Title: PSI 2019/2020 - Quantum Matter Part 1 - Lecture 11

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Collection: PSI 2019/2020 - Quantum Matter Part 1

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Symmetry Breaking

$[H(\lambda), T] = 0$ $\quad$ T is a global symmetry

e.g. $T = \bigotimes_{j \in \Lambda} \sigma_j^x$

$\lambda > \lambda_c$ $\quad$ GS is unique $\iff [\psi_0, T] = 0$

There is Δ $\quad \Rightarrow \langle 0 | AB | 0 \rangle \sim e^{-d_{AB}/\xi}$

$\lambda < \lambda_c$ $\quad$ degeneracy in the GS $\quad$ e.g. $\mathcal{h} = \mathrm{span}\{|0\rangle^{\otimes N}, |1\rangle^{\otimes N}\} = \mathrm{span}\left\{ \frac{|0\rangle^{\otimes N} \pm |1\rangle^{\otimes N}}{\sqrt{2}} \right\}$

$T|0\rangle^{\otimes N} = |1\rangle^{\otimes N}$ $\quad$ $|\phi^+\rangle, |\phi^-\rangle$

$\| [|0\rangle\langle 0|^{\otimes N}, T] \|$ is max over $\mathcal{h}$ $\quad$ unique

$- d_{AB}/\xi$

$$\frac{|0\rangle^{\otimes N} \pm |1\rangle^{\otimes N}}{\sqrt{2}}$$

$|\phi^+\rangle, |\phi^-\rangle$

Unique

$\langle \phi^+|\sigma_i^z \sigma_j^z|\phi^+\rangle \sim n_0^2(\lambda)$ Long-Range order

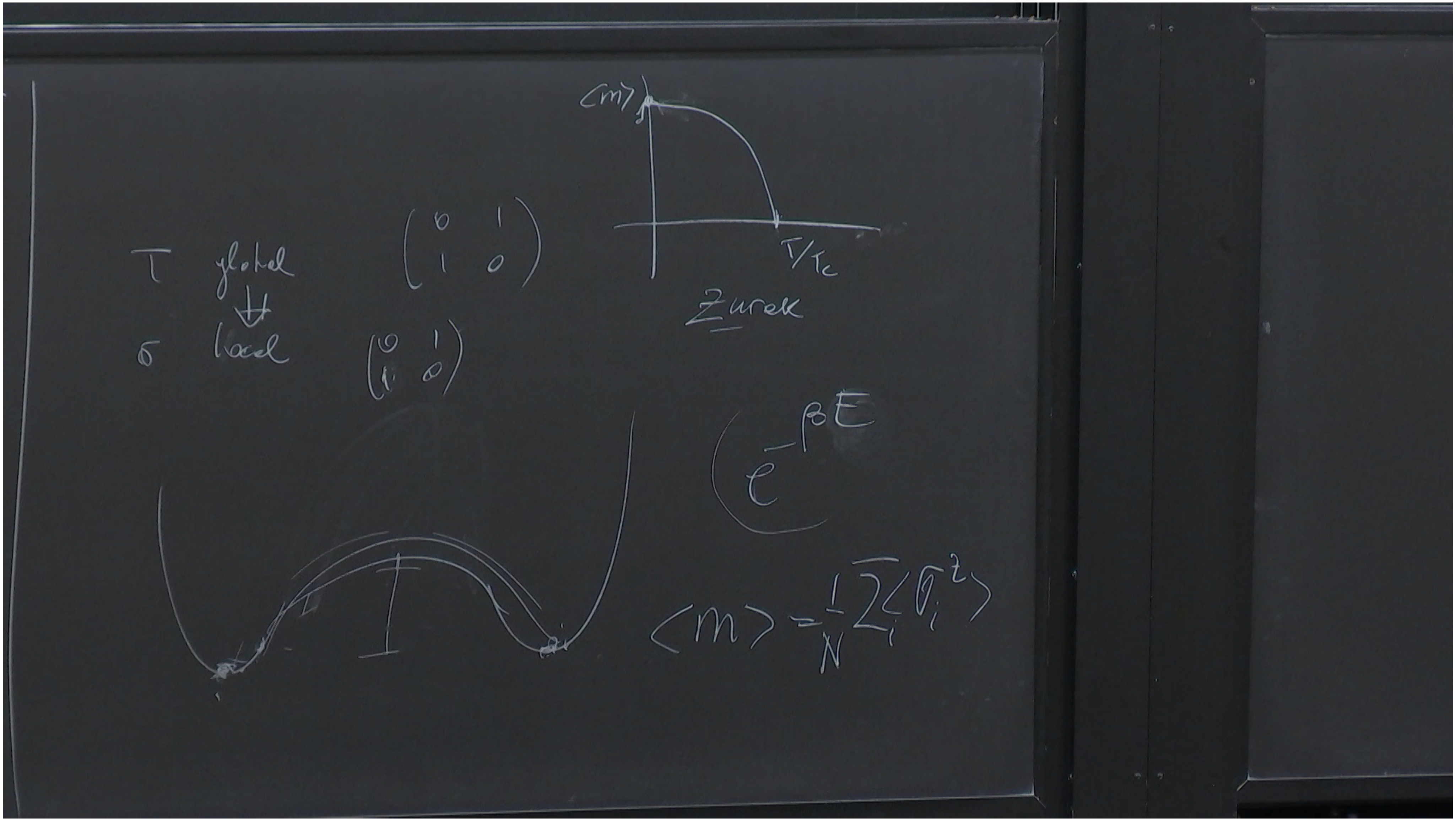
$\langle \sigma_i^z \rangle_{\psi_0 \in L} \neq 0$ Spontaneous symmetry breaking

$\langle \phi^+|\sigma_i^z|\phi^+\rangle = 0$

$|0\rangle^{\otimes N} \xrightarrow{T} |1\rangle^{\otimes N}$ global ?

$|\phi^+\rangle \xrightarrow{\sigma_i^z} |\phi^-\rangle$ local

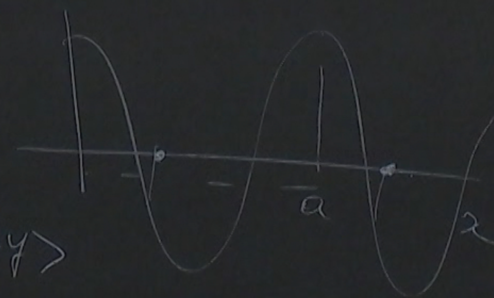
$\rightarrow$ fragile


T global
σ local
⟨m⟩
T/Tc
Zurek
e^{-βE}
⟨m⟩ = 1/N Σ_i ⟨σ_i^z⟩

Quantum Gauge Theory (Lattice)

Particle on a straight line $\mathcal{H} \overset{\text{span}}{=} \{ |x\rangle : x \in \mathbb{R} \}$

$$H = \frac{p^2}{2m} + \bar{V} \cos \frac{2\pi x}{a}$$



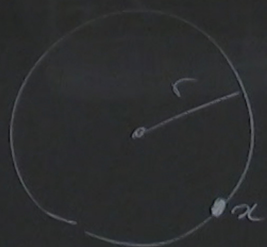
translation operator $T_y |x\rangle = |x+y\rangle$

$$[T_a, H] = 0 \quad \text{symmetry}$$

Particle on a circle

$a = 2\pi r$

$$\mathcal{H} = \{ |x + ka\rangle \, ; \, x \in \mathbb{R}, \, k \in \mathbb{N} \}$$



$x \longrightarrow |x\rangle$

$x + a \longrightarrow |x+a\rangle$

$x \bmod a \; ; \; x \in \mathbb{R}$

$|x\rangle \equiv |x+a\rangle$

Gauge structure

$\mathcal{H}_{gauge} = \{ |x+ka\rangle \, ; \, x \in \mathbb{R}, \, k \in \mathbb{N} \}$

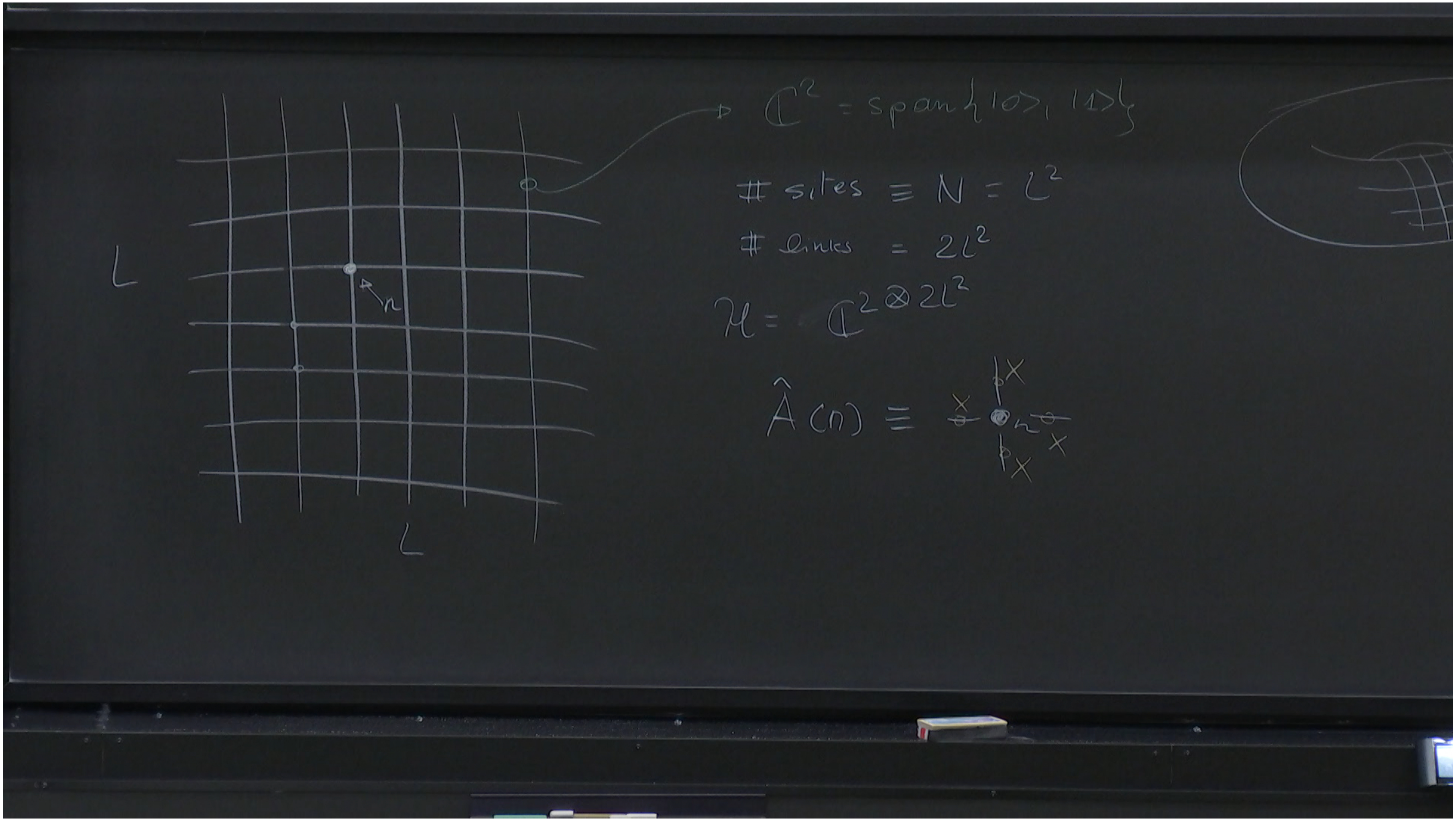
gauge
do-nothing "transf"

$T_a |x\rangle = |x+a\rangle = |x\rangle$

$[H, T_a] \neq 0$?

$|\psi\rangle \in \mathcal{H}_{gauge}$

$H|\psi\rangle \notin \mathcal{H}_{gauge}$

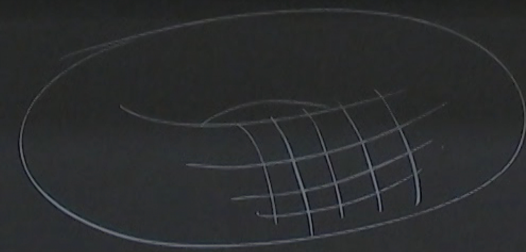

$\mathbb{C}^2 = \text{span}\{|0\rangle, |1\rangle\}$
$\#\text{ sites} \equiv N = L^2$
$\#\text{ links} = 2L^2$
$\mathcal{H} = \mathbb{C}^{2 \otimes 2L^2}$
$\hat{A}(n) \equiv$
L
L
n

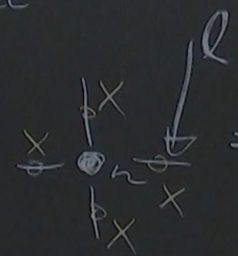
$\mathbb{C}^2 = \mathrm{span}\{|0\rangle, |1\rangle\}$

$\#\,\text{sites} \equiv N = L^2$

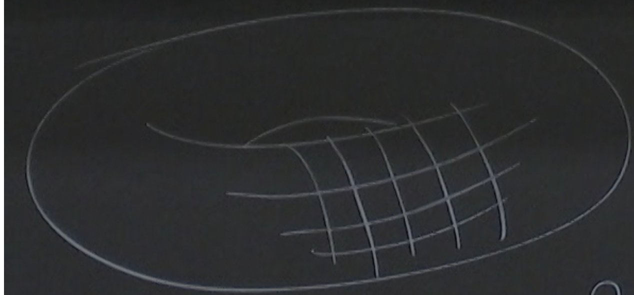
$\#\,\text{links} = 2L^2$

$\mathcal{H} = \mathbb{C}^{2 \otimes 2L^2}$



$\hat{A}(n) \equiv$  $= \prod_{\ell \in n} \sigma^x_\ell$

$|\psi\rangle \in \mathcal{H} \xrightarrow{A(n)} A(n)|\psi\rangle$



σ^x_e

$$\mathcal{H}_{gauge} = \{ |\psi\rangle \in \mathcal{H} : A(n)|\psi\rangle = |\psi\rangle \}$$

$$\mathcal{H}_{gauge} = \{ |x\rangle \in \mathcal{H} : T_e|x\rangle = |x\rangle \}$$

$n)|\psi\rangle$