Magnetic Properties of Two Finite spin-1/2 XX Chains Connected through Two Ising spins

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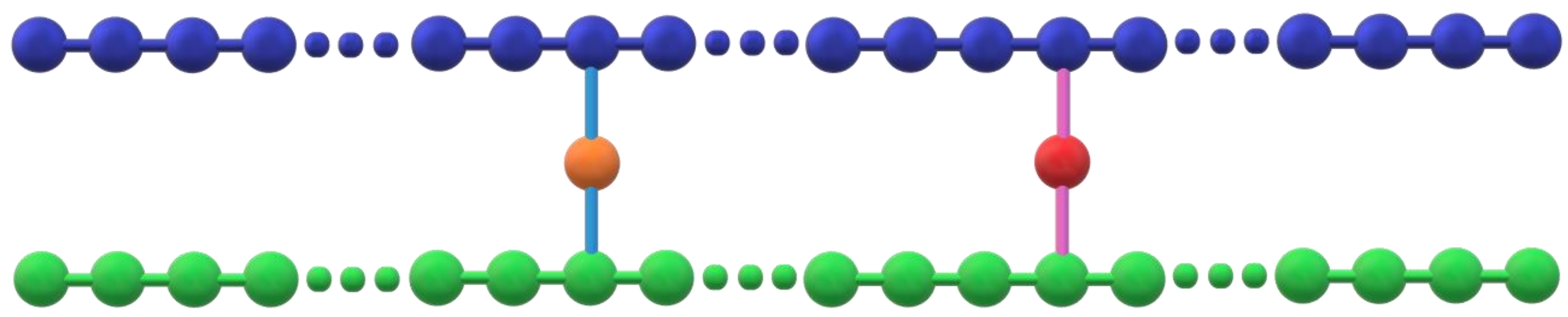
We propose exactly solvable quantum model based on finite spin-1/2 XX chains with two bridging Ising spins, connecting XX chains at two intermediate lattice sites.



Model Hamiltonian has the form:

$$\mathbf{H} = -g_1\mu_B H\sum_{n=1}^{N_1} S_{1,n}^z - J_1\sum_{n=1}^{N_1-1}\left(S_{1,n}^x S_{1,n+1}^x + S_{1,n}^y S_{1,n+1}^y\right) - g_2\mu_B H\sum_{n=1}^{N_2} S_{2,n}^z - J_2\sum_{n=1}^{N_2-1}\left(S_{2,n}^x S_{2,n+1}^x + S_{2,n}^y S_{2,n+1}^y\right) -$$

$$-g_{01}\mu_B H\sigma_1^z - g_{02}\mu_B H\sigma_2^z - J_{01}\sigma_1^z\left(S_{1,n_1}^z + S_{2,n_3}^z\right) + J_{02}\sigma_2^z\left(S_{1,n_2}^z + S_{2,n_4}^z\right).$$

Z-projections of Ising additional spins commute with model Hamiltonian and are the good quantum numbers. This property permits us to consider Hamiltonian (1), as the Hamiltonian of the finite XX-chain with an effective impurity spin S = 1/2 at lattice sites $1,n_1;\ 1,n_2;\ 2,n_3;\ 2,n_4$. Spin-1/2 XX chain is the well known example of exactly solvable model [1]. The XX model Hamiltonian one can rewrite as the Hamiltonian of ideal gas of spinless fermions.

Dispersion relations

$$\left(1+\beta_1 x_1\frac{1-x_1^{-2n_1}}{x_1^2-1}\right)\left(1+\beta_2 x_1\frac{\left(1-x_1^{-2(N_1+1-n_2)}\right)}{x_1^2-1}\right)x_1^{N_1+1} - \left(1+\beta_1 x_1\frac{\left(1-x_1^{2n_1}\right)}{1-x_1^2}\right)\left(1+\beta_2 x_1\frac{\left(1-x_1^{2(N_1+1-n_2)}\right)}{1-x_1^2}\right)x_1^{-(N_1+1)} = 0;$$

$$\left(1+\beta_1 x_2\frac{1-x_2^{-2n_3}}{x_2^2-1}\right)\left(1+\beta_2 x_2\frac{\left(1-x_2^{-2(N_2+1-n_4)}\right)}{x_2^2-1}\right)x_2^{N_2+1} - \left(1+\beta_1 x_2\frac{\left(1-x_2^{2n_3}\right)}{1-x_2^2}\right)\left(1+\beta_2 x_2\frac{\left(1-x_2^{2(N_2+1-n_4)}\right)}{1-x_2^2}\right)x_2^{-(N_2+1)} = 0;$$

Low temperature thermodynamics

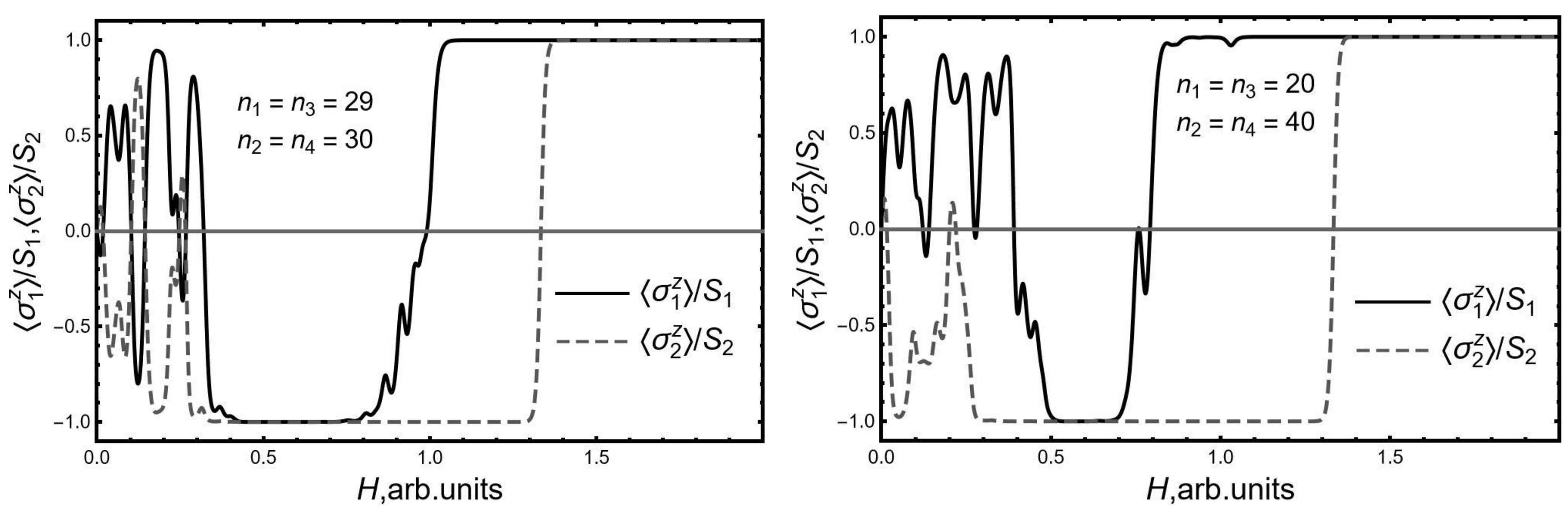


Fig. 1. Field dependence of $\langle\sigma_i^z\rangle/S_i$, $i=1,2$; at $T=0.01$, $g_1=1$, $g_2=2$, $g_{01}=1$, $g_{02}=1.5$, $J_1/J_2=2$, $J_{01}/J_2=-1$, $J_{02}/J_2=-2$, $N_1=N_2=50$

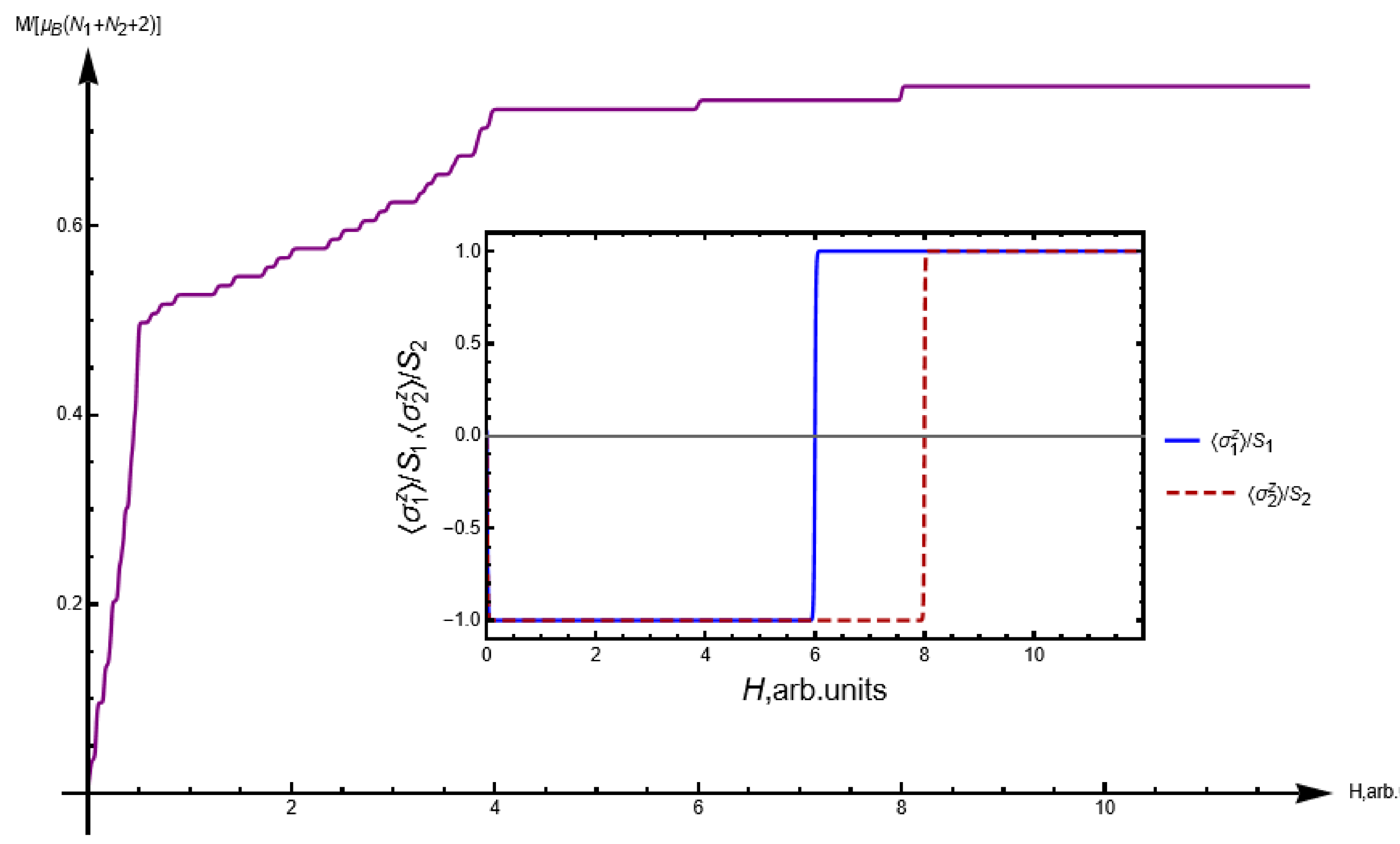


Fig. 2. Field dependence of magnetization per spin at $T=0.01$, $g_1=1$, $g_2=2$, $g_{01}=1$, $g_{02}=1.5$, $J_1/J_2=4$, $J_{01}/J_2=-6$, $J_{02}/J_2=-12$, $N_1=N_2=50$, $n_1=n_3=20$, $n_2=n_4=40$

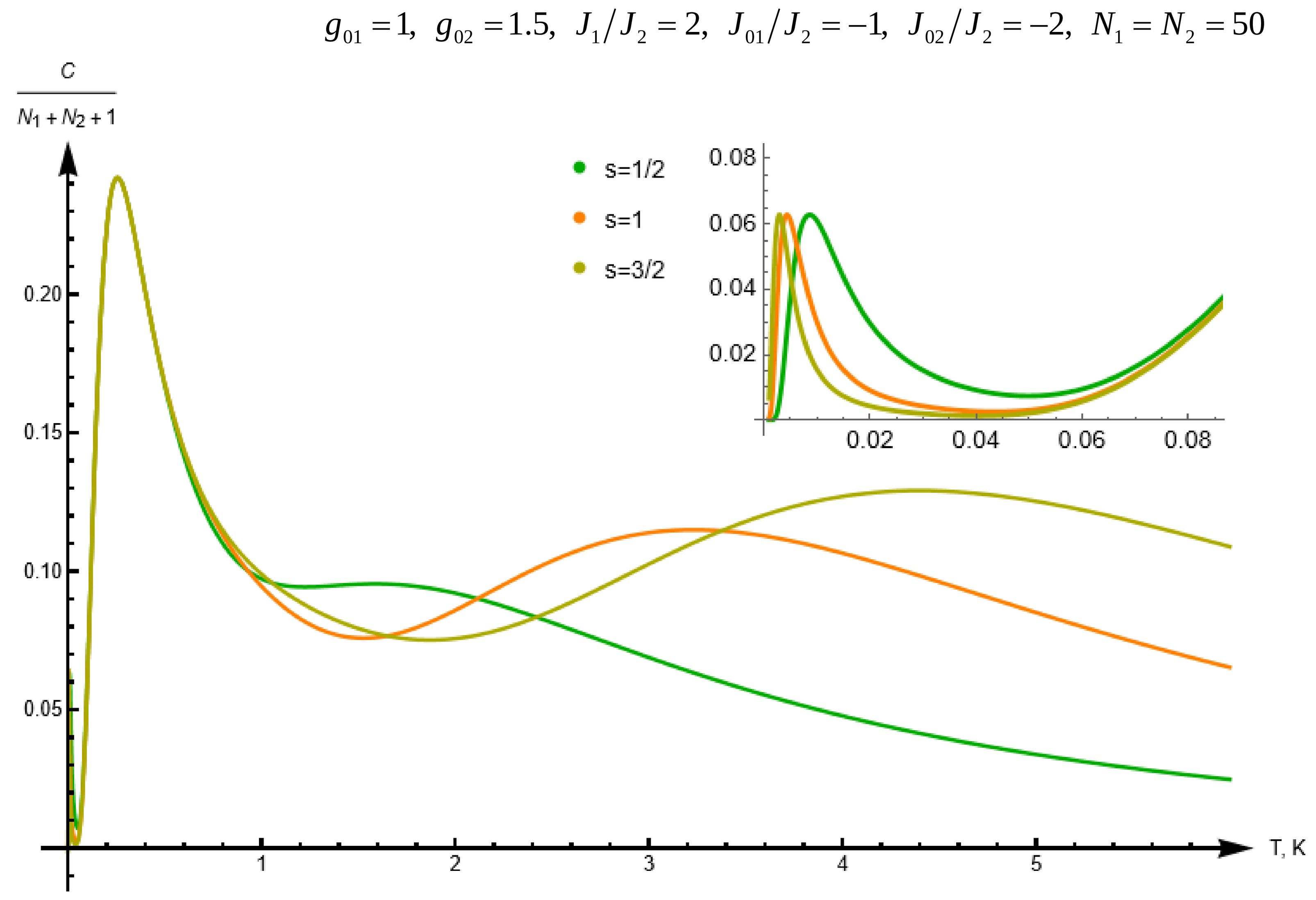
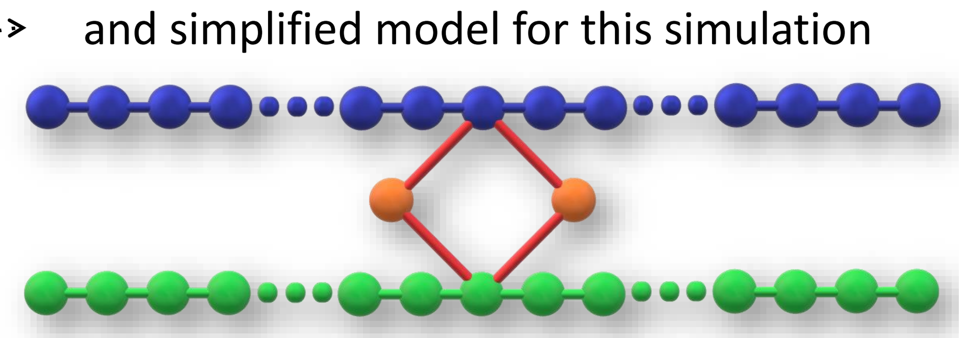


Fig. 3. Temperature dependence of heat capacity at different spin values at $H=0$, $g_1=1$, $g_2=1$, $g_{01}=1.2$, $g_{02}=1.3$, $J_1/J_2=1$, $J_{01}/J_2=10$, $J_{02}/J_2=2$, $N_1=N_2=6$, $n_1=n_2=n_3=n_4=3$,

and simplified model for this simulation



Summary:

- We derive exact dispersion equations for the stationary states with one inverted spin. The spectrum consists of two quasi-continuous zones and several localized impurity levels.
- The peculiarities of field and temperature dependences of the thermodynamic characteristics of the model were investigated numerically.
- The behavior of the average *z*-projection of Ising spins and longitudinal Ising impurity spin-spin correlation functions at low temperatures have been studied numerically.
- It was shown that under certain conditions, the average *z*-spin projection for impurity spins may have the finite jumps and non-monotonic dependence on the magnetic field at very low temperatures.
- Field dependence of magnetization may demonstrate two intermediate plateaus for strong AF Ising interactions at very low temperatures.
- We found numerically three maxima behavior of zero field temperature dependence of specific heat at some values of model parameters.

References

[1] A. A. Zvyagin, Quantum Theory of One-Dimensional Spin Systems (Cambridge Scientific Publishers, Cambridge, 2010).

[2] P.M. Duxbury, J. Oitmaa, M.N. Barber, A. van der Bilt, K.O. Joung, R.L. Carlin, Phys.Rev. B 24, 5149 (1981). DOI: https://doi.org/10.1103/PhysRevB.24.5149

[3] M. Kenzelmann, R. Coldea, D.A. Tennant, D. Visser, M. Hofmann, P. Smeibidl, Z. Tylczynski, Phys. Rev. B, 65, (2002). DOI: https://doi.org/10.1103/PhysRevB.65.144432