低次元磁性体における量子効果による新奇な磁気秩序の理論的研究

Theoretical Study of the Novel Magnetic Order Induced by Quantum Effects in Low Dimensional Magnets

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1 $S = 1/2$ frustrated Heisenberg chain with period 3 exchange modulation

The Hamiltonian of $S = 1/2$ frustrated Heisenberg chain with period 3 exchange modulation[1, 2] is given by,

$$\mathcal{H} = J\sum_{l=1}^{N/3}\left[(1-\alpha)\left(\boldsymbol{S}_{3l-1}\boldsymbol{S}_{3l} + \boldsymbol{S}_{3l}\boldsymbol{S}_{3l+1}\right) + (1+\alpha)\boldsymbol{S}_{3l+1}\boldsymbol{S}_{3l+2}\right] + J\delta\sum_{i=1}^{N}\boldsymbol{S}_i\boldsymbol{S}_{i+2} \quad (1)$$

where $\boldsymbol{S_i}$ is the spin 1/2 operator. The ground state phase diagram for $\alpha \leq 0$ and $0 \leq \delta \leq 0.8$ is obtained by exact numerical diagonalization (ED) of finie size system as shown in Fig. 1.

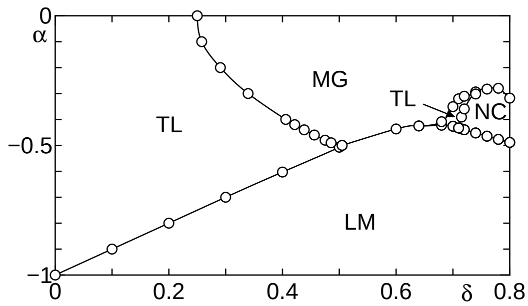

Figure 1: Ground state phase diagram of (1). TL, MG, NC and LM stand for Tomonaga-Luttinger liquid phase, Majumdar-Ghosh type dimer phase, noncollinear and Lieb-Mattis ferrimagnetic phases, respectively.

For large negative α and large δ, the ground state is ferrimagnetic with magnetization $M = M_{\rm s}/3$. This phase is the Lieb-Mattis type ferrimagnetic phase. With the decrease in $|\alpha|$, the ferrimagnetic state with magnetization less than $M_{\rm s}/3$ appears. The magnetization curve and the magnetization profile calculated by DMRG is presented in Fig. 2, for $(\alpha, \delta) = (-0.39, 0.8)$ and $N = 96$ with open boundary condition.

2 Ferrimagnetic and Long Period Antiferromagnetic Phases in High Spin Heisenberg Chains with D-Modulation [3]

The ground state properties of the high spin Heisenberg chains with alternating single site anisotropy δD are investigated by means of ED and DMRG method. It is found that the ferrimagnetic state appears between the Haldane phase and period doubled Néel phase for the integer spin chains as shown in Fig. 3 for $S = 2$. On the other hand, the transition from the Tomonaga-Luttinger liquid state into the ferrimagnetic state takes place for the half-odd-integer spin chains. In the ferrimagnetic phase, the spontaneous magnetization varies continuously with δD. Eventually, the magnetization is locked to fractional values of the saturated magnetization. These fractional values satisfy the Oshikawa-Yamanaka-Affleck condition. In contrast to the case of frustration induced ferrimagnetism, no incommensurate magnetic superstructure is found.

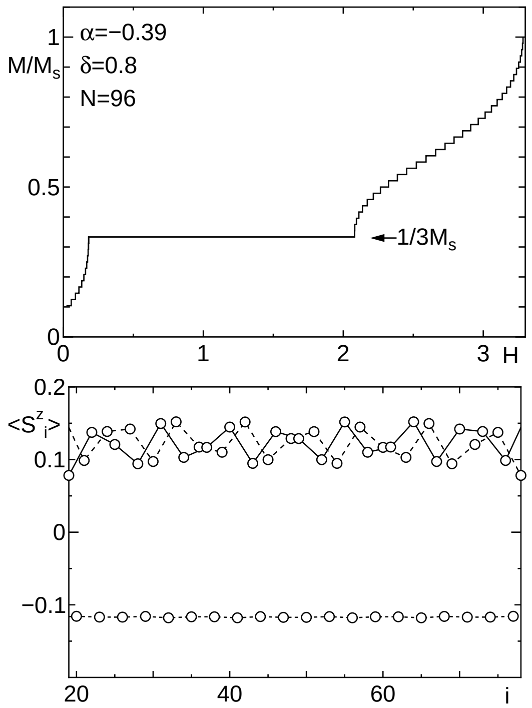

Figure 2: Magnetization curve and local magnetization profile in noncollinear ferrimagnetic phase with $(\delta, \alpha) = (0.8, -0.39)$ for $N = 96$ calculated by DMRG method.

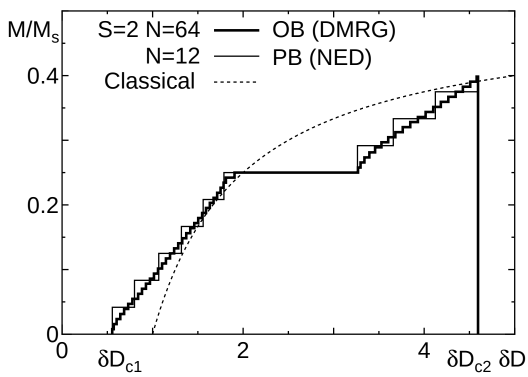

Figure 3: The spontaneous magnetization for $S = 2$ with $N = 12$ and $N = 64$ plotted against δD. The dotted lines are the classical spontaneous magnetization.

3 Field-Induced Multiple Reentrant Phase Transitions in Randomly Dimerized Antiferromagnetic S=1/2 Heisenberg Chains [4]

The $S = 1/2$ antiferromagnetic Heisenberg chains with random bond alternation in the magnetic field are investigated by the DMRG method combined with interchain mean field approximation. It is assumed that odd-th bonds are antiferromagnetic with strength J and even-th bonds can take the values $J_{\rm S}$ and $J_{\rm W}$ ($J_{\rm S} > J > J_{\rm W} > 0$) randomly with the probabilities p and $1 - p$, respectively.

For $p = 0$ and $p = 1$, this model exhibits a field-induced antiferromagnetism in the presence of interchain coupling if Zeeman energy due to the magnetic field exceeds the spin gap. For $0 < p < 1$, antiferromagnetism is induced by randomness even in the small field region. At the same time, this model exhibits randomness-induced plateaus at several values of magnetization where the antiferromagnetism is destroyed. As a consequence, we find a series of reentrant quantum phase transitions between antiferromagnetic phases and disordered plateau phases with the increase of magnetic field. Above the main plateaus, the magnetization curve consists of a series of small plateaus and jumps between them. The antiferromagnetism is induced by infinitesimal interchain coupling at the jumps. We conclude that this antiferromagnetism is supported by the mixing of low-lying excited states by the staggered interchain mean field even though the spin correlation function is short ranged in the ground state of each chain.

The numerical diagonalization program is based on the package TITPACK ver.2 coded by H. Nishimori.

References

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