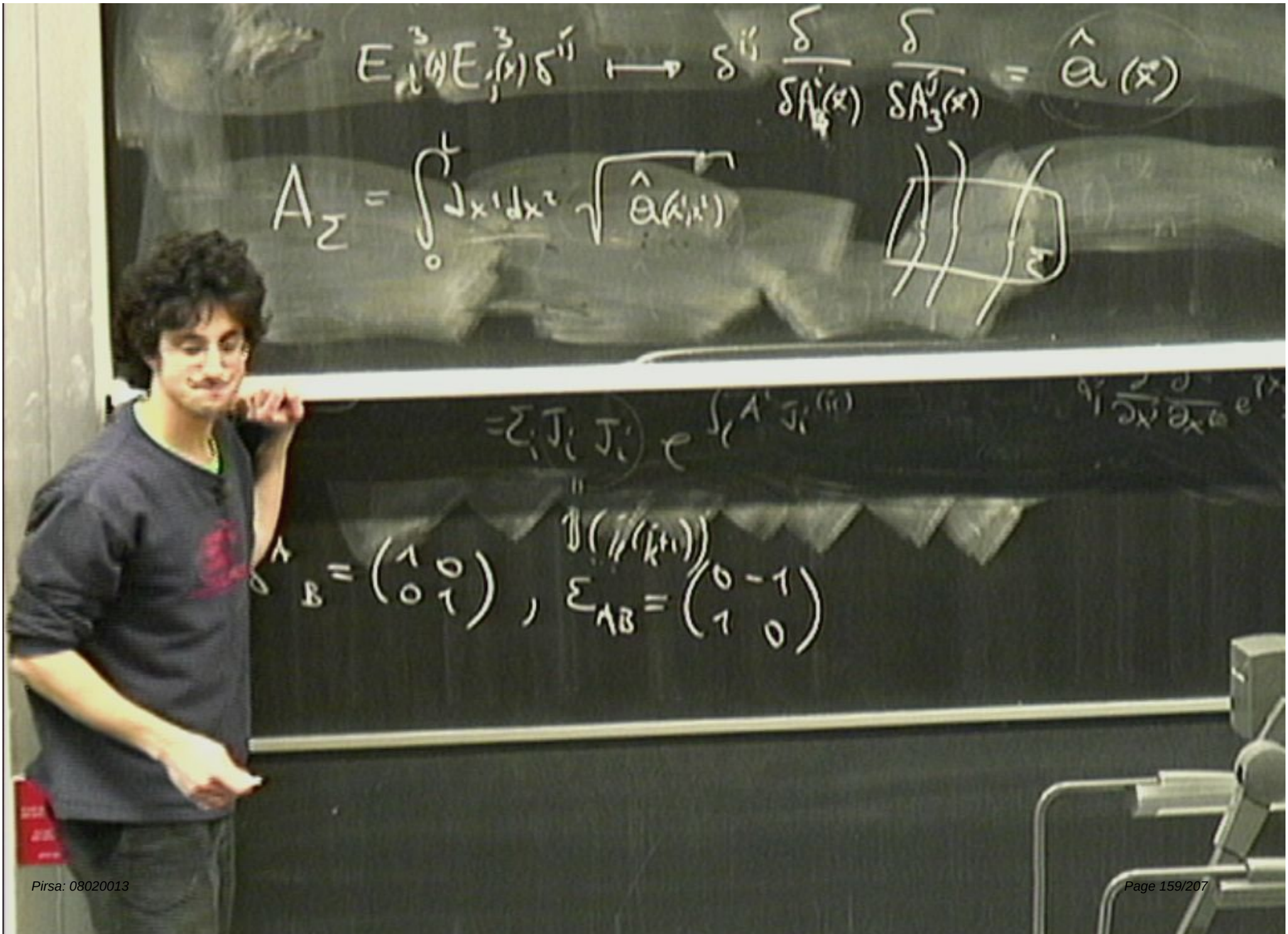
$$= \Sigma_i \underbrace{J_i J_i}_{\mathbb{1}(\dot{x}(k+1))} e^{\int_\ell A^i J_i(\dot{x})}$$

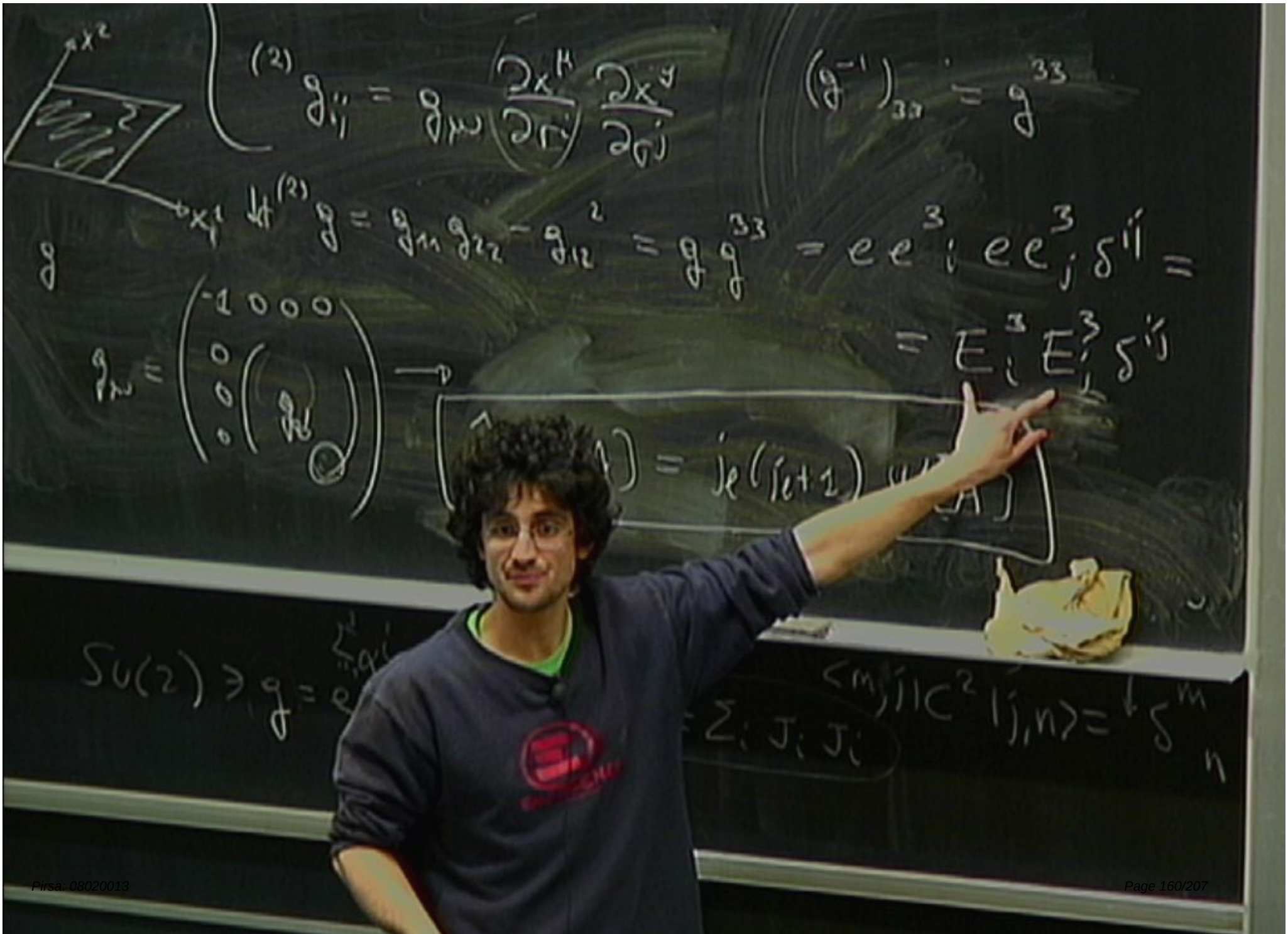
$$\frac{\partial}{\partial x^i} e^{p^i x}$$

$$\delta^{ij} \frac{\partial}{\partial x^j} \frac{\partial}{\partial x^i} e^{p^i x}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$\begin{tikzcd}
\mathcal{H} \arrow[r, "G_i=0"] & \mathcal{H}_0 \arrow[r, "\mathcal{H}^a=0"] & \mathcal{H}_D \arrow[r, "\mathcal{H}=0"] & \mathcal{H}_{Phys} \\
\psi(A) \arrow[u, phantom, "\in"] & W_\gamma(A) \arrow[u, phantom, "\in"] \arrow[d] & & \\
& \psi(\sigma, \{i_e\}, \{i_n\}) \; (\{g_e\}) & &
\end{tikzcd}$$


$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$
Σ
$= \Sigma_i J_i J_i \, e^{\int A^i J_i}$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \; \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$

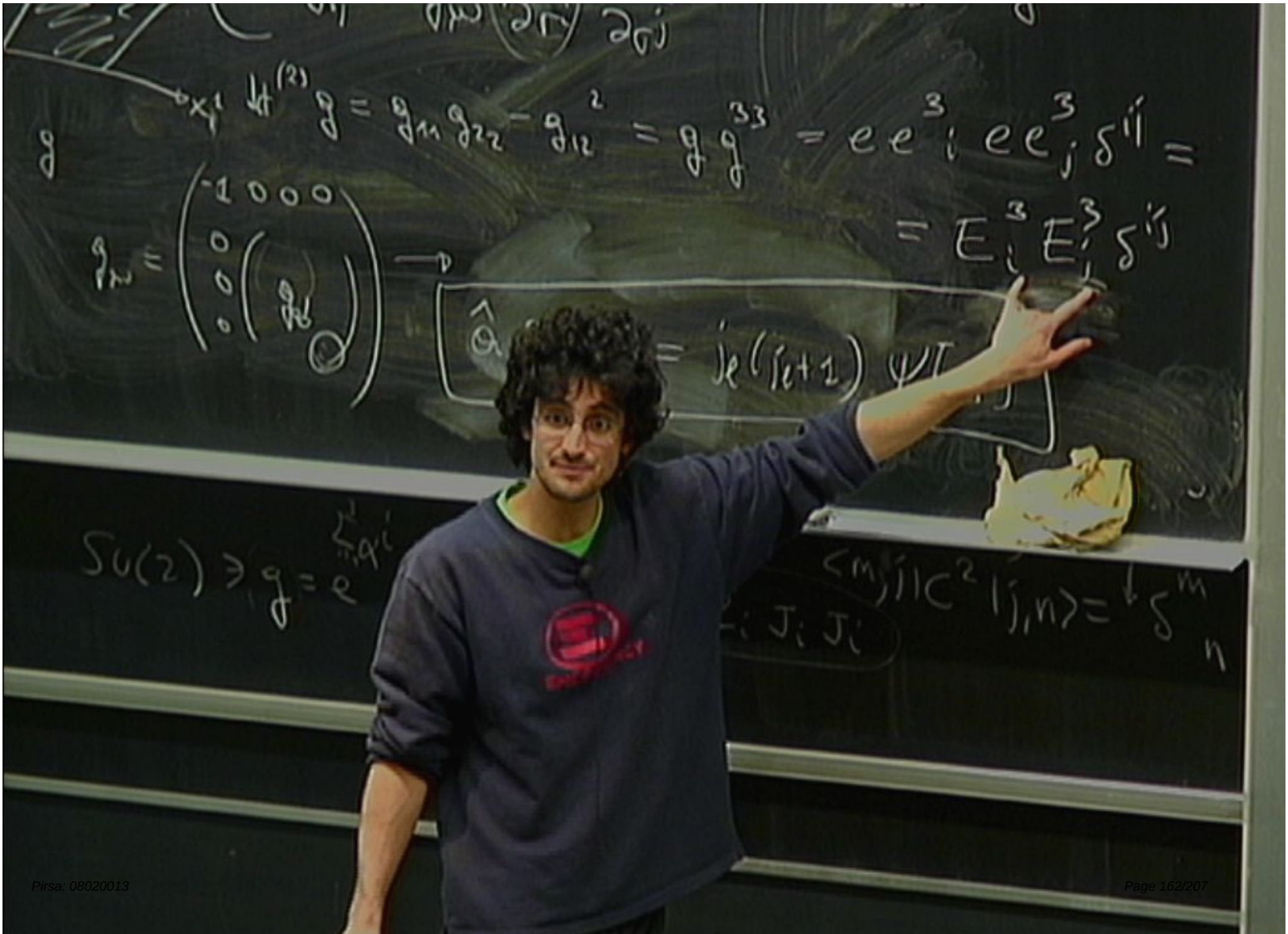

$g_{ij}^{(2)} = g_{\mu\nu} \frac{\partial x^\mu}{\partial \sigma^i} \frac{\partial x^\nu}{\partial \sigma^j}$
$(g^{-1})_{33} = g^{33}$
$\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$
$= E^3_i E^3_j \delta^{ij}$
$g_{\mu\nu} = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & g_{ab} & \\ 0 & & & \end{pmatrix}$
$SU(2) \ni g =$
$\langle m, j | C^2 | j, n \rangle = \delta^m_n$
$= \sum_i J_i J_i$

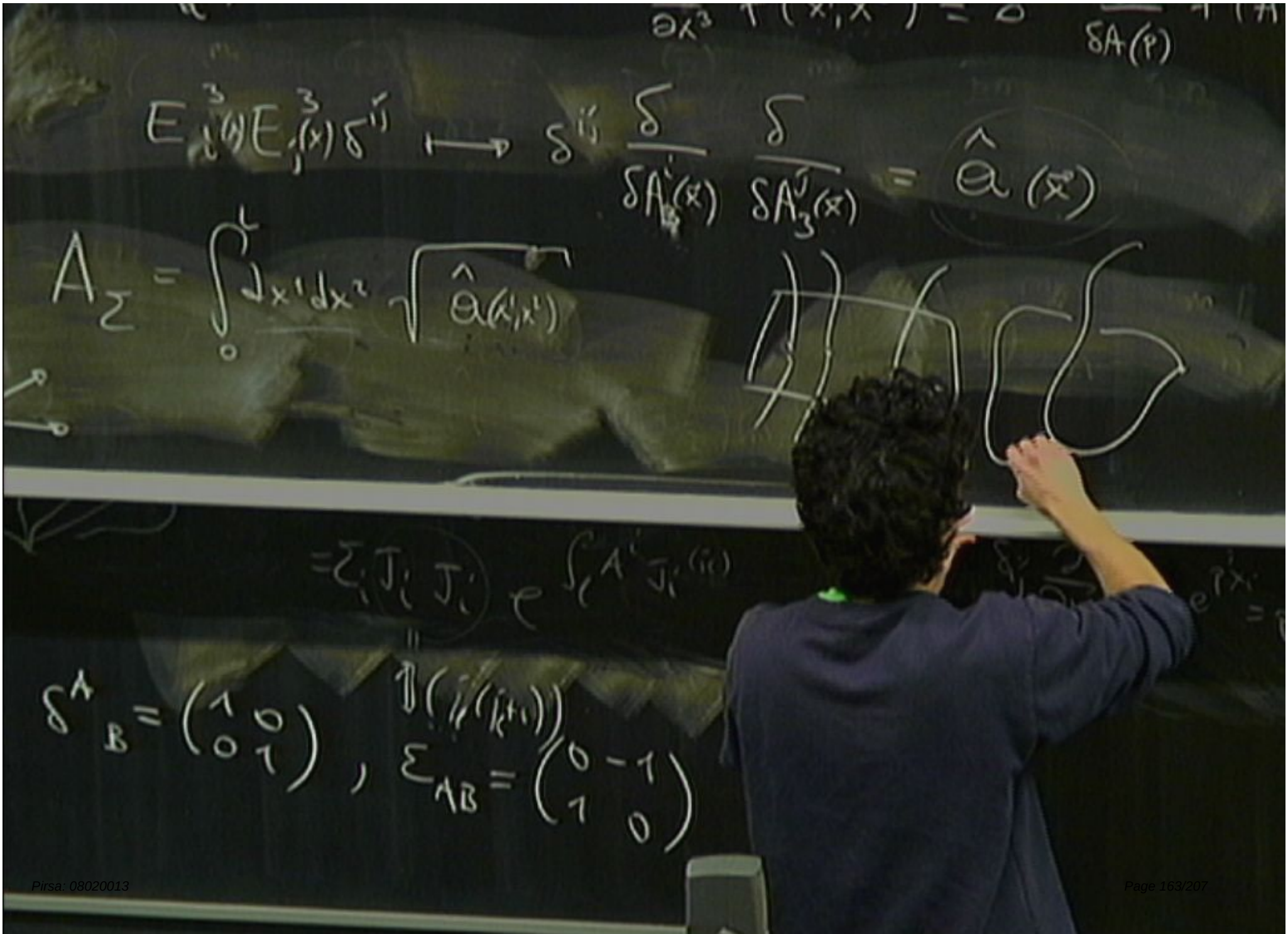
$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$$

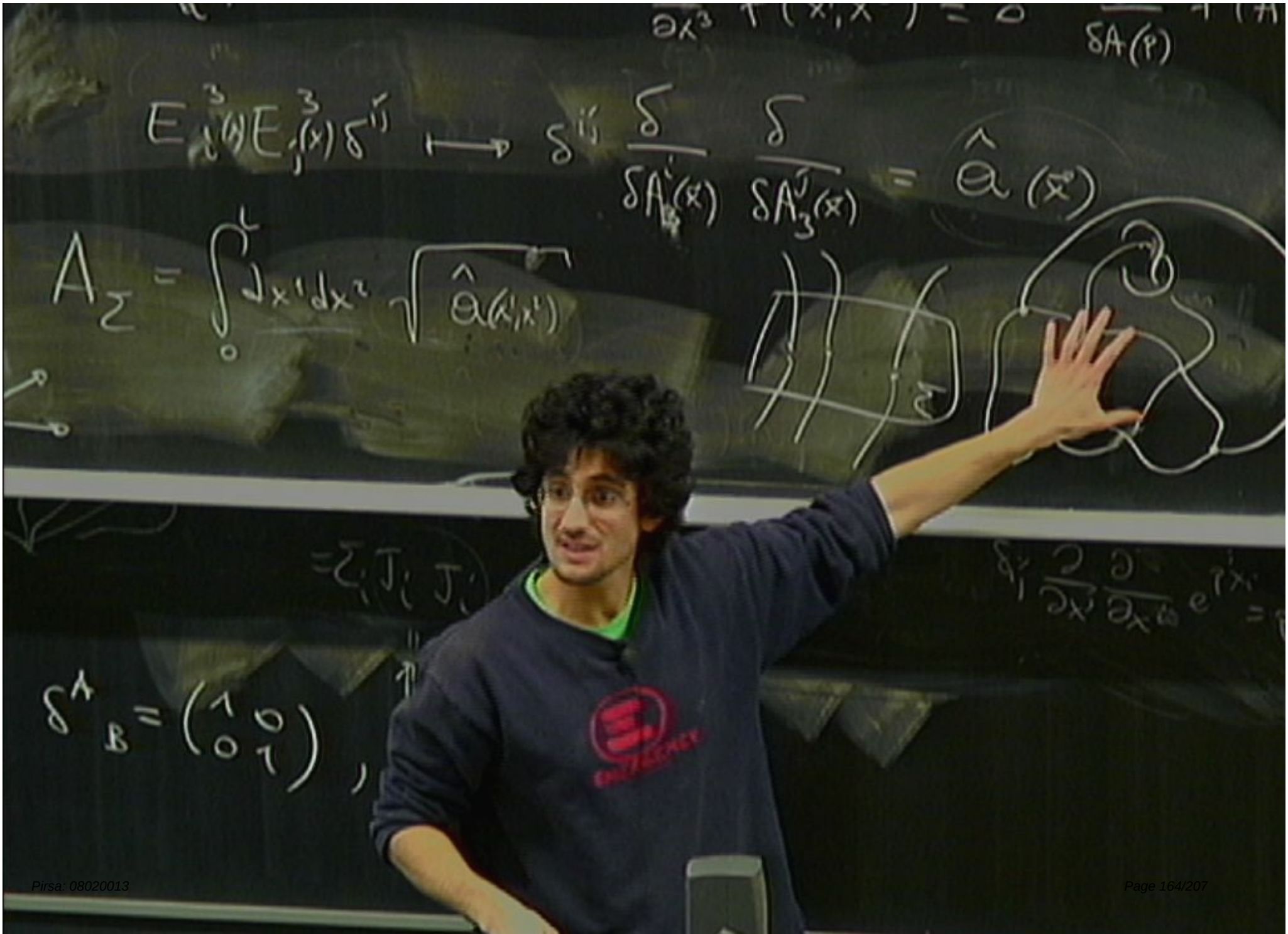
$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

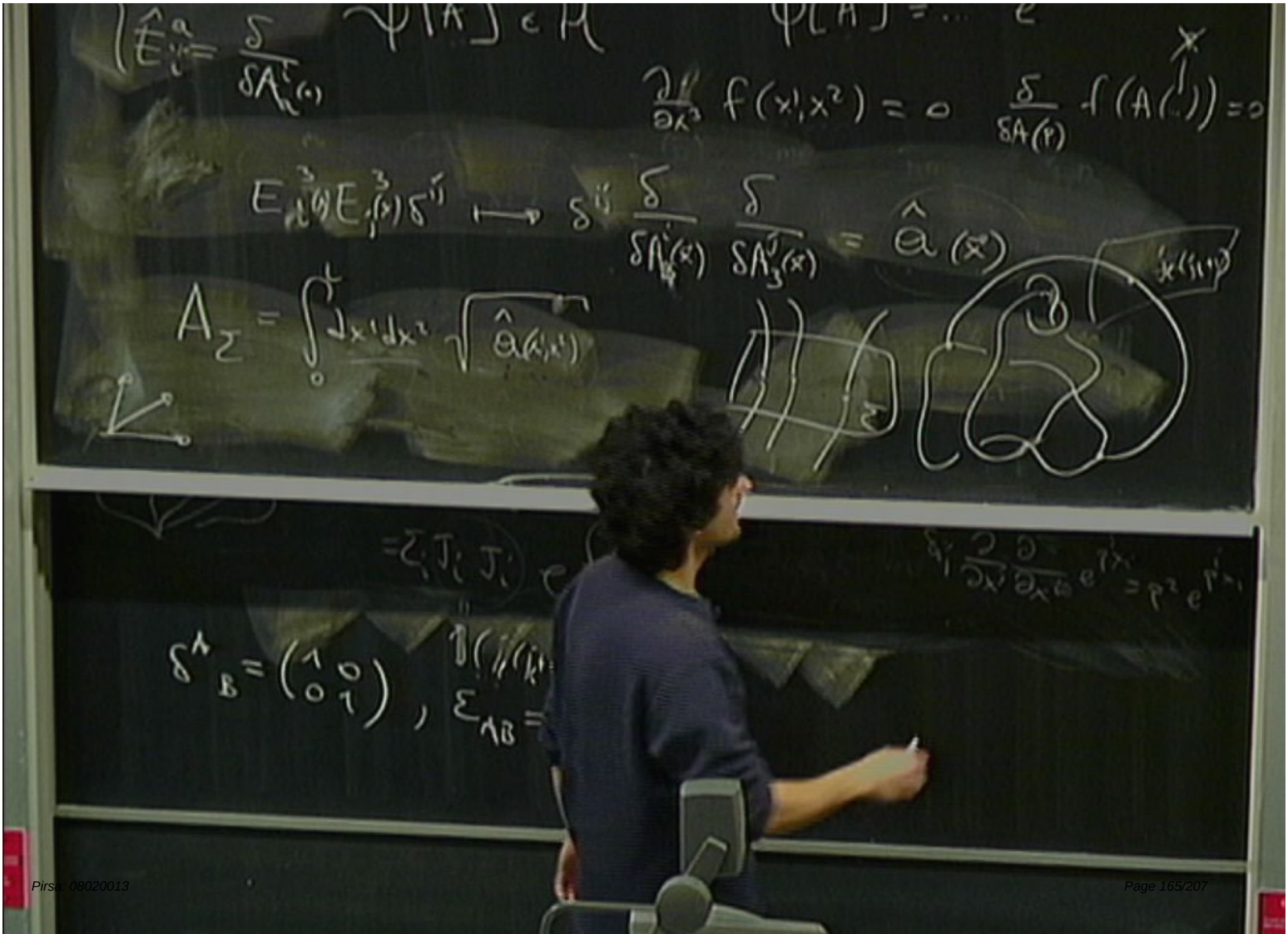
$$= \sum_i J_i J_i \, e^{\int_\Sigma A^i J_i(x)}$$

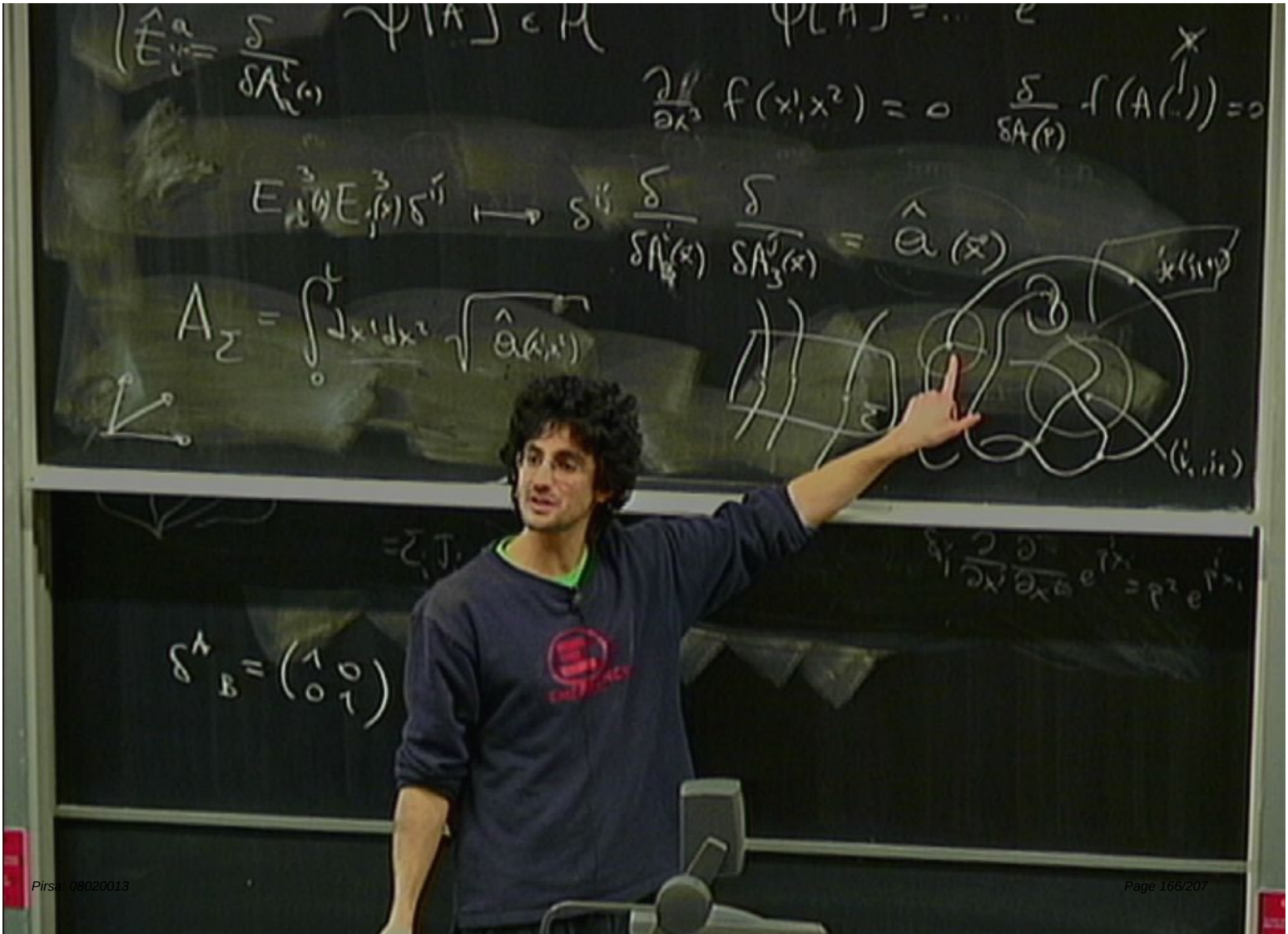
$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

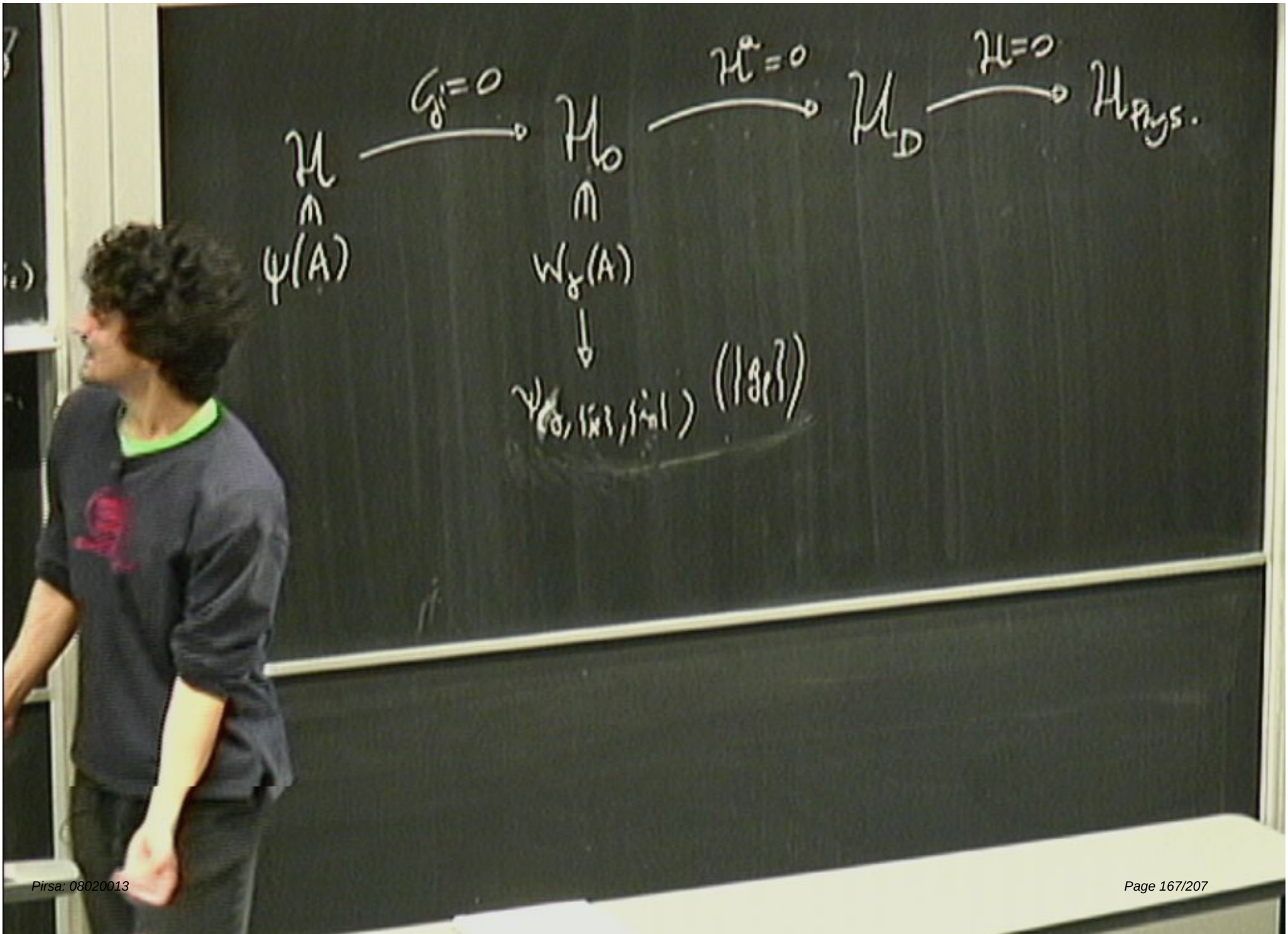

SU(2)


$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$


$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$


$\hat{E}^a_i = \frac{\delta}{\delta A^i_a(x)}$
$\psi[A] \in H$
$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0$
$\frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$
$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $\varepsilon_{AB} =$


$\hat{E}^a_i = \frac{\delta}{\delta A^i_a(x)}$
$\psi[A] \in \mathcal{H}$
$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0$
$\frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$
$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_4(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

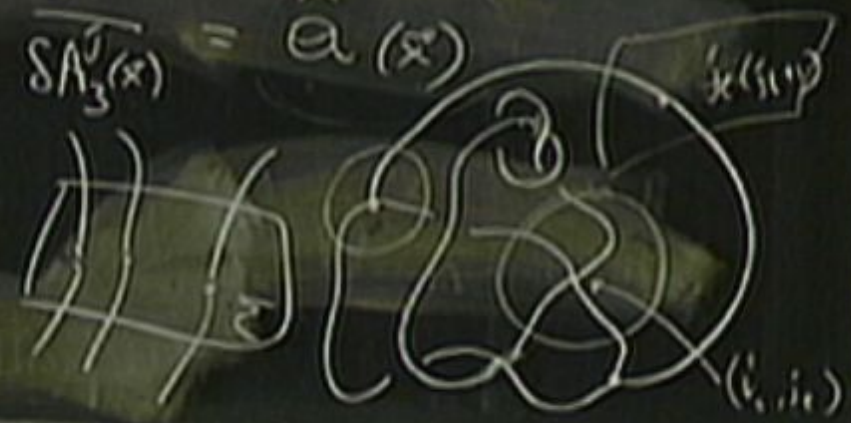

$\mathcal{H} \xrightarrow{G_i=0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a=0} \mathcal{H}_D \xrightarrow{\mathcal{H}=0} \mathcal{H}_{Phys.}$
$\psi(A) \in \mathcal{H}$
$W_\gamma(A) \in \mathcal{H}_0$
$\psi(\gamma, \{x\}, \{\dot{x}\})$
$(|\mathcal{S}_\gamma|)$

$$\hat{E}^a_i = \frac{\delta}{\delta A^i_a(x)} \qquad \psi[A] \in \mathcal{H} \qquad \psi[A] = \ldots e$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$$

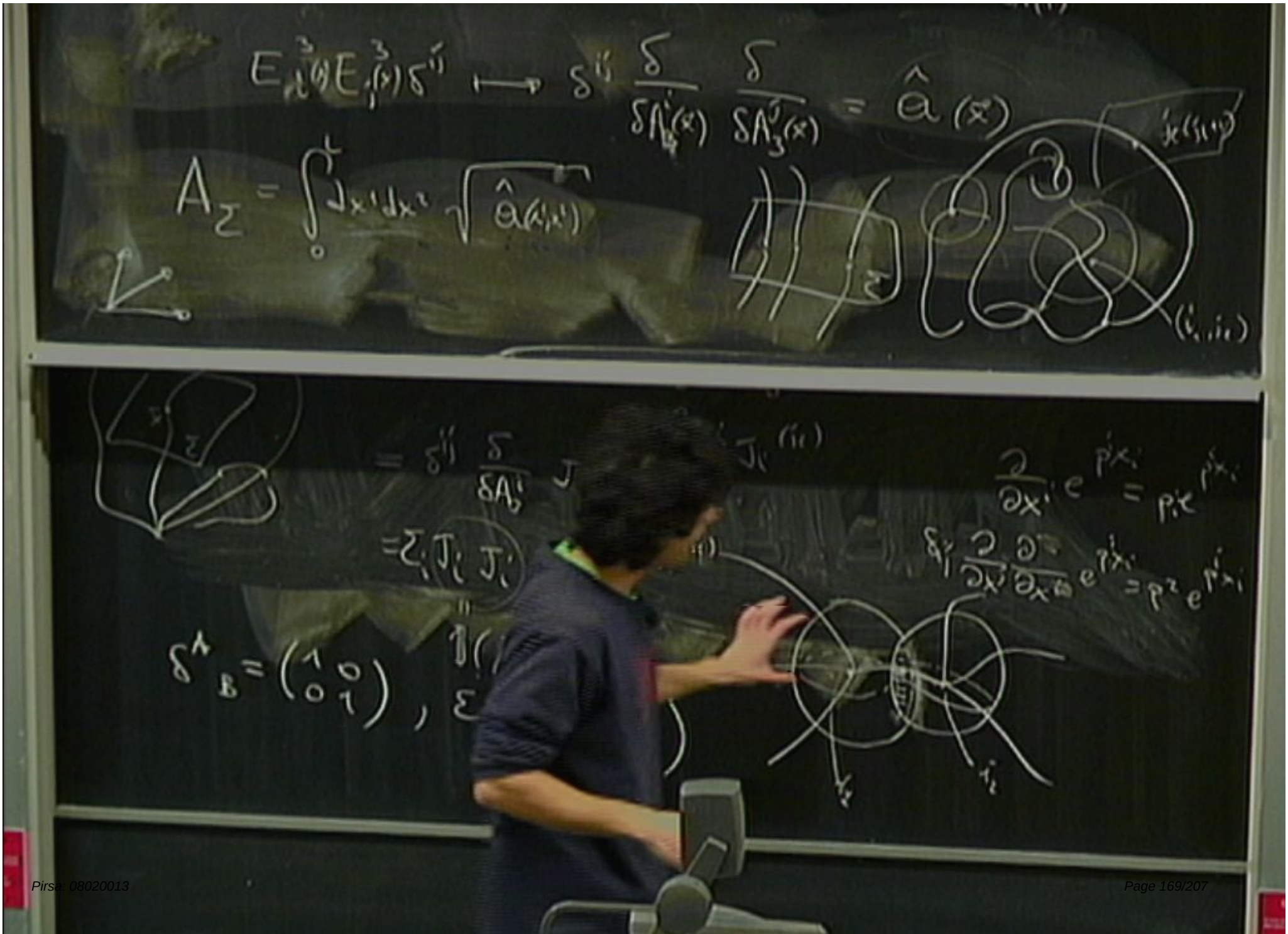
$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$



$$= \zeta_i J_i J_i \, e^{\int_\zeta A^i J_i(s)} \qquad \delta^{ij} \frac{\partial}{\partial x^i} \frac{\partial}{\partial x^j} e^{ix^i} = p^2 e^{ix^i}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$


$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$
$= \delta^{ij} \frac{\delta}{\delta A^i_3} J$
$= \Sigma_i J_i J_i$
$\frac{\partial}{\partial x^i} e^{p^i x_i} = p_i e^{p^i x_i}$
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

$$E^3_i(x)E^3_j(x)\delta^{ij} \longmapsto \delta^{ij}\frac{\delta}{\delta A^i_a(x)}\frac{\delta}{\delta A^j_b(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^1 dx^1 dx^2 \sqrt{\hat{a}(x^1,x^2)}$$

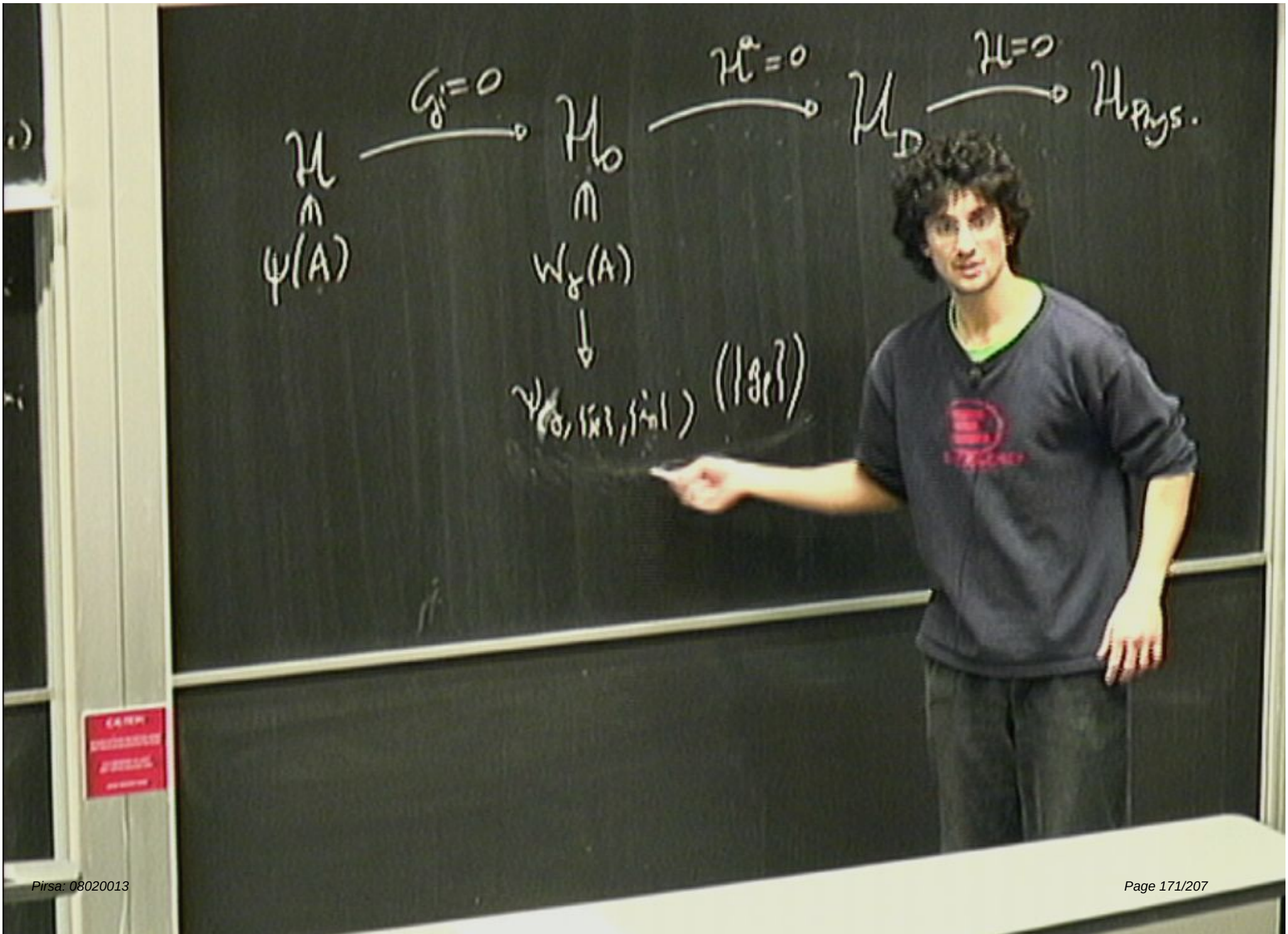
$$= \delta^{ij}\frac{\delta}{\delta A^i_j} J_j\, e^{\int_\Sigma A^i J_i(x)}$$

$$= \Sigma_i J_i J_i\, e^{\int_\Sigma A^i J_i(x)}$$

$$\frac{\partial}{\partial x^i} e^{p^i x_i} = p_i e^{p^i x_i}$$

$$\delta^i \frac{\partial}{\partial x^i}\frac{\partial}{\partial x^i} e^{p^i x_i} = p^2 e^{p^i x_i}$$

$$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

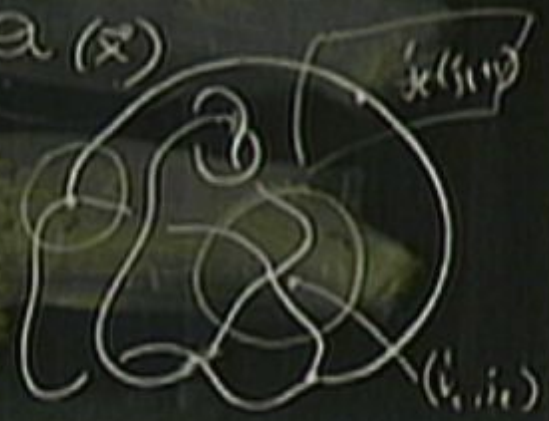

$\mathcal{H} \xrightarrow{G_i=0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a=0} \mathcal{H}_D \xrightarrow{\mathcal{H}=0} \mathcal{H}_{Phys.}$
$\psi(A) \in \mathcal{H}$
$W_\gamma(A) \in \mathcal{H}_0$
$\psi(\gamma, \{x\}, \{i\})$
$(|\gamma\rangle)$

$$\left(E^a_i = \frac{\delta}{\delta A^i_a(x)}\right) \qquad \frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$$

$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$$

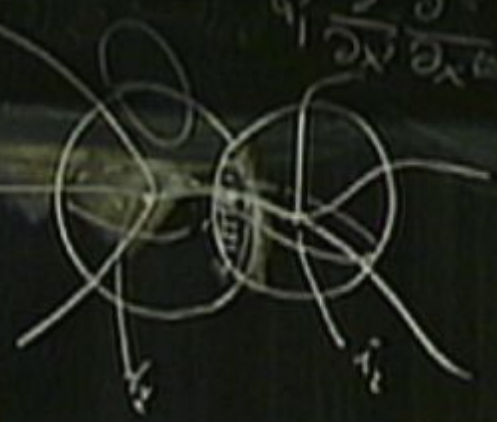
$$A_\Sigma = \int_0^t dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

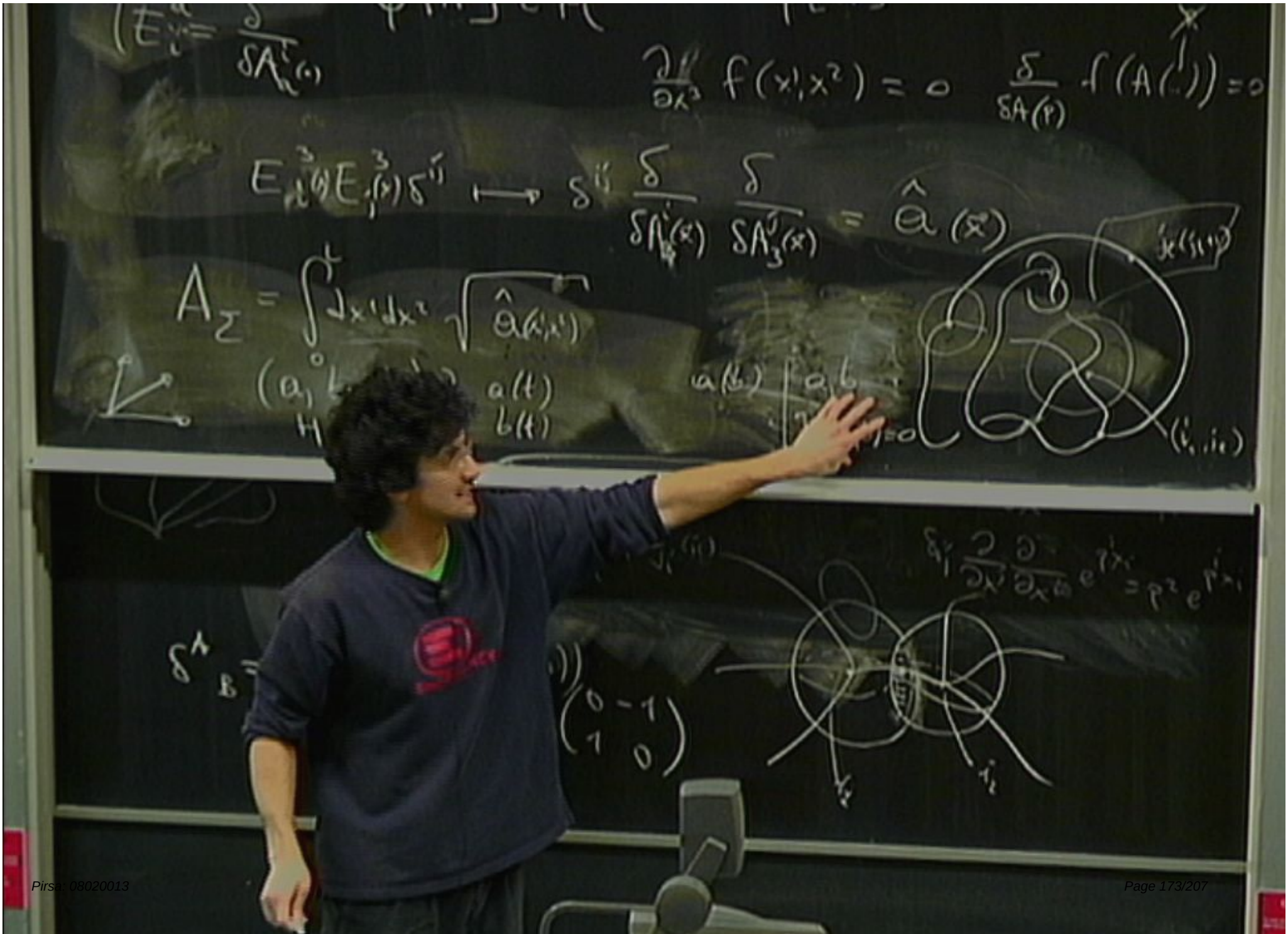
$$(a, b, t) \quad \begin{cases} a(t) \\ b(t) \end{cases}$$

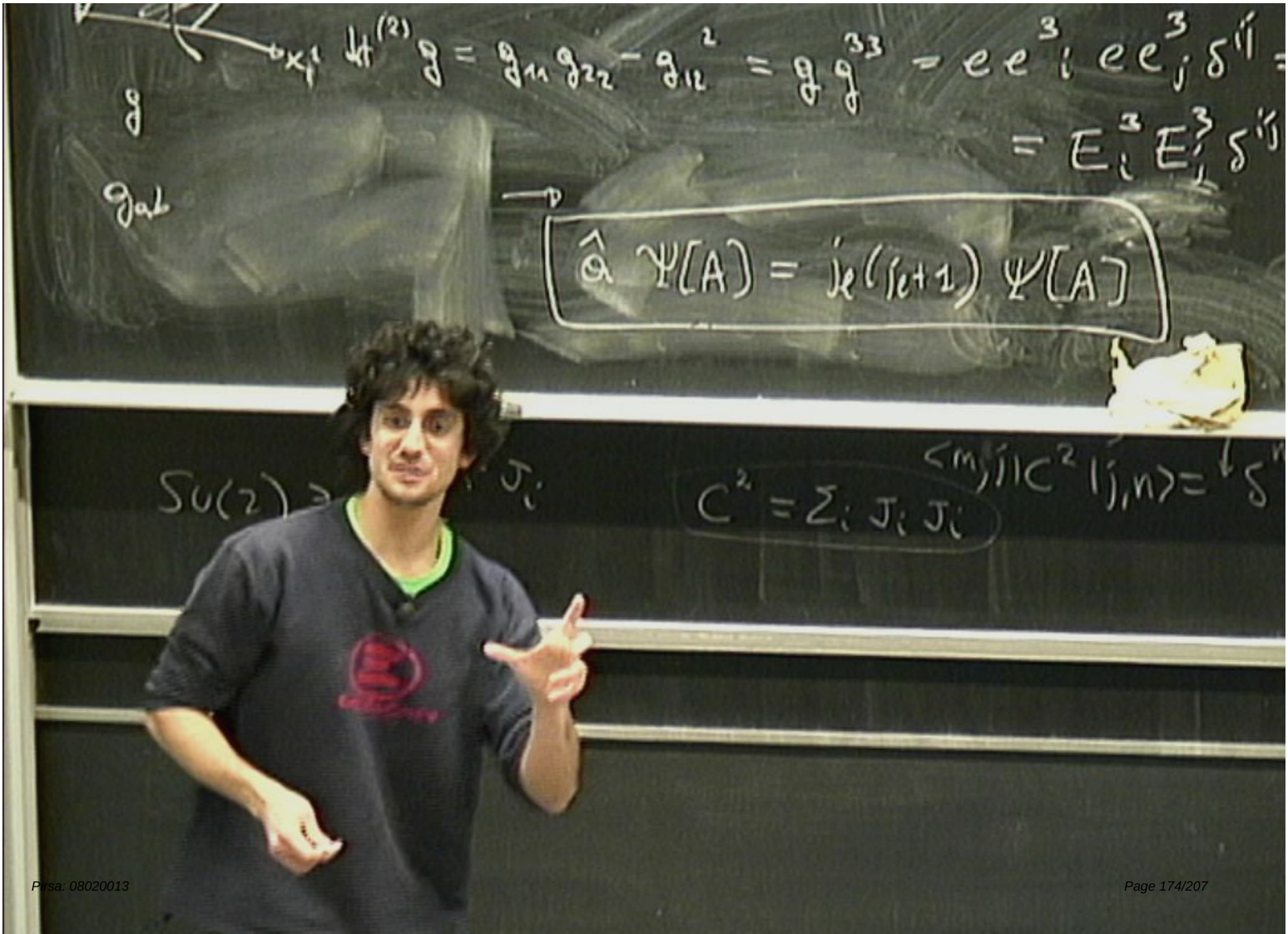


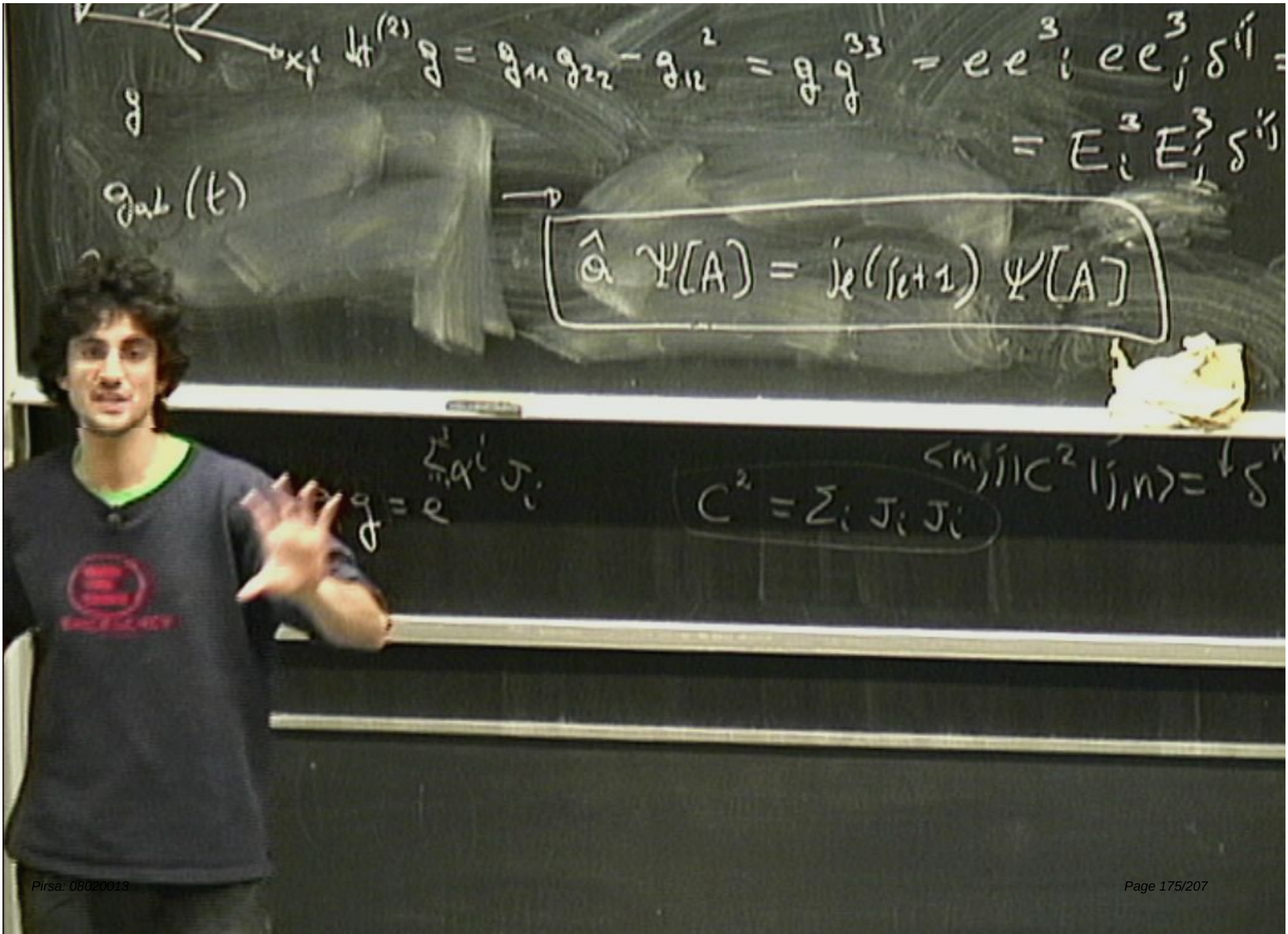
$$= \sum_i J_i J_i \; e^{\int A^i J_i(x)}$$

$$\delta^A_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad \varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$




$\frac{\partial^2}{\partial x^2} f(x^1, x^2) = 0$
$\frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$
$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$
$a(t)$
$b(t)$
$\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$


$\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$
$= E^3_i E^3_j \delta^{ij}$
g
g_{ab}
$\hat{Q}\, \Psi[A] = k(k+1)\, \Psi[A]$
$SU(2)$
J_i
$C^2 = \sum_i J_i J_i$
$\langle m, j | C^2 | j, n \rangle = \delta$


$g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e\, e^3_i\, e\, e^3_j\, \delta^{ij} =$
$= E^3_i E^3_j \delta^{ij}$
$g_{ab}(t)$
$\hat{a}\, \Psi[A] = i k (k+1)\, \Psi[A]$
$g = e^{\sum_i a^i J_i}$
$C^2 = \sum_i J_i J_i$

x_1^1 $\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$

g

$= E^3_i E^3_j \delta^{ij}$

$g_{ab}(t, \vec{x})$

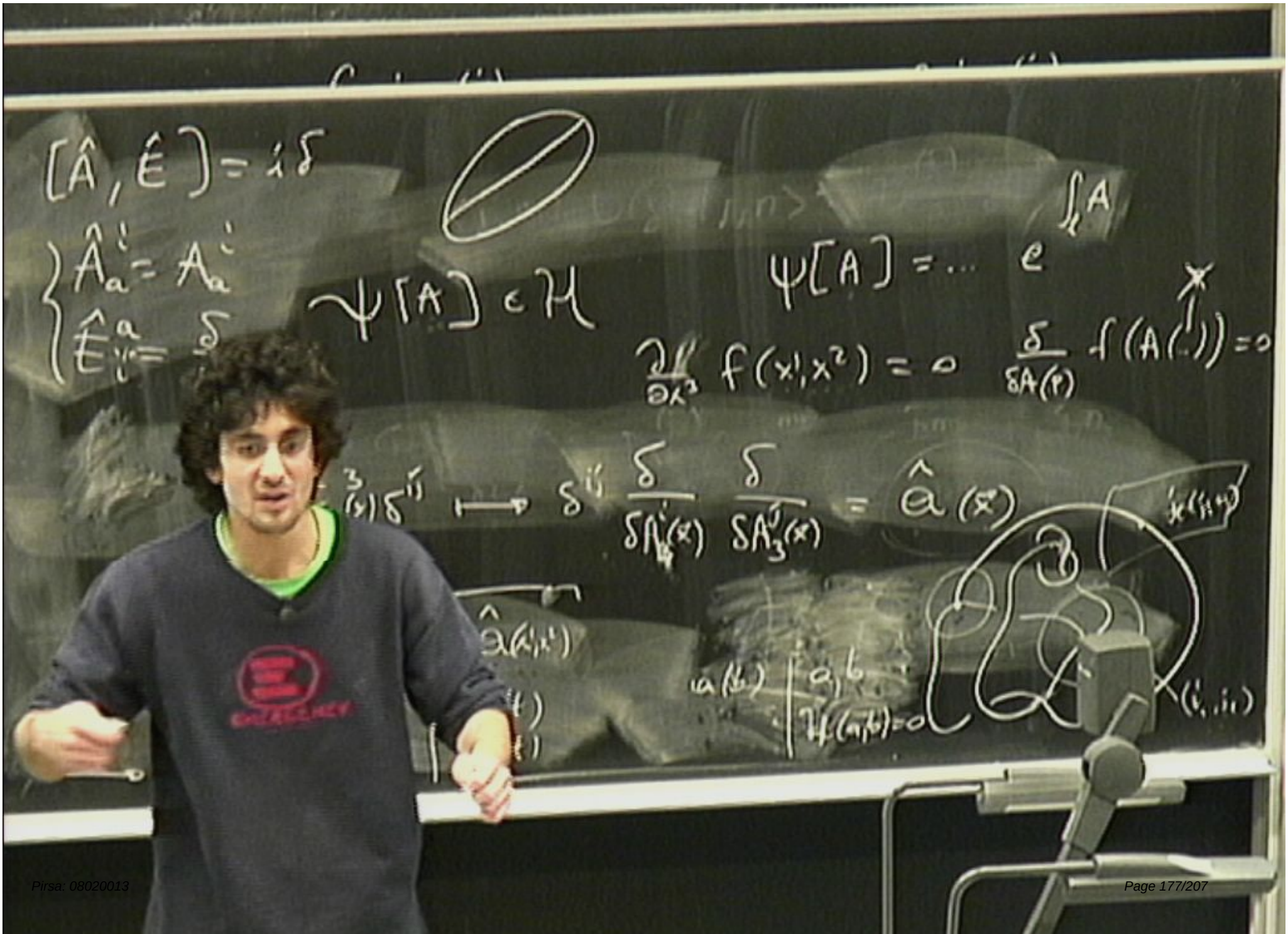
$\mathcal{H}$

$$\boxed{\hat{a}\, \Psi[A] = k(k+1)\, \Psi[A]}$$

$SU(2) \ni g = e^{\sum_i a^i J_i}$

$\langle m, j | C^2$

$$\boxed{C^2 = \sum_i J_i J_i}$$


[Â, Ê] = iδ
Â = A
Ê = δ
ψ[A] ∈ H
ψ[A] = ...
f(x¹, x²) = 0
δ/δA(p) f((A(...))) = 0
δ/δA(x) δ/δA(x) = â(x)
a, b

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}^a_i = \dfrac{\delta}{\delta A^i_a(x)} \end{cases}$$

$$\psi[A] \in \mathcal{H}$$

$$\psi[A] = \dots e^{\int_\ell A}$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ell)) = 0$$

$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$$

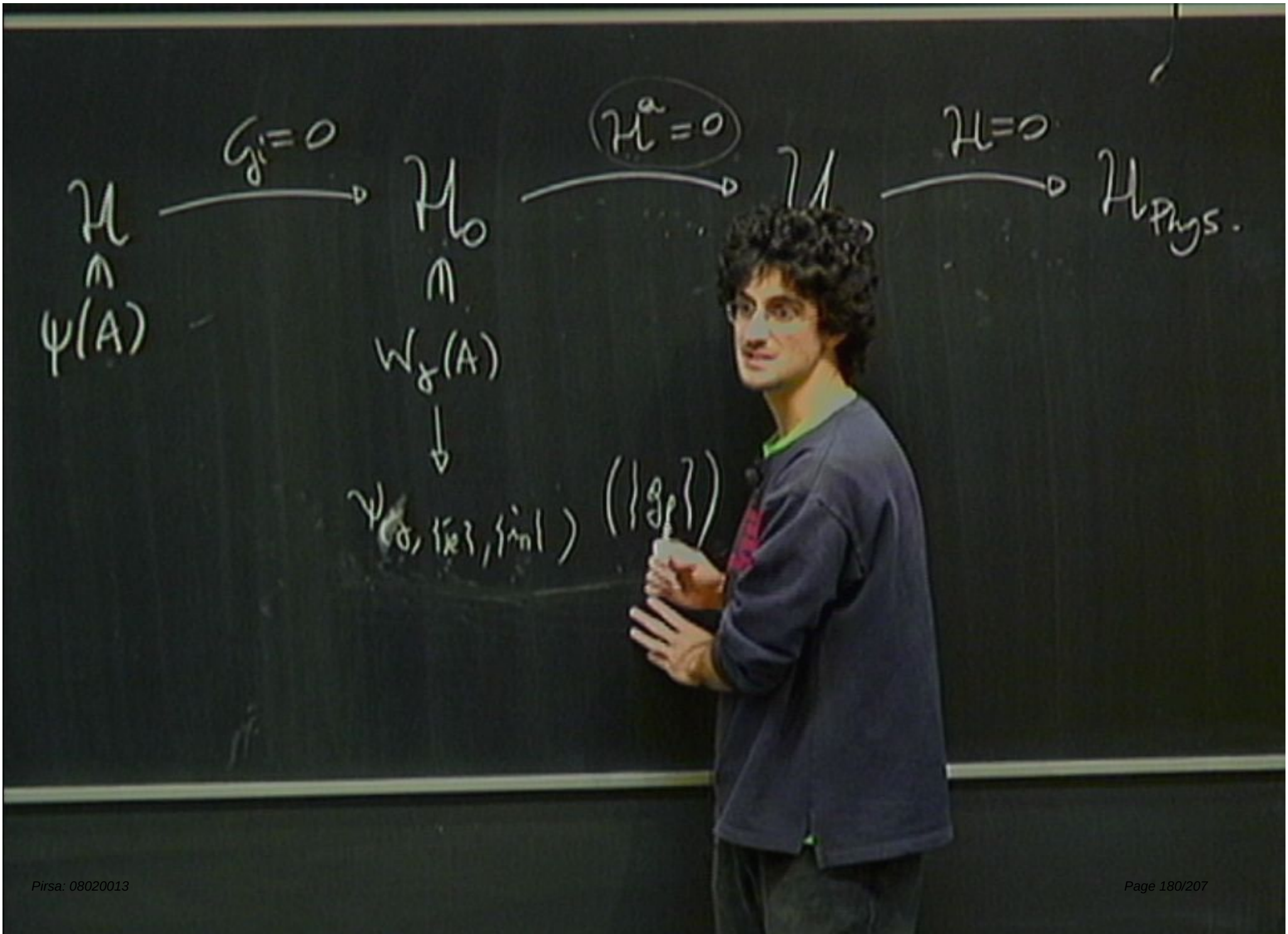
$$A_\Sigma = \int_0^1 dx^1 dx^2 \sqrt{\hat{a}(x^1, x^1)}$$

$$(a, b, t) \quad \begin{cases} a(t) \\ b(t) \end{cases}$$

$$a(b) \quad \begin{vmatrix} a, b \\ \psi(a, b) = 0 \end{vmatrix}$$

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

$$\mathcal{H}_0 \supset W_\gamma(A) \longrightarrow \Psi(\gamma, \{k_e\}, \{i_n\}) \quad (\{g_e\})$$


$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H} \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys.}$
$\psi(A) \in \mathcal{H}$
$W_\gamma(A) \in \mathcal{H}_0$
$\psi(\gamma, \{k_e\}, \{k_n\})$
$(|g_\gamma|)$

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

$$\psi(A) \in \mathcal{H}, \qquad W_\gamma(A) \in \mathcal{H}_0$$

$$e^{\int_\gamma A}$$

$$W_\gamma(A) \longrightarrow \psi_{(\gamma, \{k_e\}, \{n_l\})}(\{g_e\})$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}^a_i = \dfrac{\delta}{\delta A_a^i(\cdot)} \end{cases}$$

$$\psi[A] \in \mathcal{H}$$

$$\psi[A] = \dots e^{\int_\ell A}$$

$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\cdot)) = 0$$

$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_3^i(x)} \frac{\delta}{\delta A_3^j(x)} = \hat{a}(x)$$

$$= \int_0^t dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$(a, b, t) \quad \begin{cases} a(t) \\ b(t) \end{cases}$$

$$a(t_1) \quad \Big| \quad a, b \quad \psi(a, b) = 0$$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}^a_i = \dfrac{\delta}{\delta A^i_a(x)} \end{cases}$$

$$\psi[A] \in \mathcal{H}$$

$$\psi[A] = \ldots e^{\int_\ell A}$$

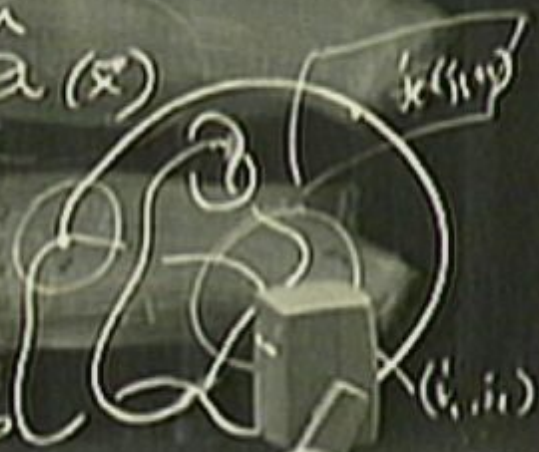
$$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$$

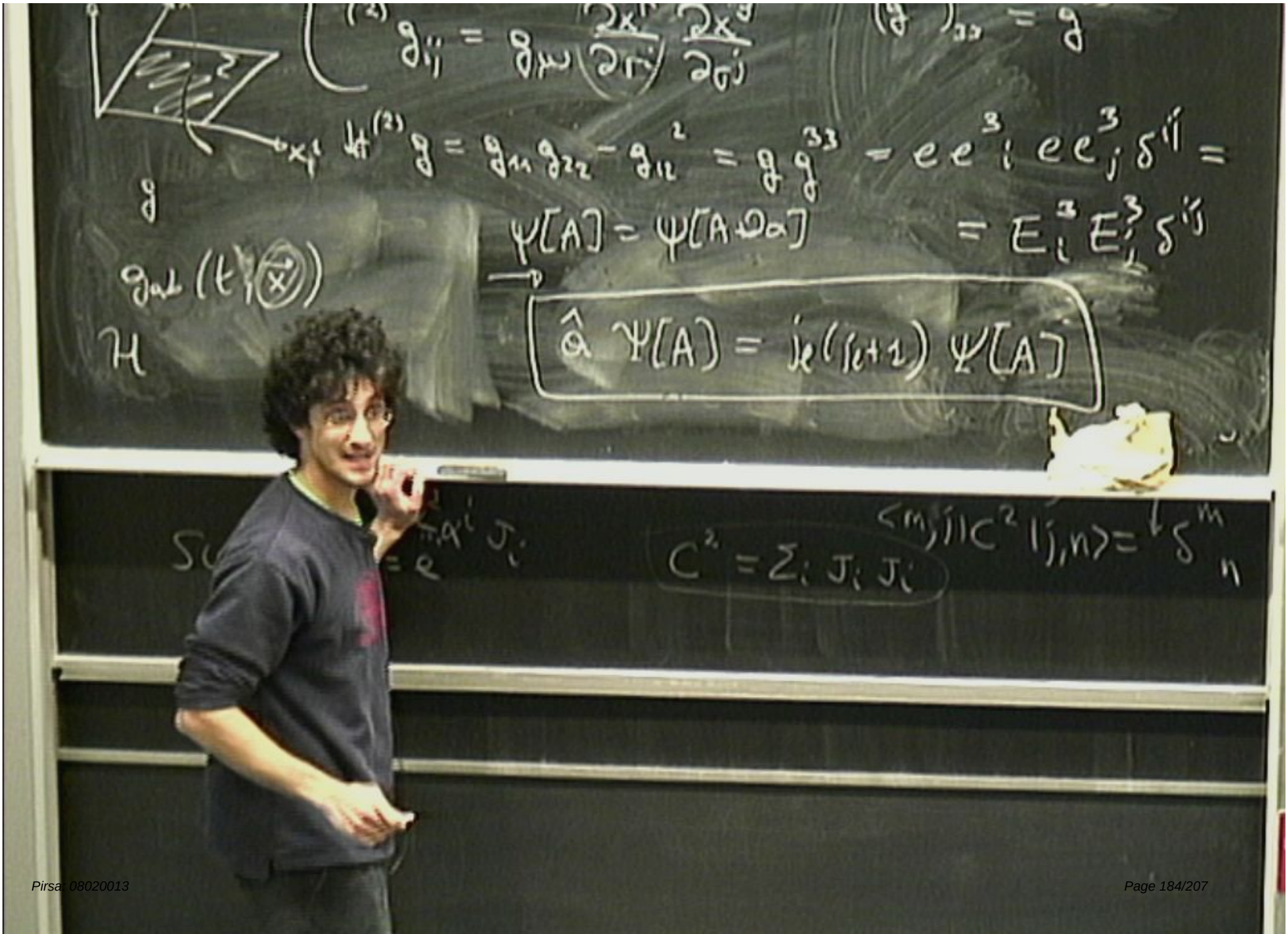
$$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^t dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$(a, b, t) \quad \begin{cases} a(t) \\ b(t) \end{cases}$$

$$a(t_1) \quad \begin{vmatrix} a, b \\ \psi(a, b) = 0 \end{vmatrix}$$




$\Psi[A] = \Psi[A+\partial\alpha]$
$\hat{a}\,\Psi[A] = ie(k+1)\,\Psi[A]$
$C^2 = \Sigma_i J_i J_i$

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(x)} \end{cases}$$

$$\psi[A] \in \mathcal{H}$$

$$\psi[A] = \ldots e^{\int_\ell A}$$

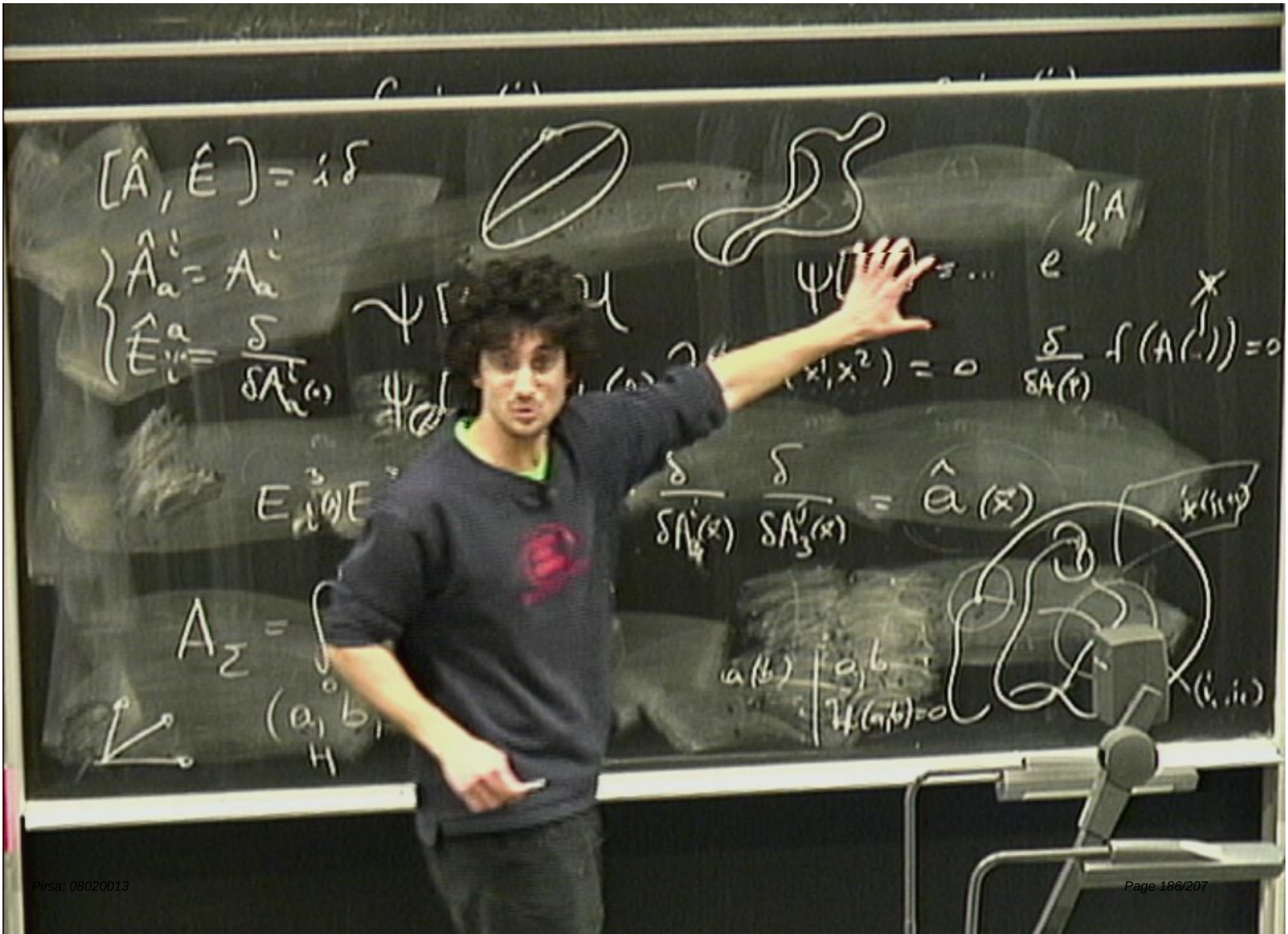
$$\psi_{\mathcal{O}}[A] = \psi_{\mathcal{O}}(A) \quad \frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots)) =$$

$$E_i^3(x) E_j^3(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_4^i(x)} \frac{\delta}{\delta A_3^j(x)} = \hat{a}(x)$$

$$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

$$(a, b, t) \quad \begin{cases} a(t) \\ b(t) \end{cases}$$

$$a(b) \quad \begin{vmatrix} a, b \\ \psi(a, b) = 0 \end{vmatrix}$$


[Â, Ê] = iδ
Â = A
Ê = δ/δA
A_Σ =
(a, b)
H

$$[\hat{A}, \hat{E}] = i\delta$$

$$\begin{cases} \hat{A}_a^i = A_a^i \\ \hat{E}_i^a = \dfrac{\delta}{\delta A_a^i(x)} \end{cases}$$

$$\psi[A] \in \mathcal{H}$$

$$\psi[A] = \ldots e^{\int_\ell A}$$

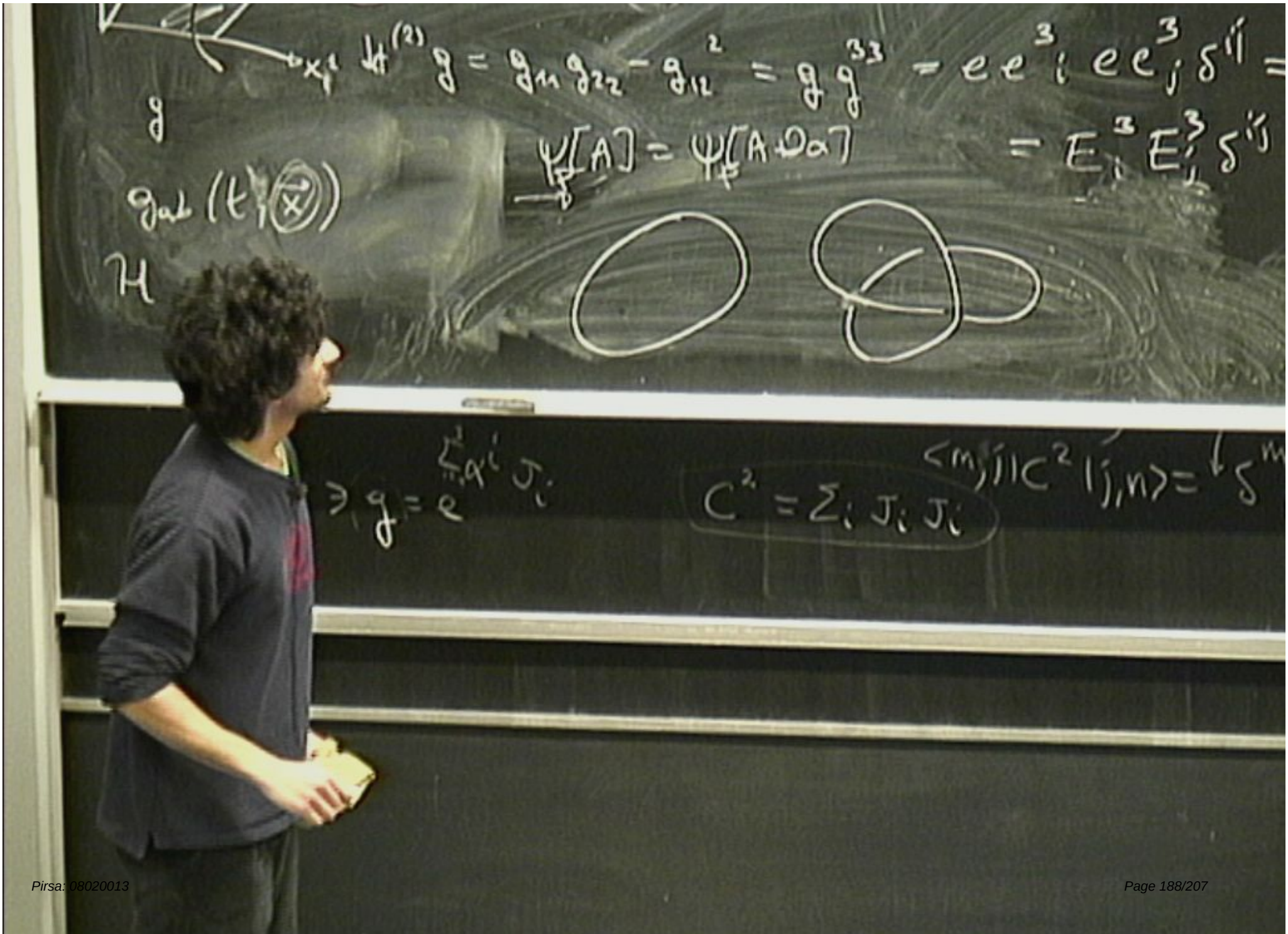
$$\psi_\varphi[A] = \psi_\beta(A) \quad \frac{\partial}{\partial x^3} f(x^1, x^2) = 0 \qquad \frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$$

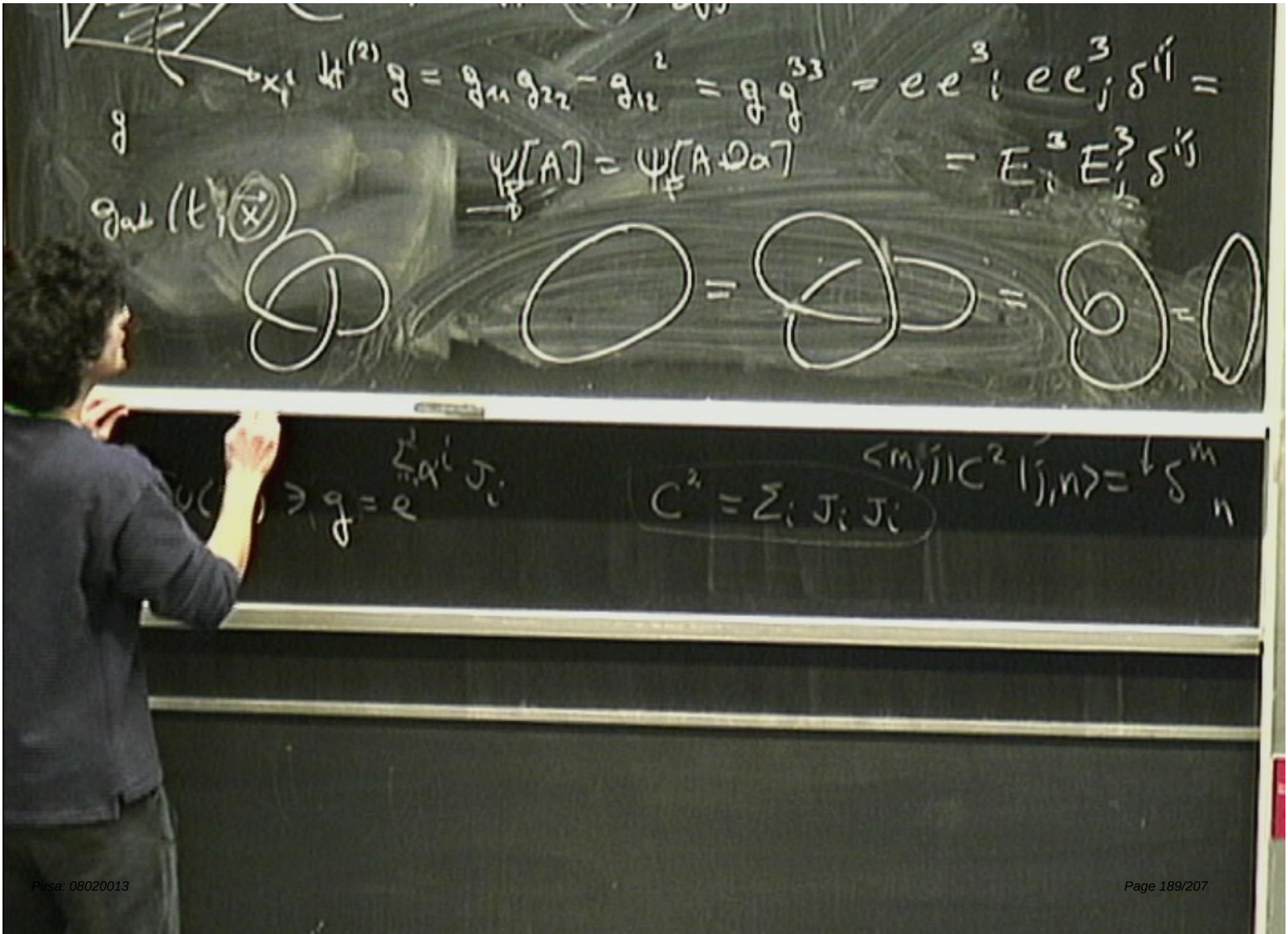
$$E_i^3(x) E_j^3(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A_i^i(x)} \frac{\delta}{\delta A_j^j(x)} = \hat{a}(x)$$

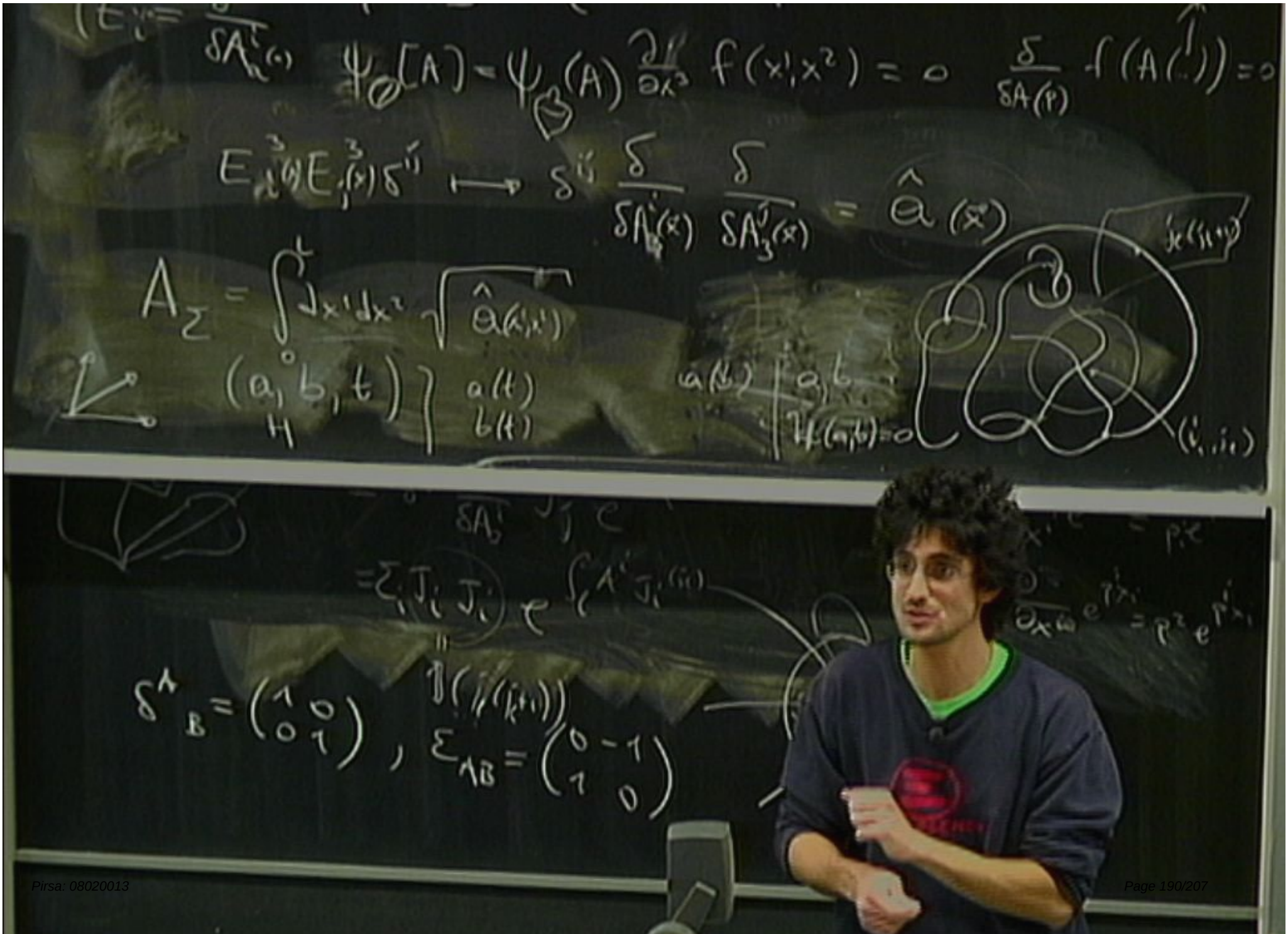
$$= \int_0^t dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$$

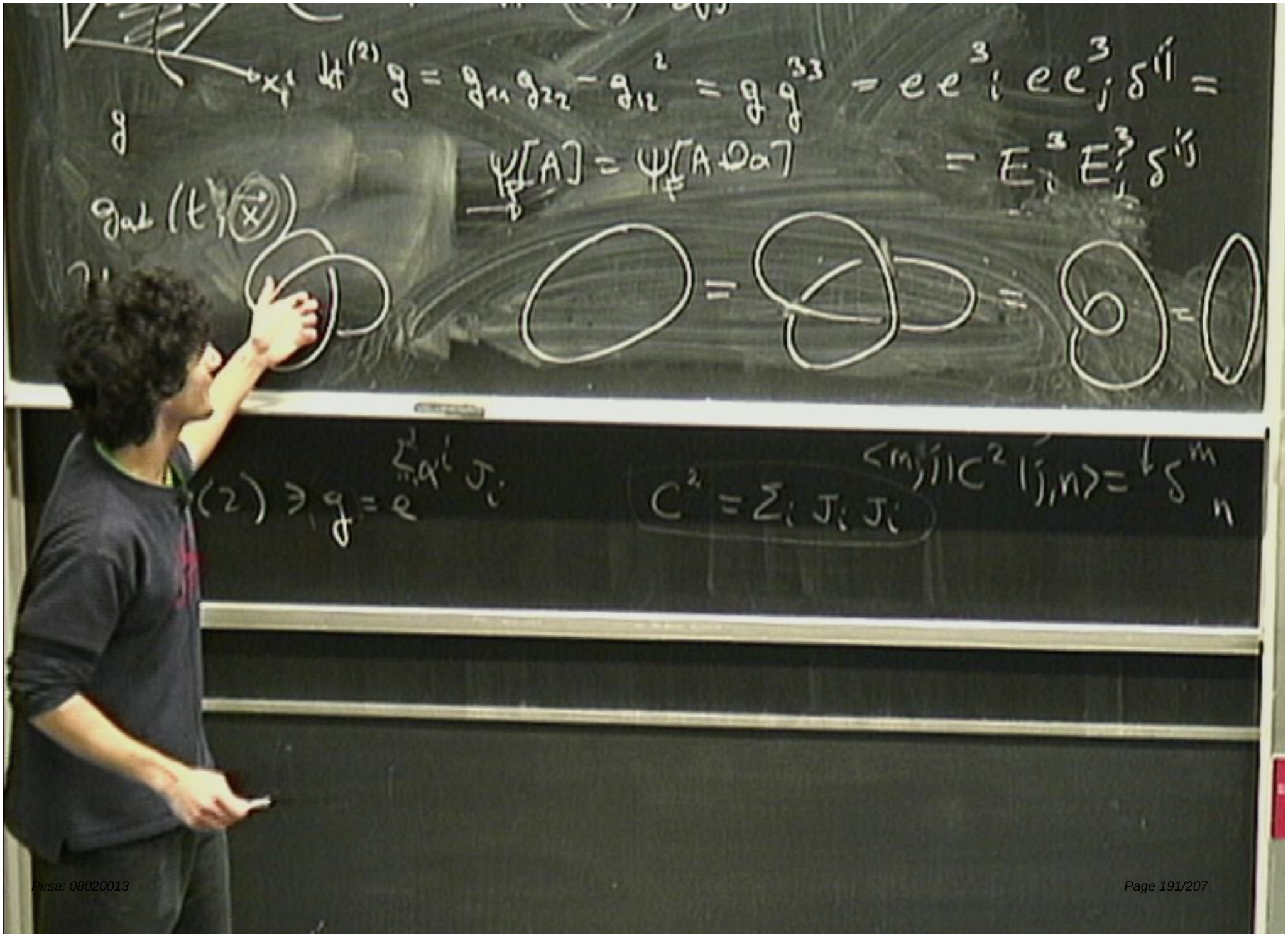
$$(a, b, t) \quad \begin{cases} a(t) \\ b(t) \end{cases}$$

$$a(b) \quad \begin{vmatrix} a, b \\ \psi(a, b) = 0 \end{vmatrix}$$


x_1^1 $\sqrt{g}^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$
g
$\Psi_\Phi[A] = \Psi_\Phi[A + \partial\alpha]$
$= E^3_i E^3_j \delta^{ij}$
$g_{ab}(t, \vec{x})$
$\mathcal{H}$
$g = e^{\sum_i \alpha^i J_i}$
$C^2 = \sum_i J_i J_i$
$\langle m, j | C^2 | j, n \rangle = \delta^m$


x_i^1 $\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$
g
$\Psi_\Phi[A] = \Psi_\Phi[A + \partial a]$
$= E^3_i E^3_j \delta^{ij}$
$g_{ab}(t, \vec{x})$
$g = e^{\sum_i a^i J_i}$
$C^2 = \sum_i J_i J_i$
$\langle m, j | C^2 | j, n \rangle = j \delta^m_n$


$\psi_\emptyset[A] = \psi_\beta(A)$
$\frac{\partial}{\partial x^3} f(x^1, x^2) = 0$
$\frac{\delta}{\delta A(p)} f(A(\ldots)) = 0$
$E^3_i(x) E^3_j(x) \delta^{ij} \longmapsto \delta^{ij} \frac{\delta}{\delta A^i_3(x)} \frac{\delta}{\delta A^j_3(x)} = \hat{a}(x)$
$A_\Sigma = \int_0^L dx^1 dx^2 \sqrt{\hat{a}(x^1, x^2)}$
(a, b, t)
$a(t)$
$b(t)$
$a(b)$
a, b
$\delta^A{}_B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $\varepsilon_{AB} = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$


det(2) g = g11 g22 − g12² = g g33 = e e3i e e3j δij =
= E3i E3j δij
ψ[A] = ψ[A+∇a]
gab (t, x)
(2) ∋ g = e^{Σ a^i J_i}
C² = Σ_i J_i J_i
⟨m,j|C²|j,n⟩ = j δ^m_n

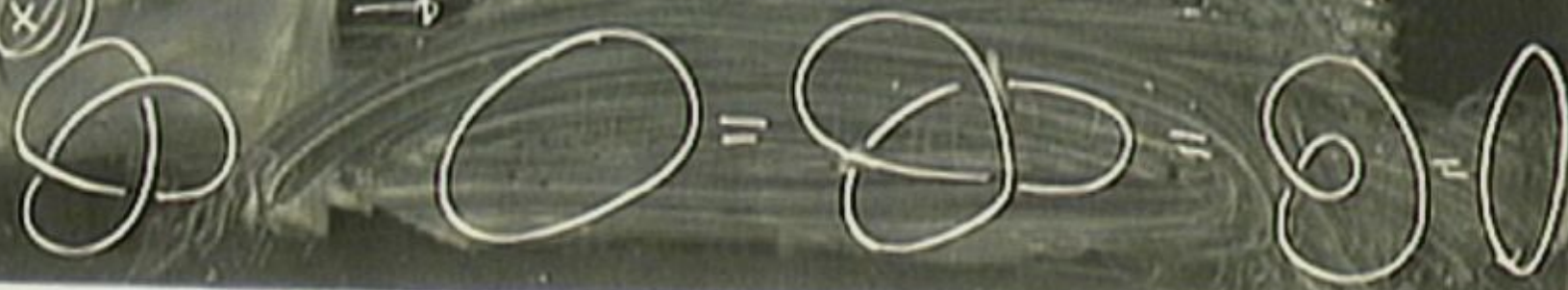
x_i $\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$

g

$\psi_t[A] = \psi_t[A + D\alpha]$ $= E^3_i E^3_j \delta^{ij}$

$g_{ab}(t, \vec{x})$

$\mathcal{H}$



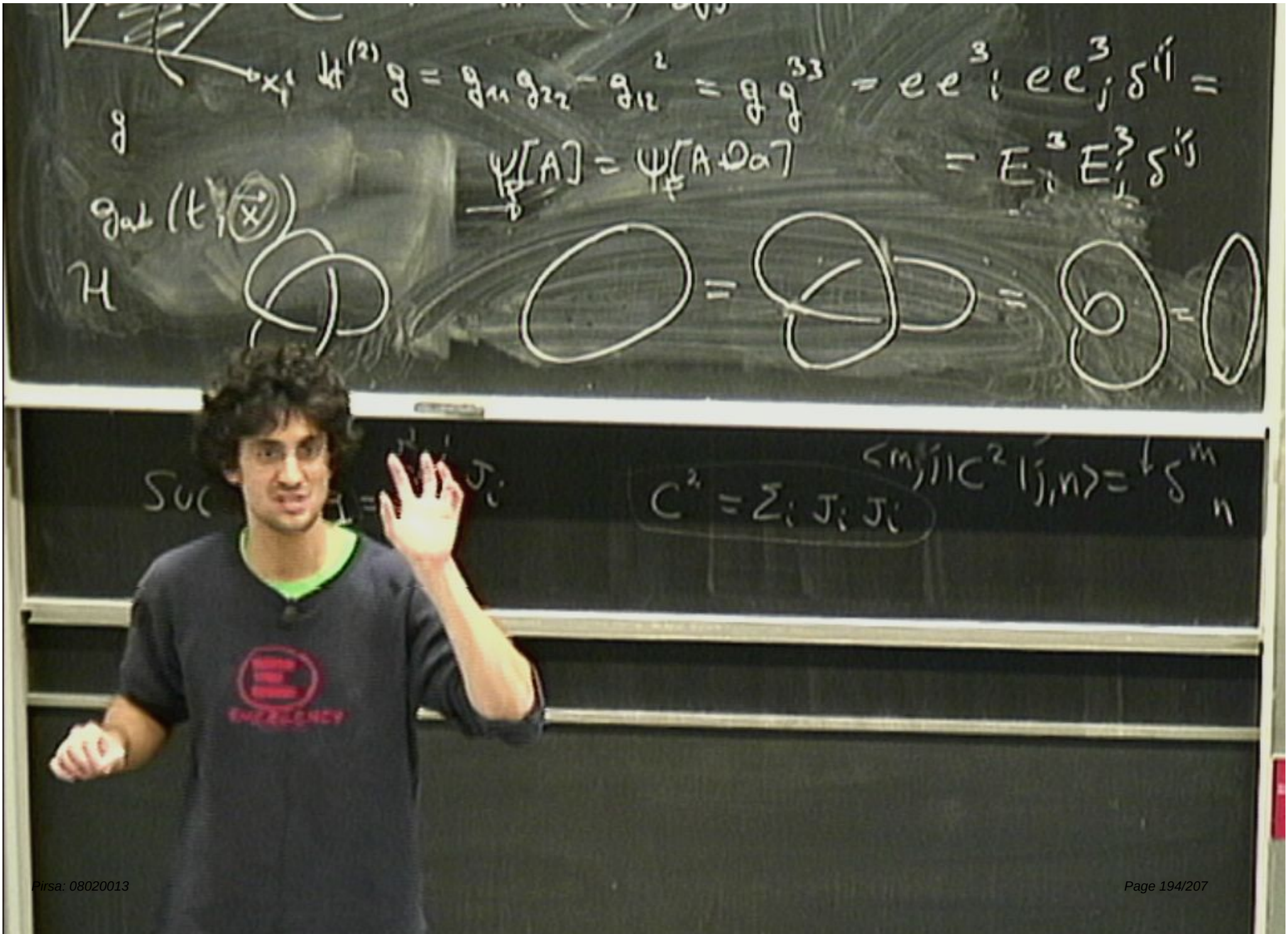
$SU(2) \ni g = e^{\sum_i \alpha^i J_i}$ $\boxed{C^2 = \sum_i J_i J_i}$ $\langle m, j | C^2 | j, n \rangle = j \delta^m_n$

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

$$\mathcal{H} \ni \psi(A) \qquad \mathcal{H}_0 \ni W_\gamma(A)$$

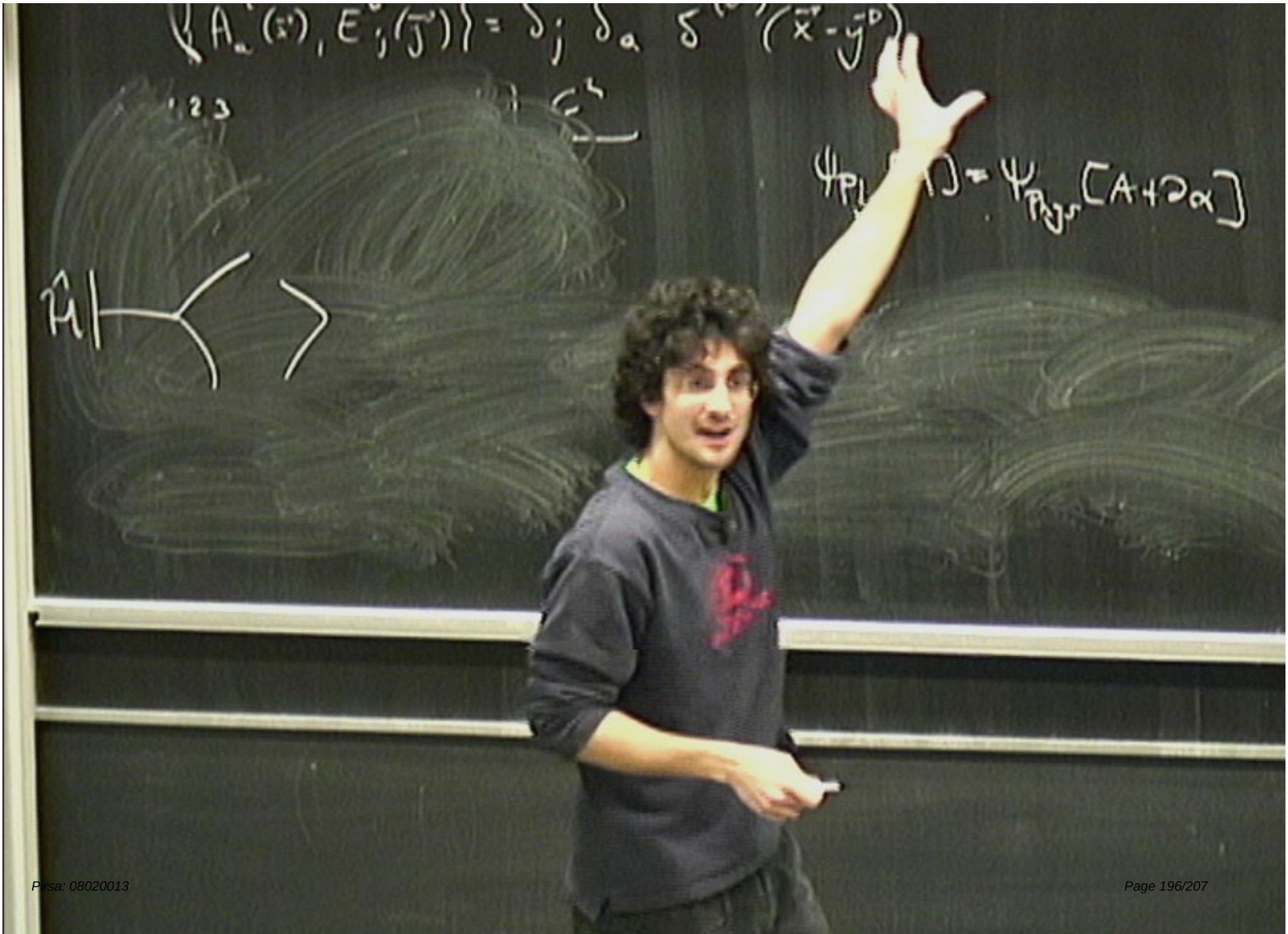
$$e^{\int_\gamma A}$$

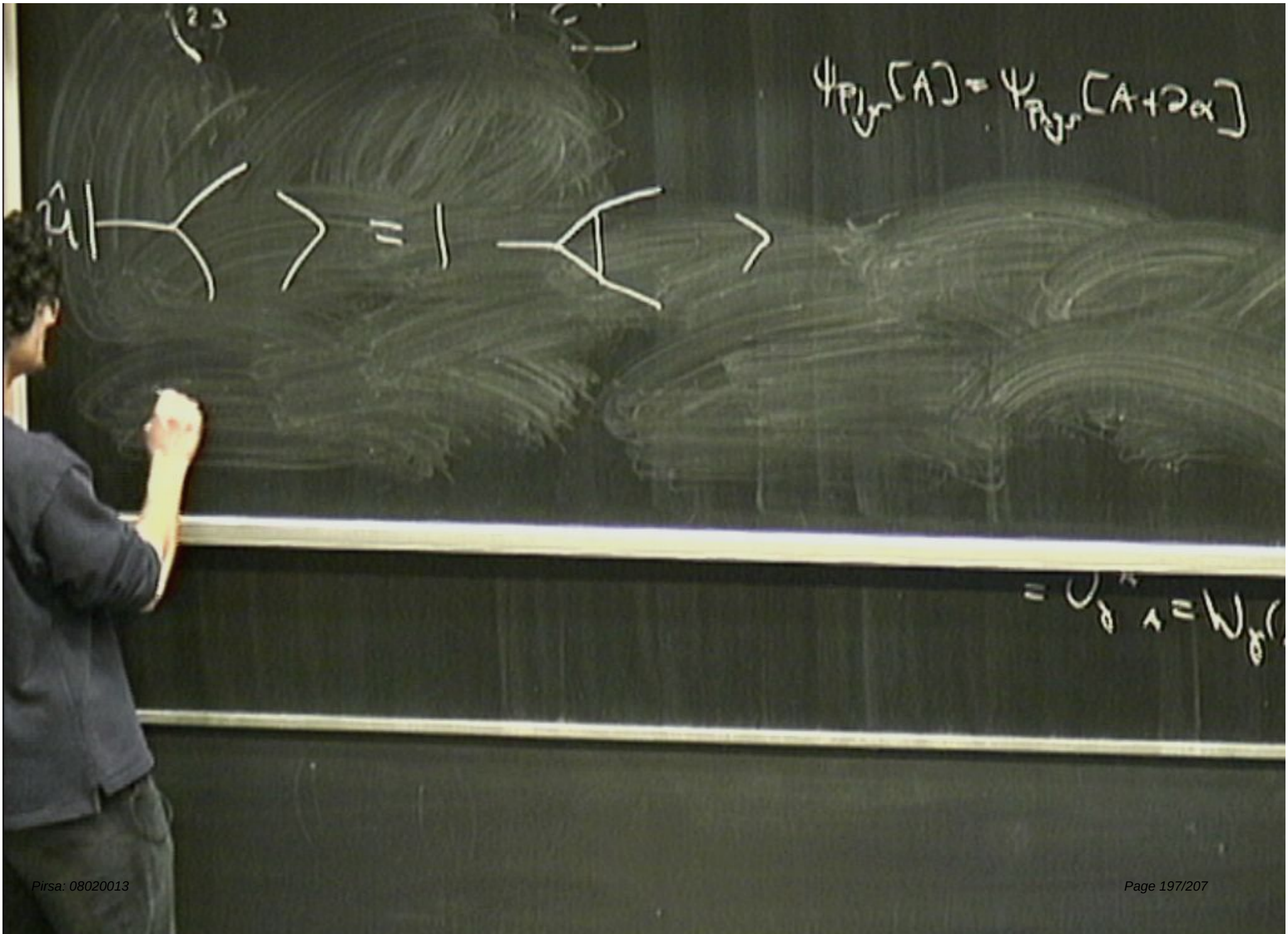
$$\psi(\gamma, \{i_e\}, \{i_n\}) \quad (\{g_e\})$$

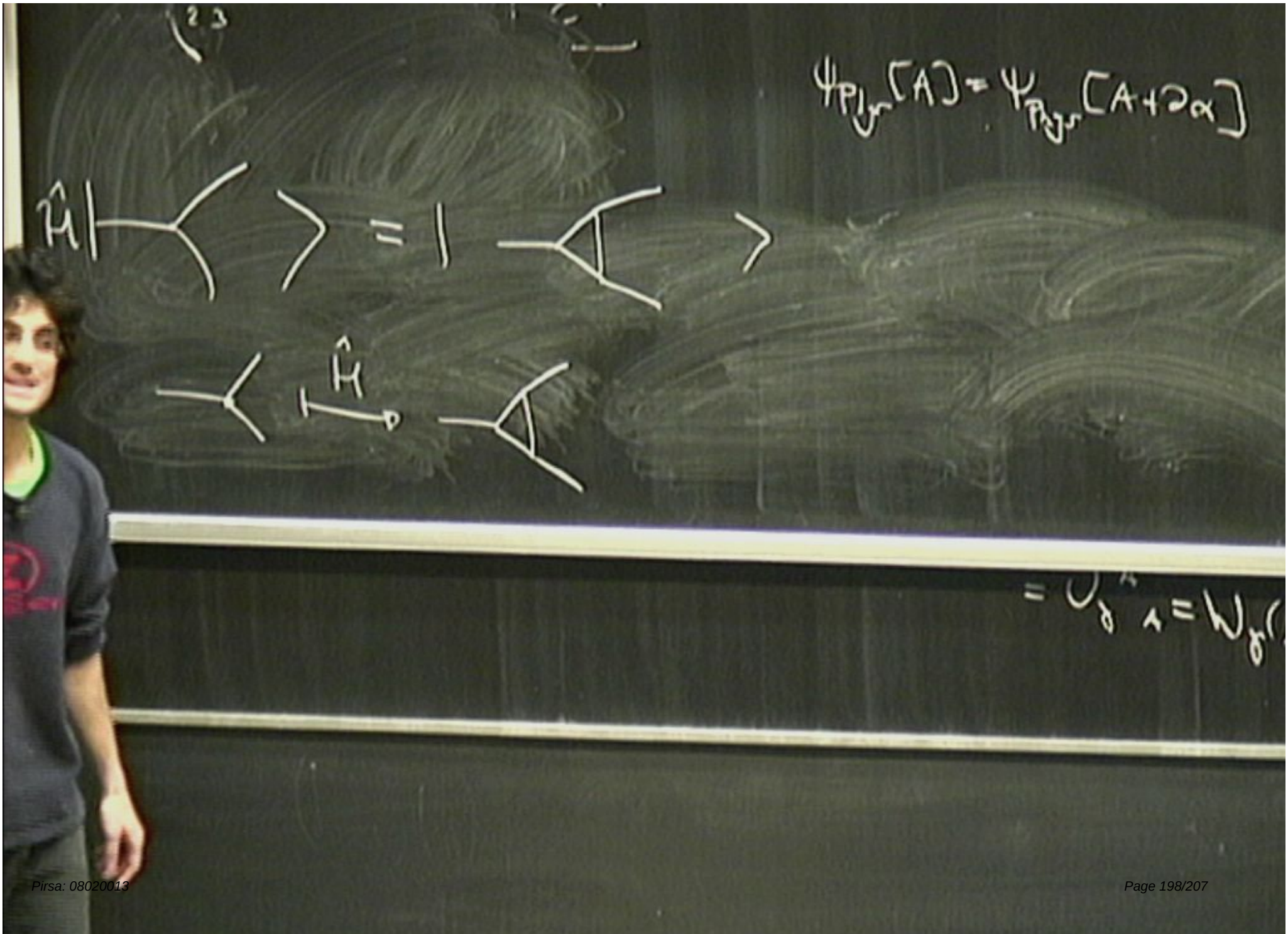

$\det^{(2)} g = g_{11} g_{22} - g_{12}^2 = g\, g^{33} = e e^3_i e e^3_j \delta^{ij} =$
$= E^3_i E^3_j \delta^{ij}$
$\Psi_\phi[A] = \Psi_\phi[A + \partial a]$
$g_{ab}(t, \vec{x})$
$\mathcal{H}$
$C^2 = \Sigma_i J_i J_i$
$\langle m, j | C^2 | j, n \rangle = \delta^m_n$

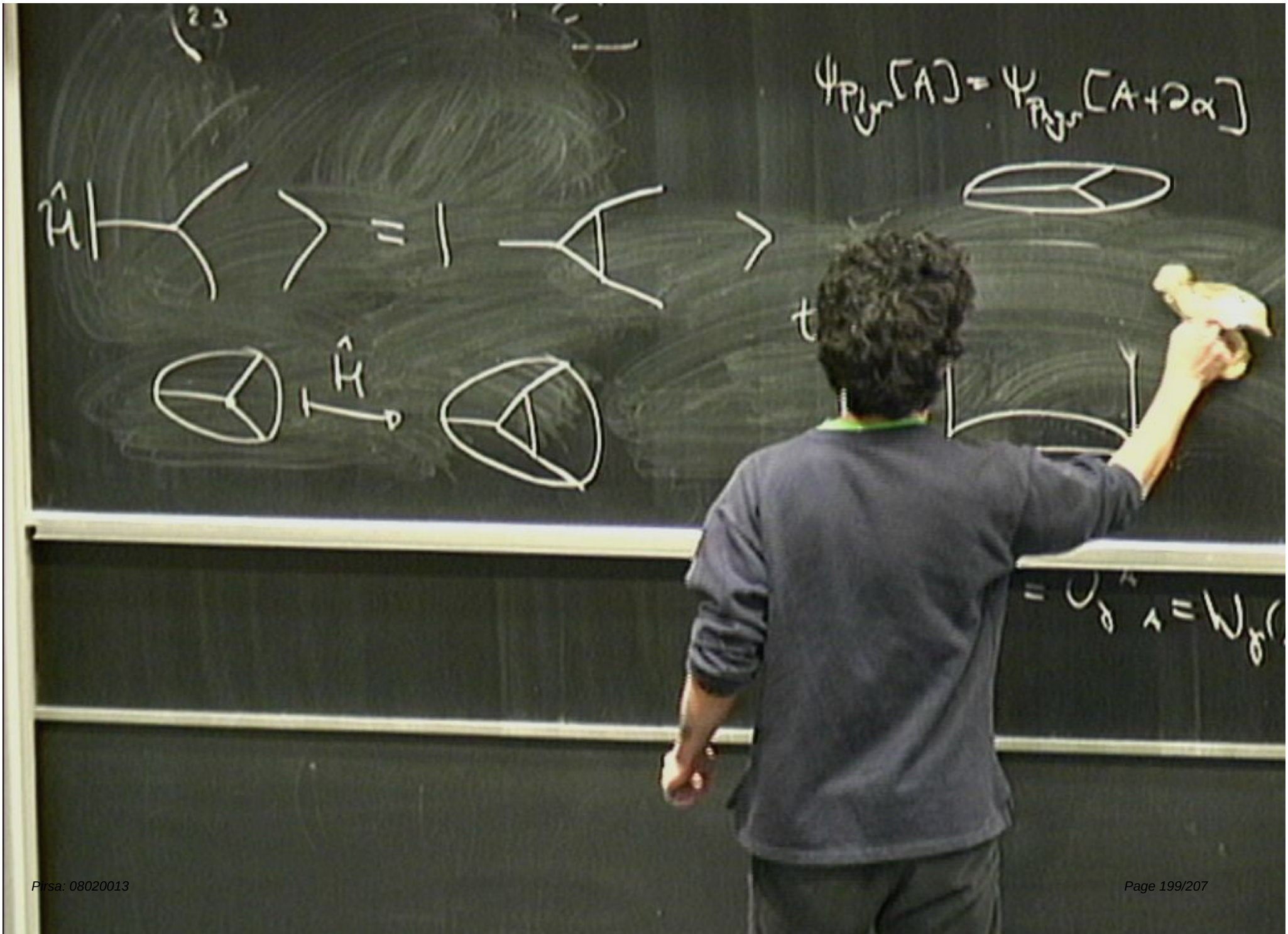
$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

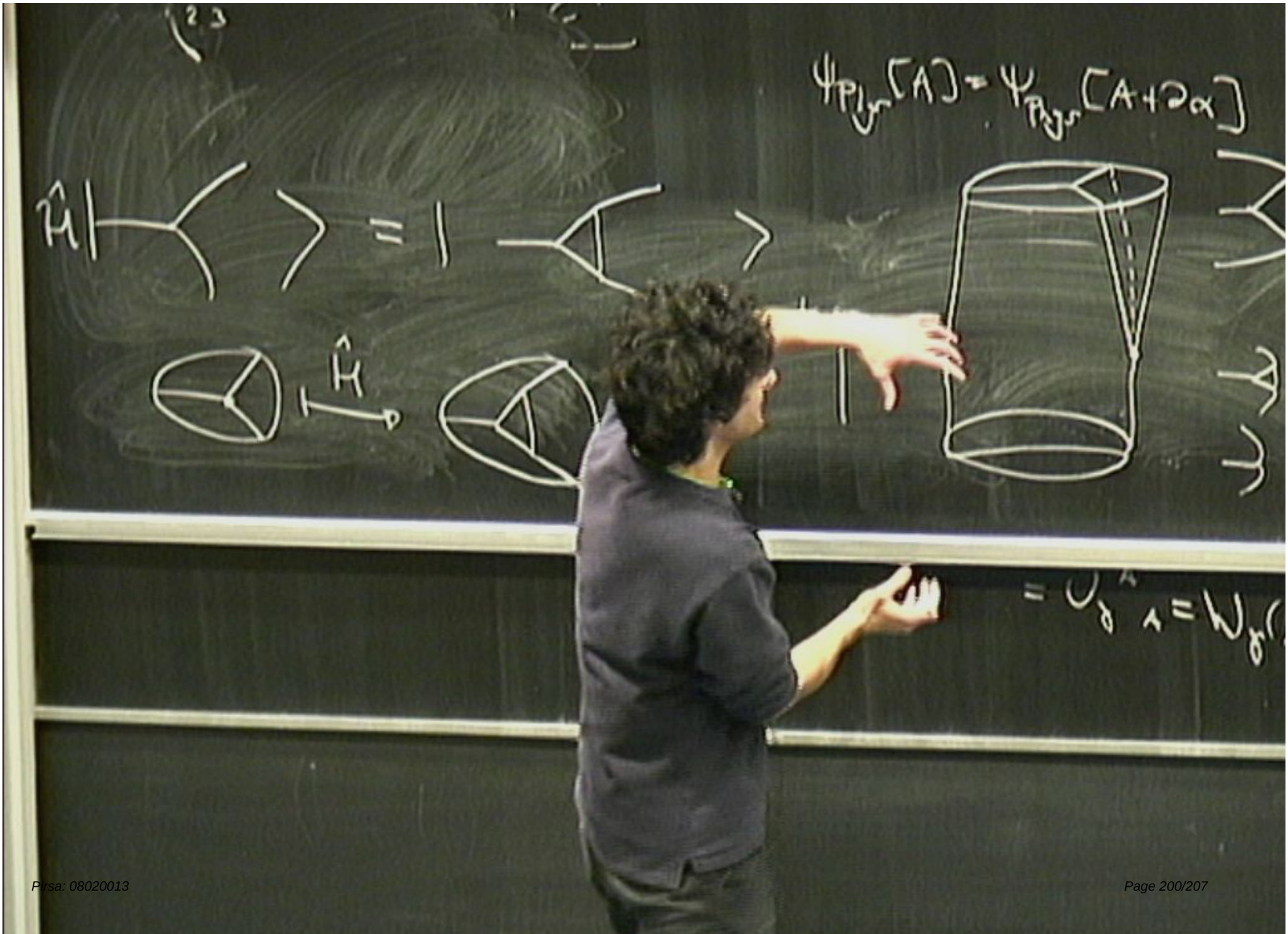
$$\begin{array}{ccccc} \mathcal{H} & & \mathcal{H}_0 & & \mathcal{H}_D \\ \cap & & \cap & & \cap \\ \psi(A) & & W_\gamma(A) & & \underline{\psi_{knot}} \\ & & \downarrow & & \\ e^{\oint_\gamma A} & & \psi(\gamma, \{k_e\}, \{i_n\}) & & (\{g_e\}) \end{array}$$

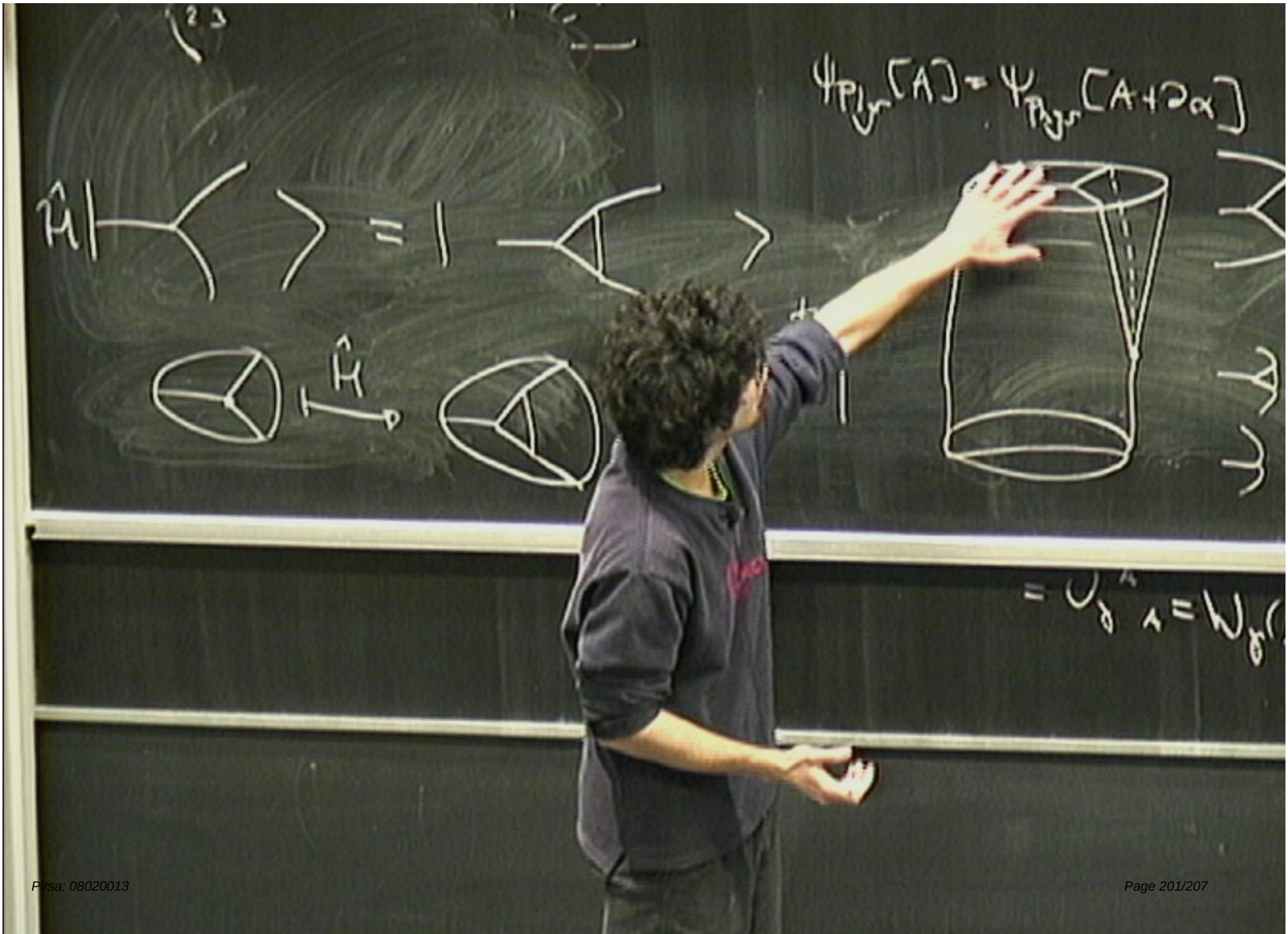

$\{A_a^i(\vec{x}), E_j^b(\vec{y})\} = \delta_j^i \delta_a^b \delta^{(3)}(\vec{x}-\vec{y})$
$\psi_{P_\mu J_{\mu\nu}}[A] = \psi_{P_\mu J_{\mu\nu}}[A+\partial\alpha]$
$\hat{H}|\ \rangle$


$\psi_{Proj}[A] = \psi_{Proj}[A+\partial\alpha]$
$\hat{u}|\ \rangle = |\ \rangle$

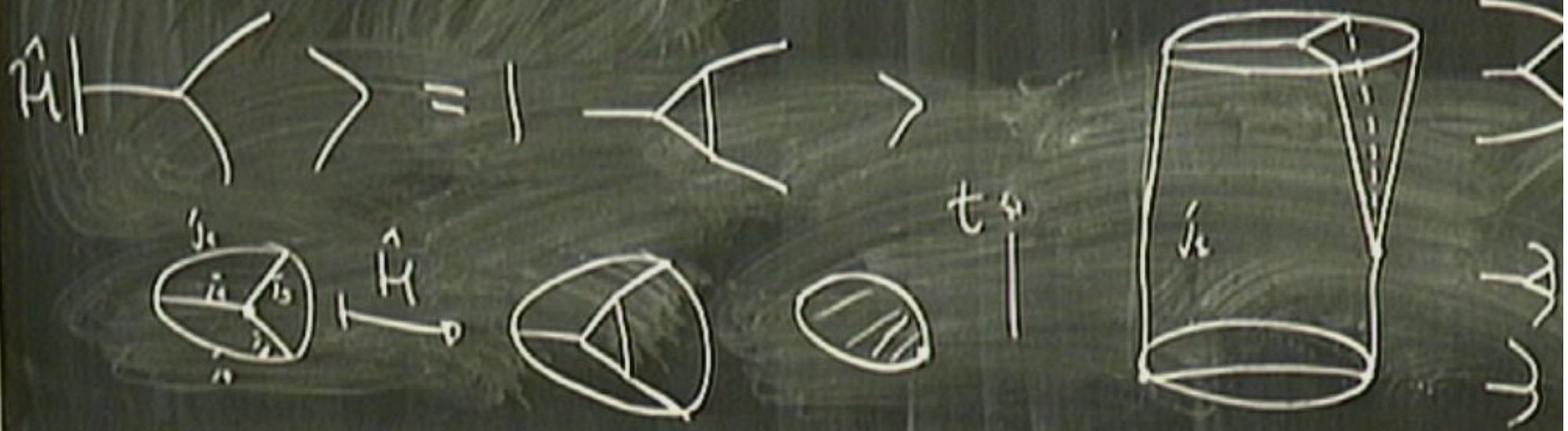

$\Psi_{PJ_\mu}[A] = \Psi_{PJ_\mu}[A+\partial\alpha]$
$\hat{H}|\ \rangle = |\ \rangle$
$\langle\ |\hat{H}|\ \rangle$


$\psi_{Pl_{\mu\nu}}[A] = \psi_{Pl_{\mu\nu}}[A+\partial\alpha]$
$\hat{H}$

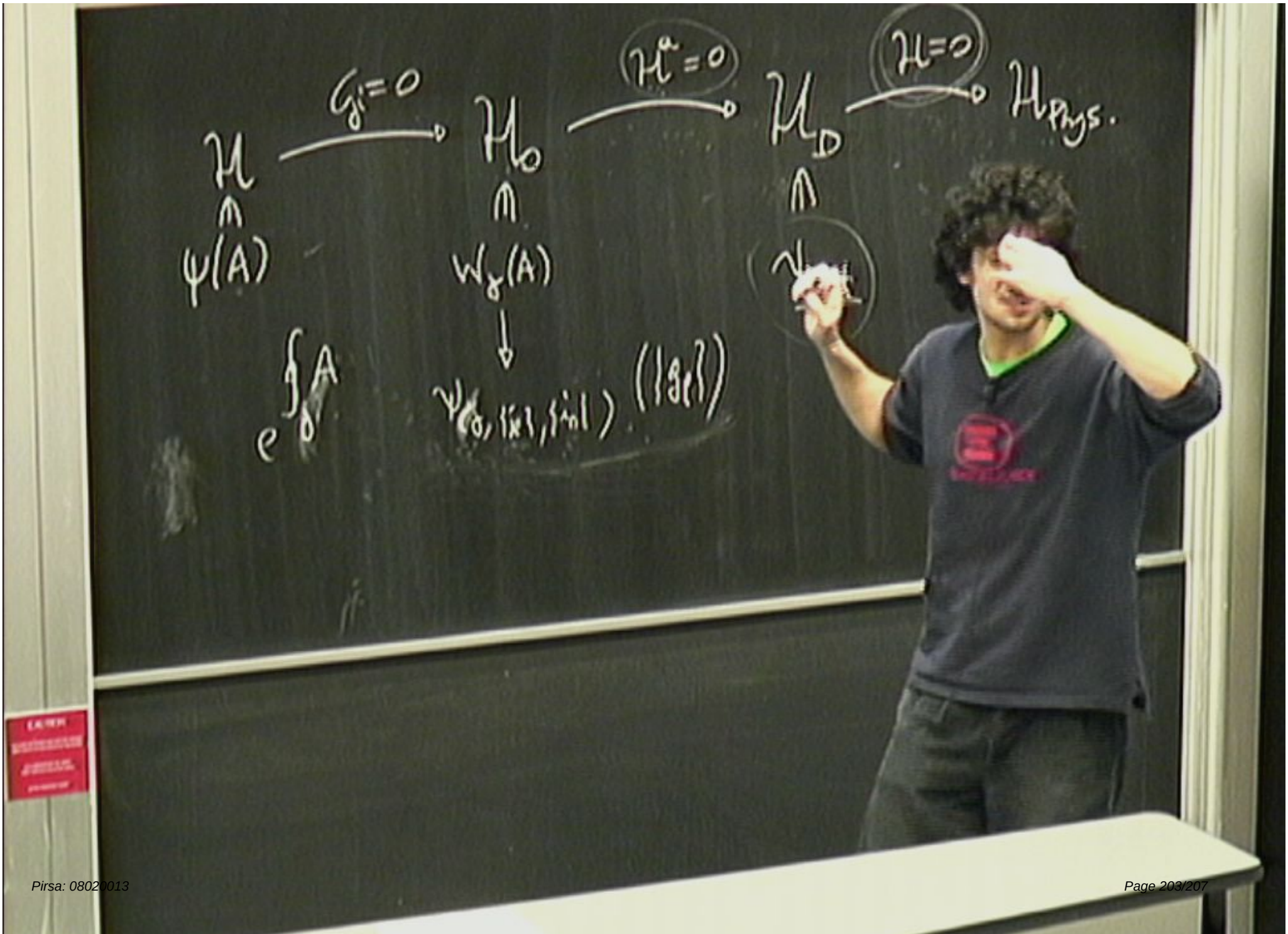

$\psi_{PJ_\mu}[A] = \psi_{PJ_\mu}[A+\partial\alpha]$
$\hat{H}$

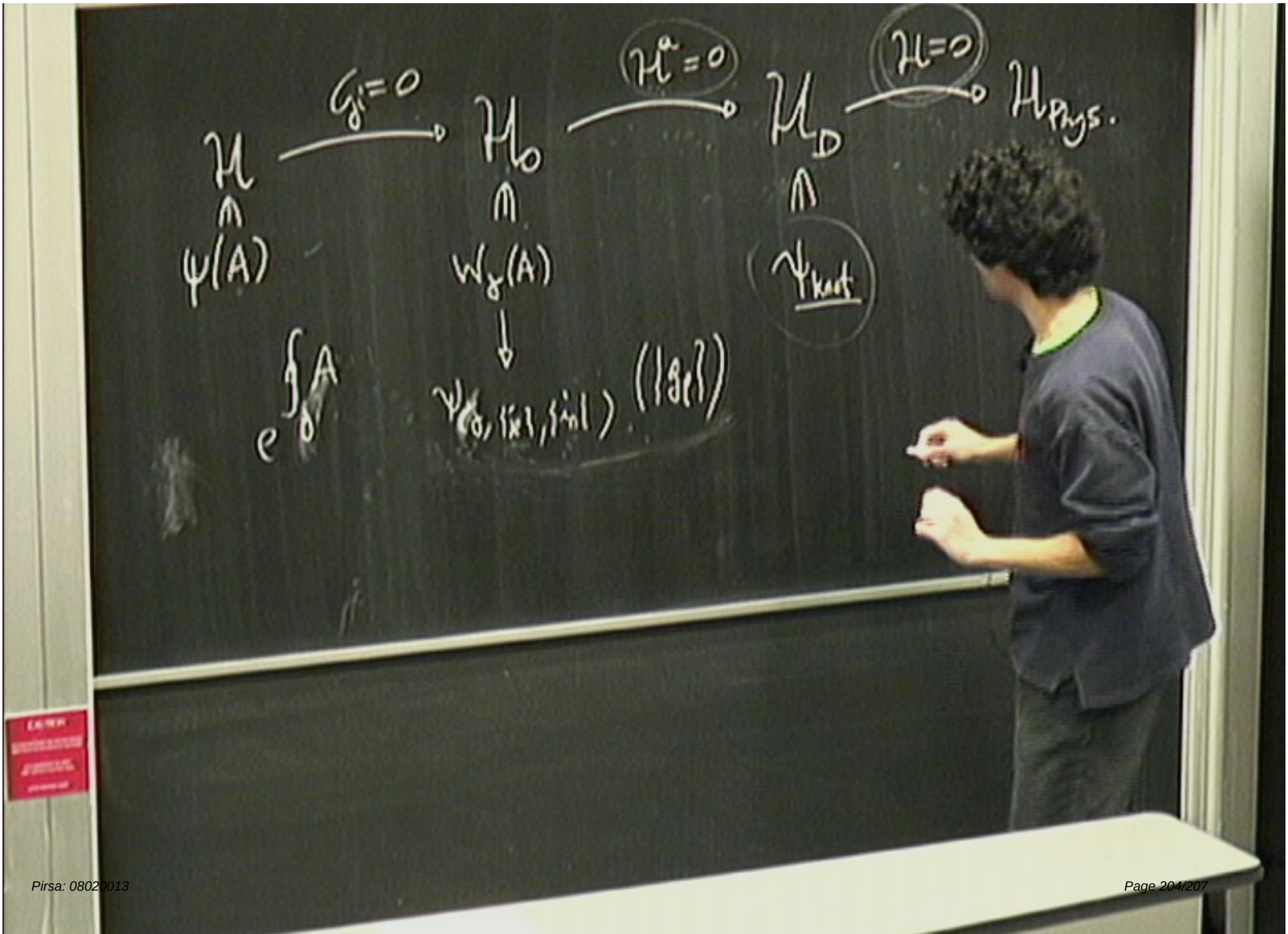

$\psi_{P_{SU}}[A] = \psi_{P_{SU}}[A + \partial\alpha]$
$\hat{H}$

$$\psi_{Pl_\gamma}[A] = \psi_{Pl_\gamma}[A + \partial\alpha]$$



$$= U_\gamma^A \, A = W_\gamma($$


$\mathcal{H} \xrightarrow{G_i=0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a=0} \mathcal{H}_D \xrightarrow{\mathcal{H}=0} \mathcal{H}_{Phys.}$
$\psi(A)$
$W_\gamma(A)$
$e^{\int_\gamma A}$
$\psi(\sigma, \{x\}, \{n\})$
$(|g_e|)$


$\mathcal{H} \xrightarrow{G_i=0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a=0} \mathcal{H}_D \xrightarrow{\mathcal{H}=0} \mathcal{H}_{Phys.}$
$\psi(A)$
$W_\gamma(A)$
ψ_{kart}
$e^{\int_\gamma A}$
$\psi(\gamma, \{x_i\}, \{n_i\})$ $(|\gamma_e|)$

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys}.$$

$$\psi(A) \in \mathcal{H} \qquad W_\gamma(A) \in \mathcal{H}_0 \qquad \psi_{knot} \in \mathcal{H}_D$$

$$e^{\oint_\gamma A}$$

$$W_\gamma(A) \longrightarrow \psi(\gamma, \{k_e\}, \{i_n\}) \quad (\{g_e\})$$

$$\hat{\mathcal{H}} |\psi\rangle = 0$$

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys.}$$

$$\psi(A) \in \mathcal{H} \qquad W_\gamma(A) \in \mathcal{H}_0 \qquad \underline{\psi_{knot}} \in \mathcal{H}_D$$

$$W_\gamma(A) \longrightarrow \psi(\sigma, \{x_e\}, \{i_n\}) \quad (\{g_e\})$$

$$e^{\oint_\gamma A}$$

$$\int_{-\infty}^{\infty} d\lambda \, e^{i\lambda H}$$

$$\hat{\mathcal{H}} |\psi\rangle = 0$$

$$\mathcal{H}_D \longrightarrow \mathcal{H}_{Phys}$$

"$\delta(\mathcal{H})$"

$$\mathcal{H} \xrightarrow{G_i = 0} \mathcal{H}_0 \xrightarrow{\mathcal{H}^a = 0} \mathcal{H}_D \xrightarrow{\mathcal{H} = 0} \mathcal{H}_{Phys.}$$

$$\psi(A) \in \mathcal{H} \qquad W_\gamma(A) \in \mathcal{H}_0 \qquad \underline{\psi_{knot}} \in \mathcal{H}_D$$

$$W_\gamma(A) \longrightarrow \psi(\gamma, \{x_e\}, \{i_n\}) \quad (\{g_e\})$$

$$e^{\oint_\gamma A}$$

$$\int_{-\infty}^{\infty} d\lambda \, e^{i\lambda H} = \text{"}\delta(H)\text{"}$$

$$\hat{\mathcal{H}} |\psi\rangle = 0$$

$$\mathcal{H}_D \longrightarrow \mathcal{H}_{Phys}$$

$$\text{"}\delta(\mathcal{H})\text{"}$$