Title: Quantum Matter Lecture

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Collection: Quantum Matter 2023/24

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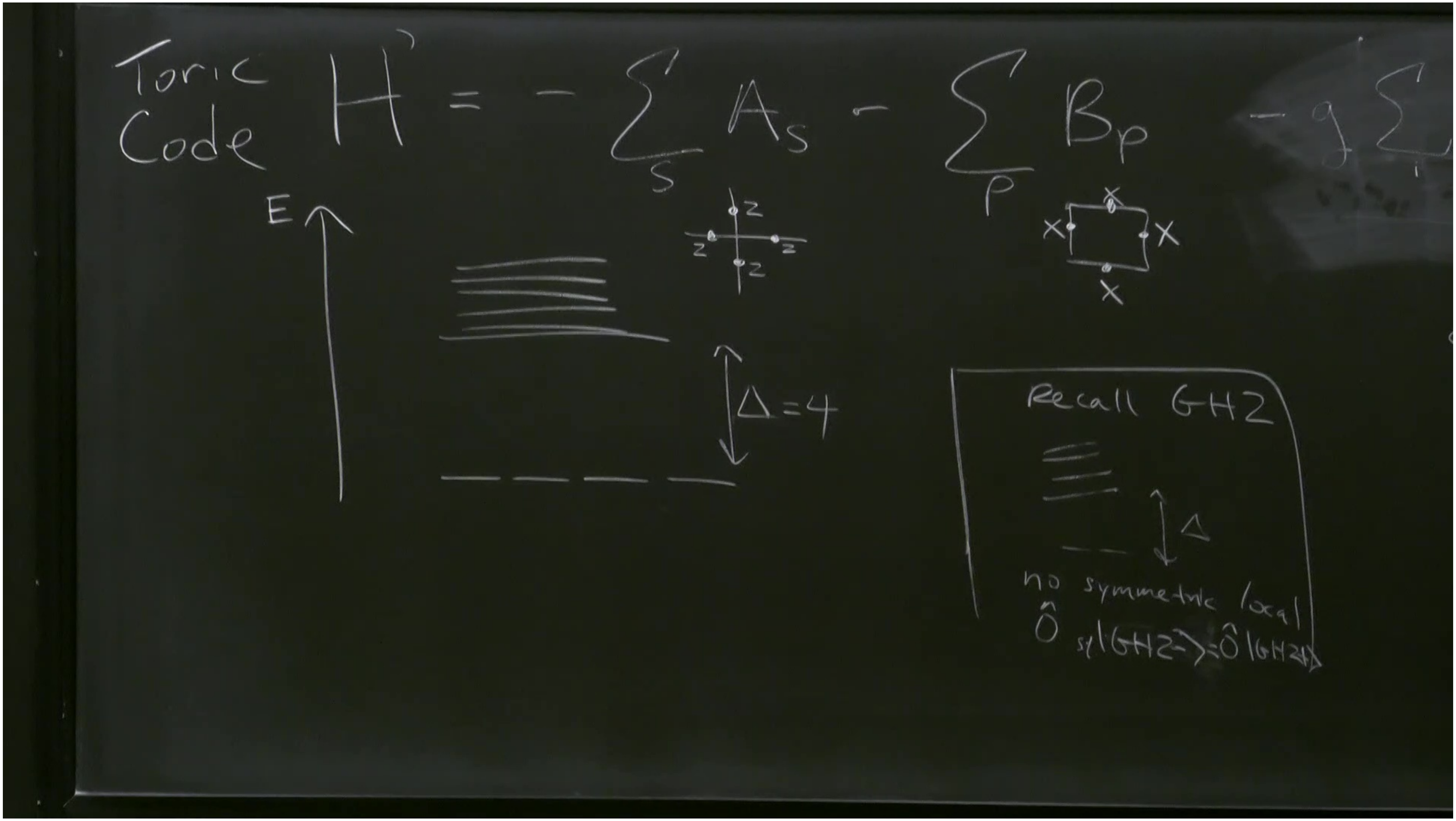
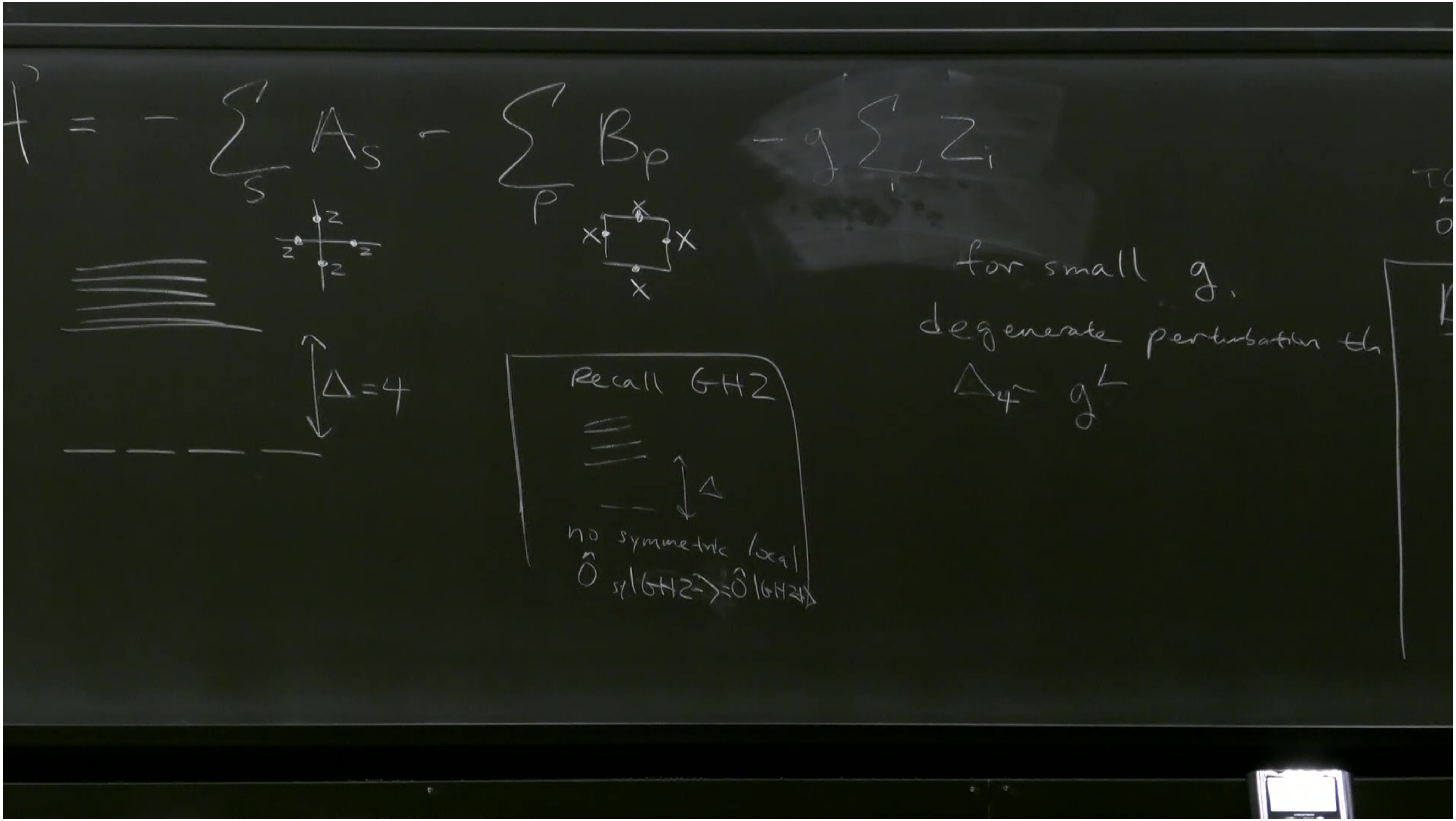
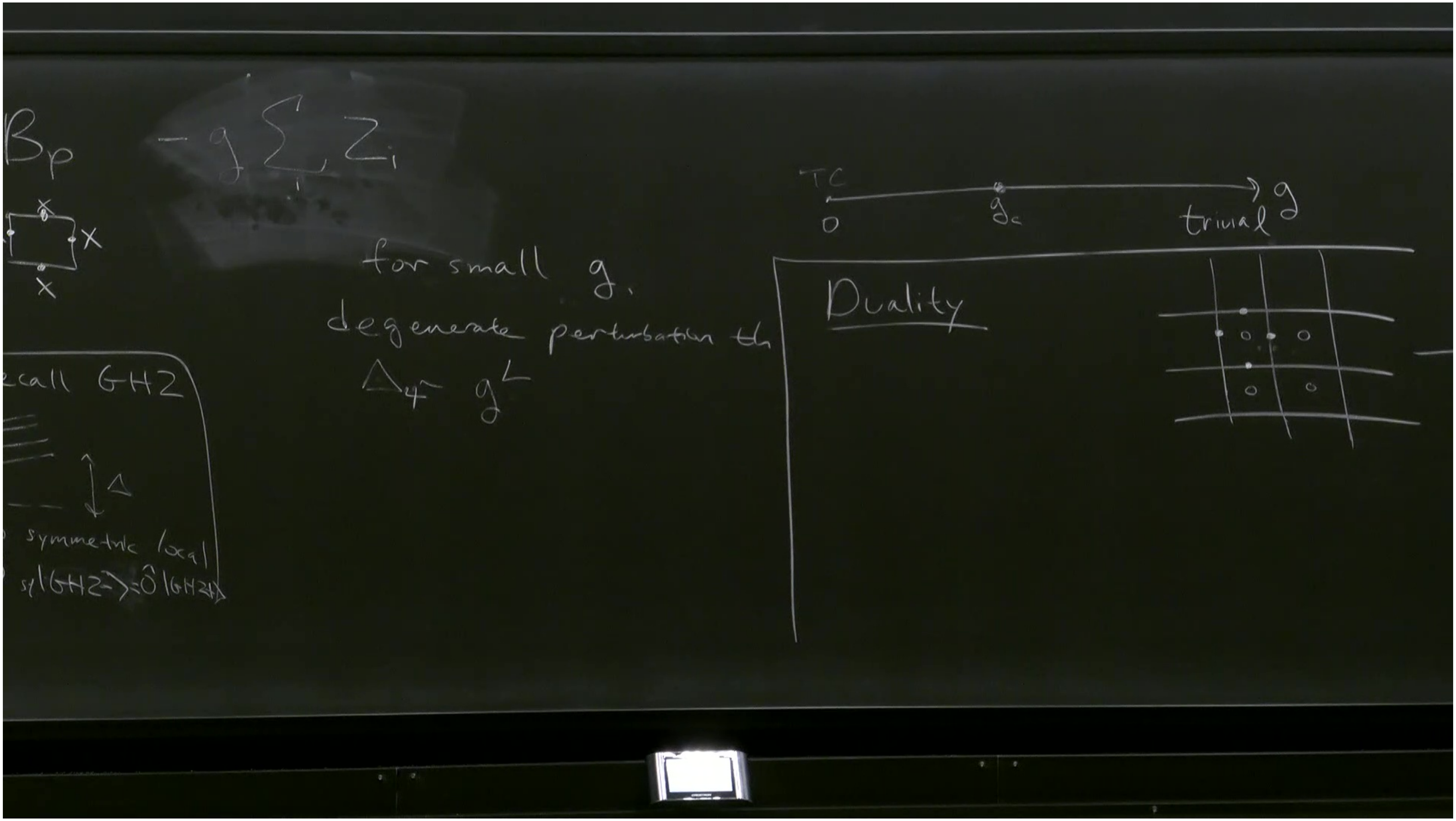
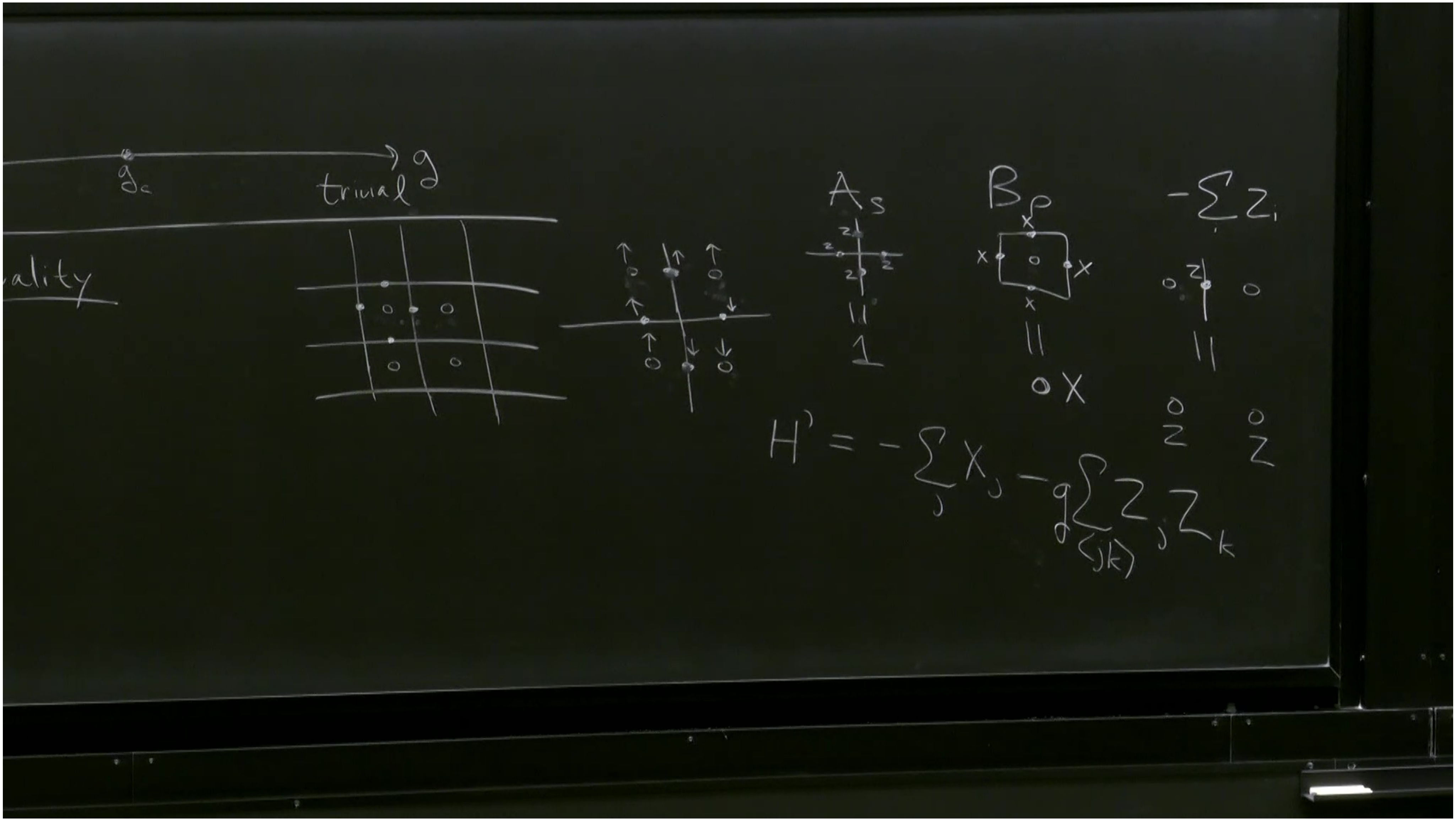
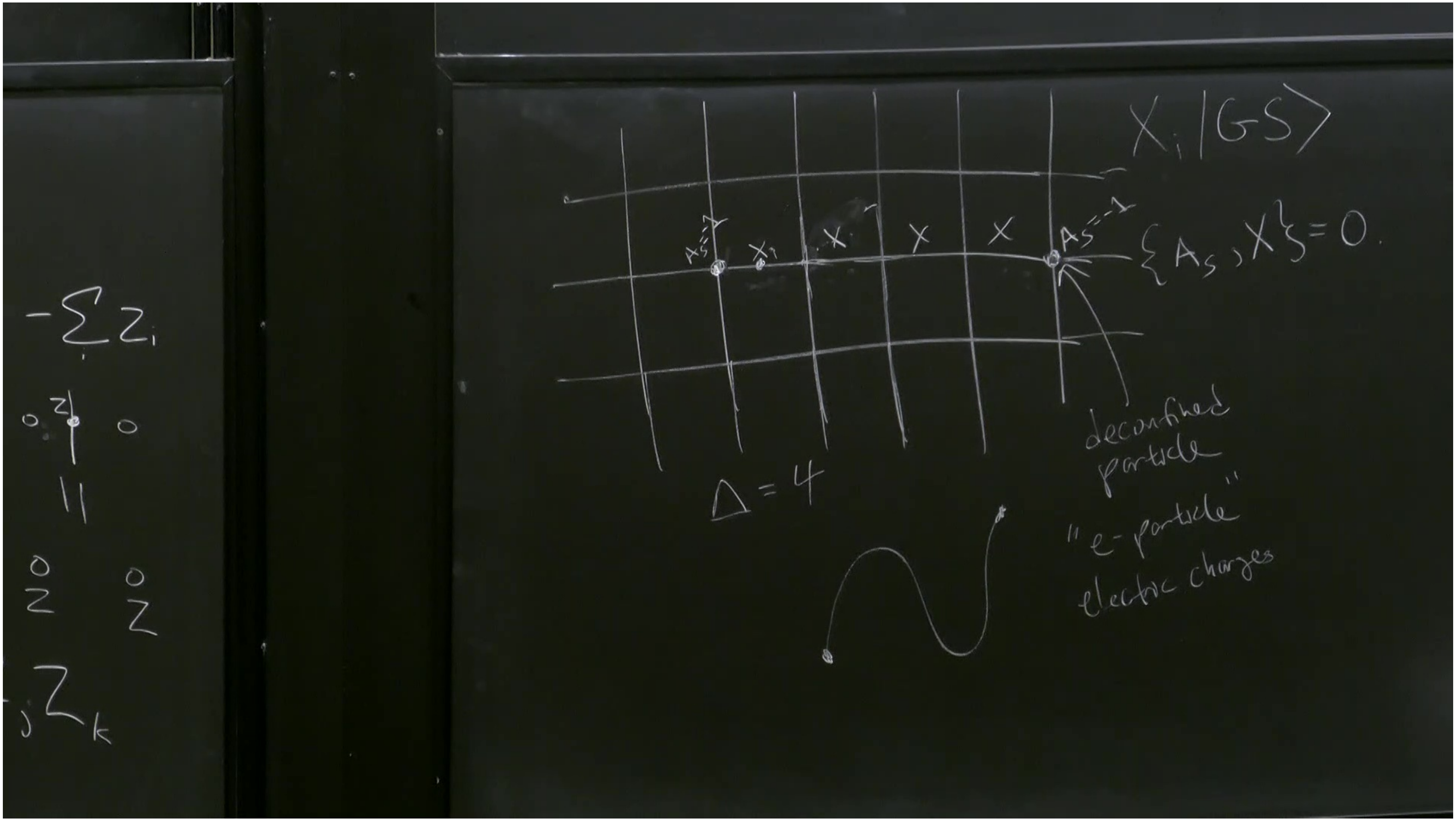

Toric Code
$H = -\sum_s A_s - \sum_p B_p - g\sum$
Z
Z
Z
Z
X
X
X
X
E
$\Delta = 4$
Recall GHZ
Δ
no symmetric local
$\hat{O}$ st $\langle GHZ-|\hat{O}|GHZ+\rangle$


$H = -\sum_s A_s - \sum_p B_p - g \sum_i Z_i$
Z Z Z Z
X X X X
$\Delta = 4$
Recall GHZ
Δ
no symmetric local
$\hat{O}_{sy} |GHZ-\rangle = \hat{O} |GHZ+\rangle$
for small g.
degenerate perturbation th
$\Delta_4 \sim g^L$

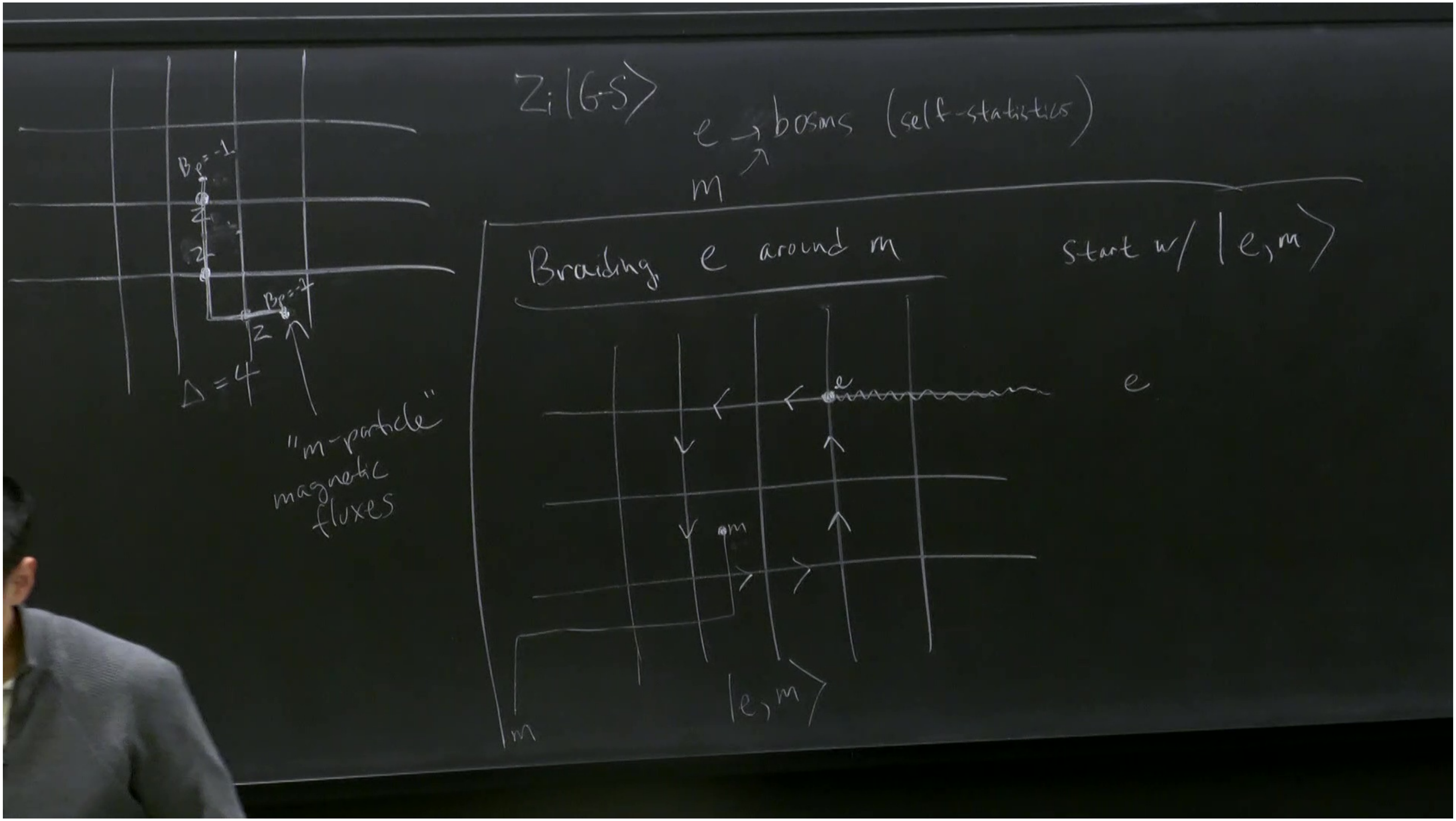

B_p −g Σ_i Z_i
X
X
X
for small g.
degenerate perturbation th
Δ_4 ~ g^L
ecall GHZ
Δ
symmetric local
TC
0
g_c
trivial
g
Duality



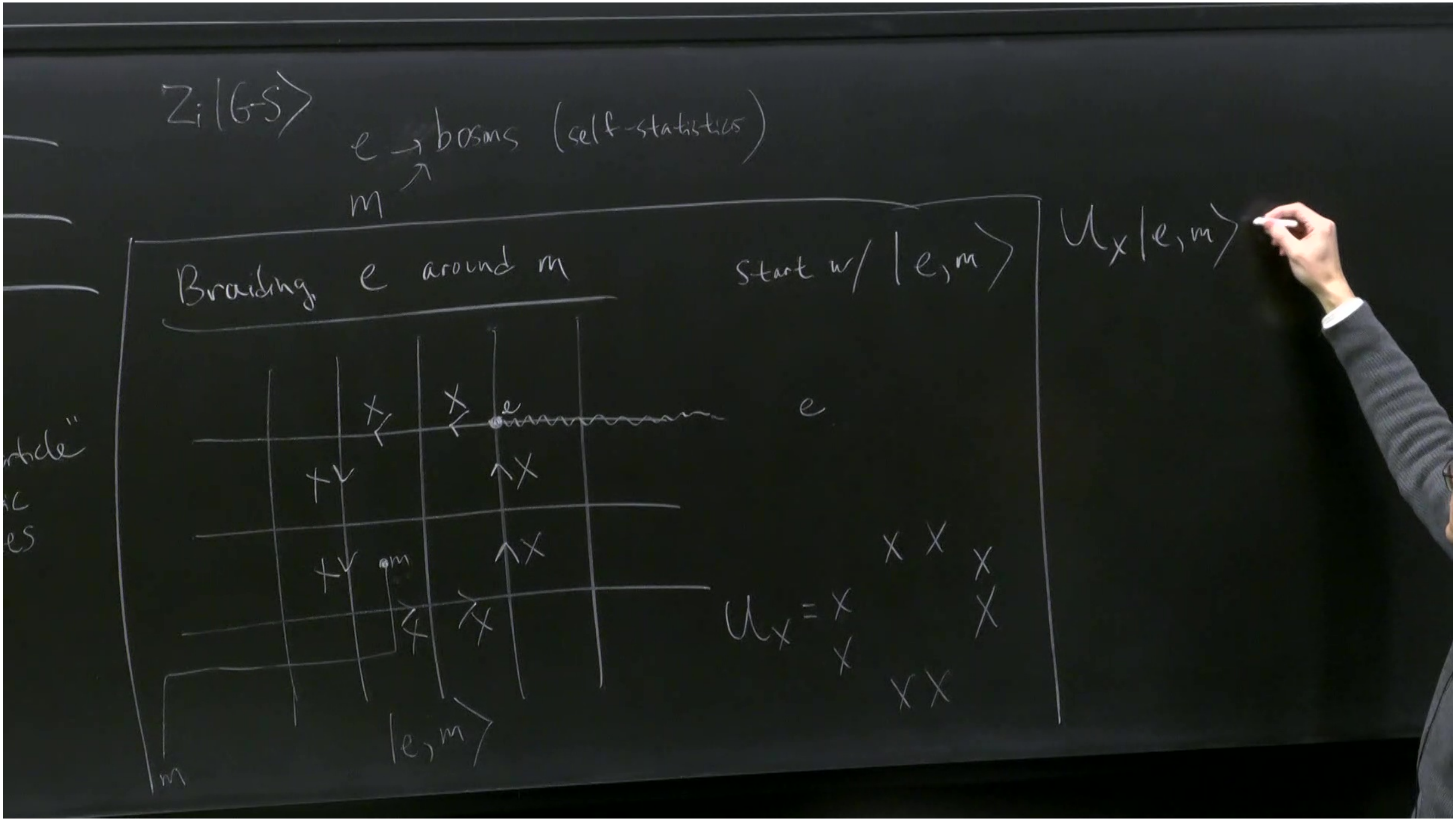
g_c
trivial
g
ality
A_s
B_p
$-\sum Z_i$
$= 1$
$= X$
$H' = -\sum_j X_j - g \sum_{\langle jk \rangle} Z_j Z_k$



$X_i|GS\rangle$
$A_s=-1$
$\{A_s, X\}=0$
deconfined particle
"e-particle"
electric charges
$\Delta=4$
$-\sum_i Z_i$



Z_i |G-S>
e → bosons (self-statistics)
m
Braiding e around m
Start w/ |e,m>
B_p = -1
Z
Z
Z
B_p = -1
Δ = 4
"m-particle"
magnetic
fluxes
e
m
e
|e,m>
m


Zi |G-S⟩
e → bosons (self-statistics)
m
Braiding e around m
Start w/ |e,m⟩
Ux |e,m⟩
e
m
Ux = X
|e,m⟩
m

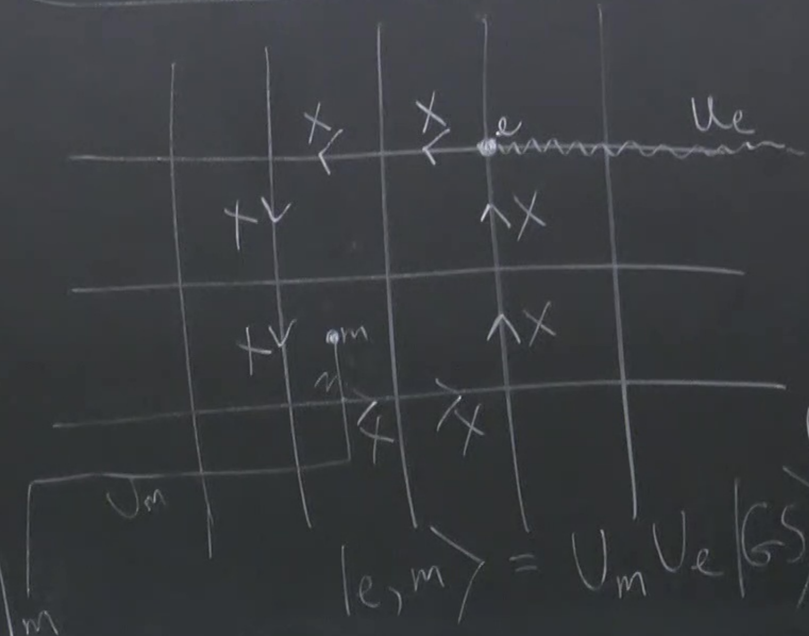
$Z_i|GS\rangle$

$e \rightarrow$ bosons (self-statistics)

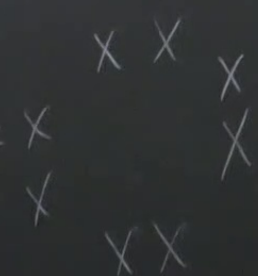
$m \nearrow$

Braiding e around m

Start w/ $|e,m\rangle$



e

$U_x =$ 

$|e,m\rangle = U_m V_e |GS\rangle$

$U_x|e,m\rangle = -|e,m\rangle$

(1) $U_x = \prod_p B_p$ $\begin{array}{|c|c|}\hline B_{p_1} & B_{p_2} \\ \hline B_{p_3} & B_{p_4} \\ \hline\end{array}$

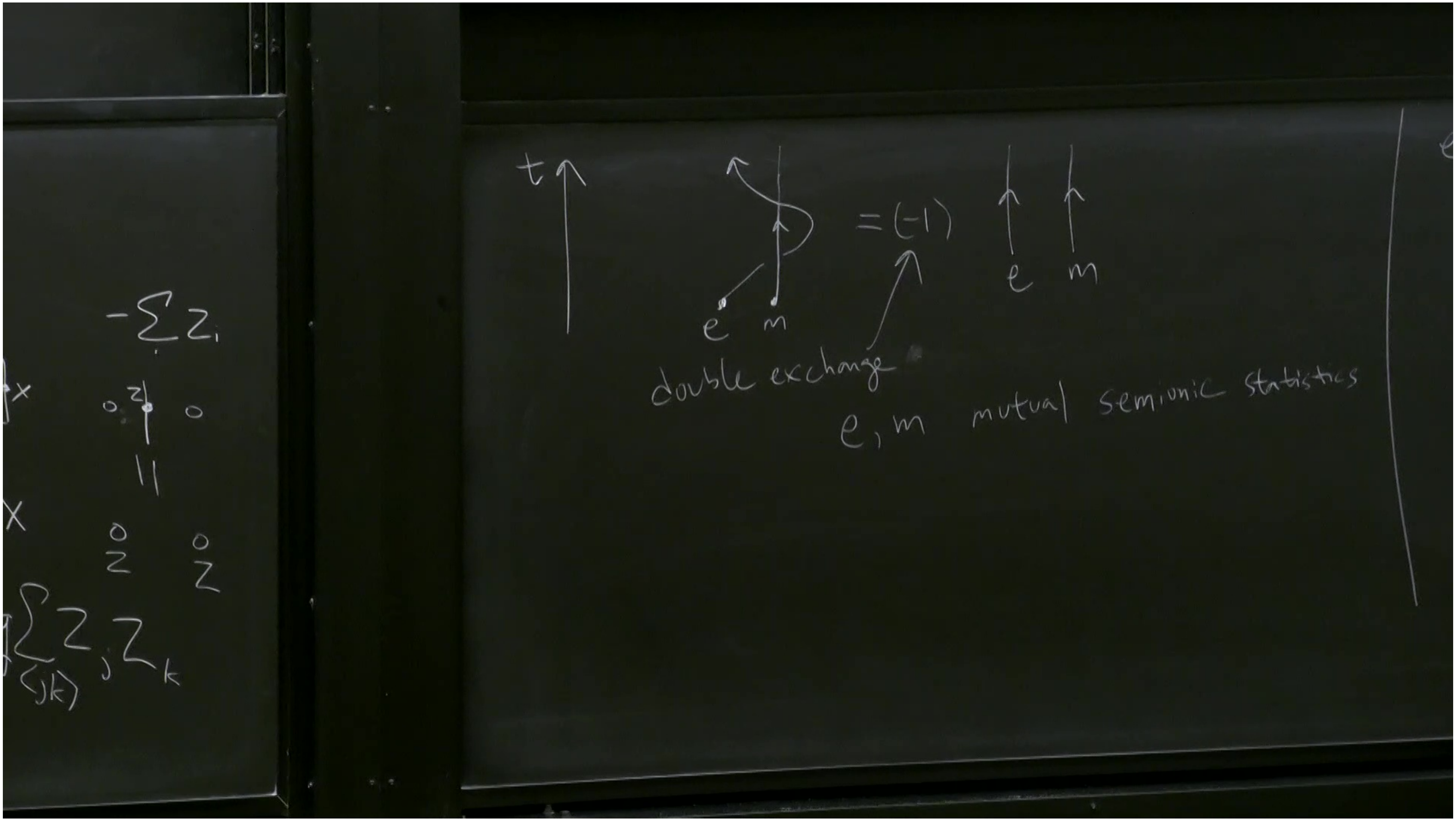
$= -1$

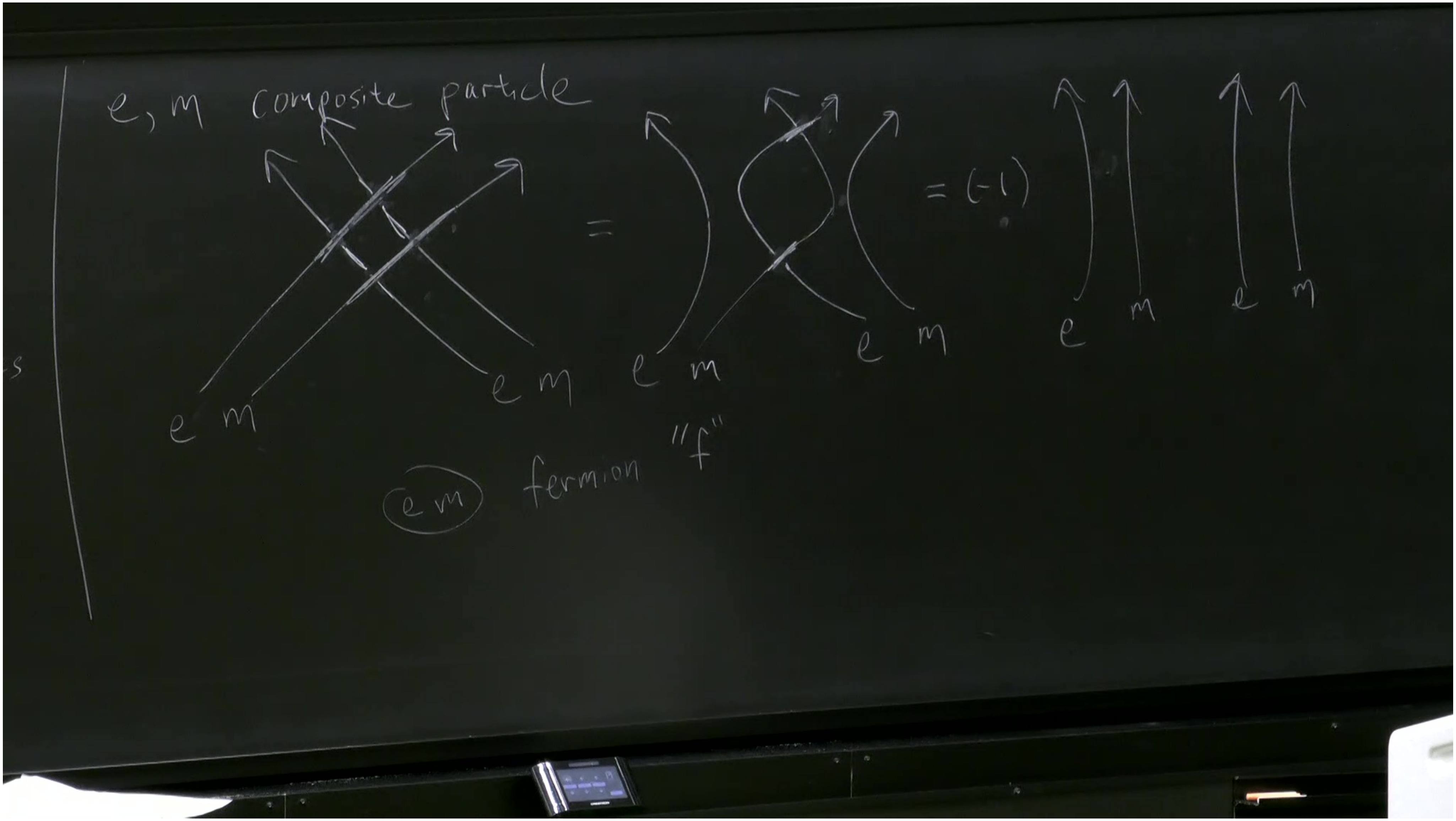
(2) $U_x|e,m\rangle$

$= [X \cdots X]\, U_m U_e |GS\rangle$

$= -U_m [X \cdots X]\, V_e |GS\rangle$

$= (-) U_m V_e \ldots |GS\rangle$


t
e m
= (-1)
e m
double exchange
e, m mutual semionic statistics
$-\sum Z_i$
$\sum_{\langle jk \rangle} Z_j Z_k$


e, m composite particle
= (-1)
e m
e m
e m
e m
e m
e m
(e m) fermion "f"

Top. order g.s. cannot be prepared w/ finite depth quantum circuit (or finite ti

Top. order g.s. cannot be prepared w/ $\underbrace{\text{finite depth quantum circuit}}_{U_{local}}$ (or finite time

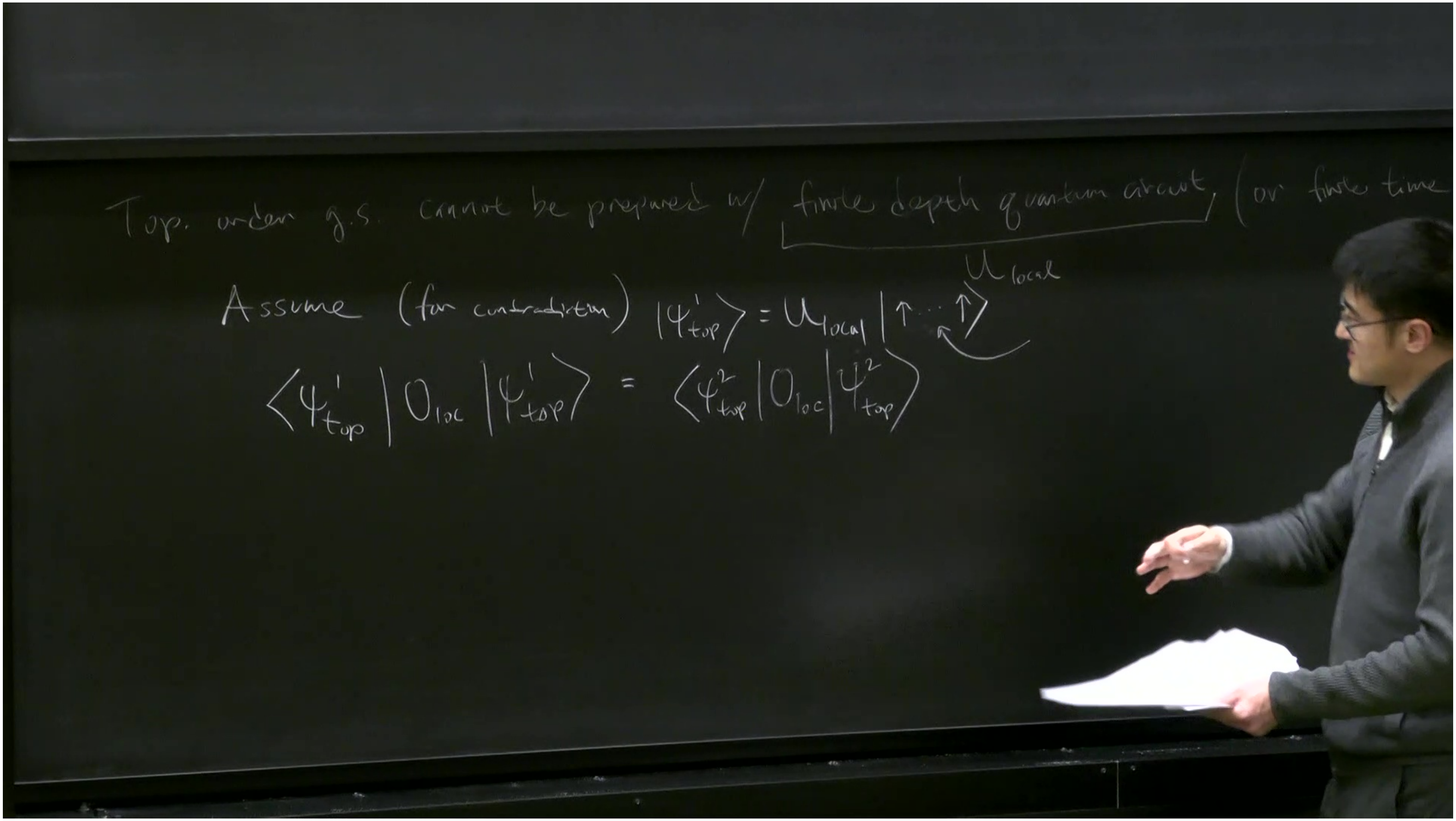
Assume (for contradiction) $|\psi^1_{top}\rangle = U_{local}|\uparrow \cdots \uparrow\rangle$ $z_i = +1 \ \forall i$ $\Longrightarrow$

$$\langle \psi^1_{top} | O_{loc} | \psi^1_{top} \rangle = \langle \psi^2_{top} | O_{loc} | \psi^2_{top} \rangle$$

...tum circuit, (or finite time local H evolution) from trivial product state

$Z_i = +1 \ \forall i \implies |\psi^1_{top}\rangle$ completely specified by $U Z_i U^\dagger = +1 \ \forall i$

$\implies |\psi^1_{top}\rangle = e^{i\theta} |\psi^2_{top}\rangle$


Top. order g.s. cannot be prepared w/ finite depth quantum circuit, (or finite time
U_{local}
Assume (for contradiction) $|\psi^1_{top}\rangle = U_{local} |\uparrow \cdots \uparrow\rangle$
$\langle \psi^1_{top} | O_{loc} | \psi^1_{top} \rangle = \langle \psi^2_{top} | O_{loc} | \psi^2_{top} \rangle$