Title: PSI 2018/2019 - Condensed Matter Review - Tutorial 1

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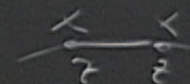
Abstract:

$$H(g) = -g \sum_i \hat{\sigma}_i^x - \sum_{(ij)} \hat{\sigma}_i^z \otimes \hat{\sigma}_j^z \qquad \boxed{g \to \infty}$$

N spins $\frac{1}{2}$ $\qquad \mathbb{C}^2 \simeq \mathrm{span}\{|0\rangle, |1\rangle\}$

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

$$|\psi(g)\rangle$$



$$T = \bigotimes_{i=1}^{N} \hat{\sigma}_i^x \qquad [T, H] = 0$$

$$T|00\,11\,0\,\ldots\rangle = |11\,00\,1\,0\,00\rangle$$

$$- \sum_{\langle ij \rangle} \hat{\sigma}_i^z \otimes \hat{\sigma}_j^z$$

$$\boxed{g \to \infty}$$

$|\psi^+\rangle = |+\rangle_1 \otimes \cdots \otimes |+\rangle_N$ Unique

span $\{|0\rangle, |1\rangle\}$

$$|+\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

$$\langle \psi^+ | \hat{\sigma}_i^z \hat{\sigma}_j^z | \psi^+ \rangle = 0$$

Paramagnetic $\langle \psi^+ | \hat{\sigma}_i^z | \psi^+ \rangle = 0$

No "spontaneous" magnetisation

$(g)\rangle$

$$\langle \psi^+ | \sigma_i^x | \psi^+ \rangle = 1$$

$T, H] = 0$

$T^2 = \mathbb{1}$

$\{\mathbb{1}, T\} \simeq \mathbb{Z}_2$

$= |1100100\rangle$

$\boxed{g \to \infty}$

$|\psi^+\rangle = |+\rangle_1 \otimes \cdots \otimes |+\rangle_N$ Unique

$|+\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$ $\quad \langle\psi^+|\hat{\sigma}^z_i \hat{\sigma}^z_j|\psi^+\rangle = 0$

Paramagnetic $\langle\psi^+|\hat{\sigma}^z_i|\psi^+\rangle = 0$ $\quad C_{ij} = e^{-|i-j|/\xi}$

No "spontaneous" magnetisation

$\xi = \frac{1}{\Delta}$

$\langle\psi^+|\sigma^x_i|\psi^+\rangle = 1$

$\boxed{g \to 0}$ Ferromagnetic phase

$|0\rangle^{\otimes N}$

$|1\rangle^{\otimes N}$

$\boxed{g \to \infty}$

$|\psi^+\rangle = |+\rangle_1 \otimes \cdots \otimes |+\rangle_N$ Unique

$|+\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$ $\quad \langle\psi^+|\hat{\sigma}^z_i \hat{\sigma}^z_j|\psi^+\rangle = 0$

Paramagnetic $\langle\psi^+|\hat{\sigma}^z_i|\psi^+\rangle = 0$ $\quad C_{ij} = e^{-|i-j|/\xi}$

No "spontaneous" magnetisation $\quad \xi = \frac{1}{\Delta}$

$\langle\psi^+|\sigma^x_i|\psi^+\rangle = 1$, $\quad T|+\rangle = |+\rangle$

$[T, |+\rangle\langle+|] = 0$

$\boxed{g \to 0}$ Ferromagnetic phase

$\mathcal{H}_{GS} \simeq \mathrm{span}\{|0\rangle^{\otimes N}, |1\rangle^{\otimes N}\}$

$\psi \in \mathcal{H}_{GS}$

$[T, \psi]$

$\boxed{g \to \infty}$

$|\psi^+\rangle = |+\rangle_1 \otimes \cdots \otimes |+\rangle_N$ Unique

$|+\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$ $\quad \langle\psi^+|\hat{\sigma}_i^z \hat{\sigma}_j^z|\psi^+\rangle = 0$

Paramagnetic $\langle\psi^+|\hat{\sigma}_i^z|\psi^+\rangle = 0$ $\quad C_{ij} = e^{-|i-j|/\xi}$

No "spontaneous" magnetisation $\quad \xi = \frac{1}{\Delta}$

$\langle\psi^+|\sigma_i^x|\psi^+\rangle = 1$; $\quad T|+\rangle = |+\rangle$

$[T, |+\rangle\langle+|] = 0$

$\boxed{g \to 0}$ Ferromagnetic phase

$\mathcal{H}_{GS} \simeq \text{span}\{|0\rangle^{\otimes N}, |1\rangle^{\otimes N}\}$

$\psi \in \mathcal{H}_{GS}$

$[T, \psi] \neq 0$

$T|0\rangle^{\otimes N} = |1\rangle^{\otimes N}$

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

$\langle 0 | \sigma^z_i \sigma^z_j | 0 \rangle \neq 0 \quad |i-j|$ large

$C_{ij} \neq 0$ Long-range order