Hubbard model for spin-1 Haldane chains

G. Catarina
J. Fernández-Rossier
International Iberian Nanotechnology Laboratory (INL), Av. Mestre José Veiga, 4715-330 Braga, Portugal
goncalo.catarina@inl.int

The Haldane phase [1] for antiferromagnetic spin-1 chains is a celebrated topological state of matter, featuring gapped excitations and fractional spin-1/2 edge states. Here [2], we provide numerical evidence that this phase can be realized with a Hubbard model at half filling, where each s=1 spin is stored in a four-site fermionic structure (Fig. 1). We find that the noninteracting limit of our proposed model describes a one-dimensional (1D) topological insulator, and we conjecture it to be adiabatically connected to the Haldane phase. Our work opens a way to engineer spin-1 Haldane chains, as well as other spin networks, through a variety of physical systems that are being explored for quantum simulation of the Hubbard model [3,4]. We also show that our proposed Hubbard model accurately describes the observation of fractionalization in nanographene triangulene chains [5].

References

[1] F. D. M. Haldane, Phys. Rev. Lett., 50 (1983) 1153.
[2] **G. Catarina**, J. Fernández-Rossier, Phys. Rev. B, 105 (2022) L081116.
[3] T. Hensgens, T. Fujita, L. Janssen, X. Li, C. J. Van Diepen, C. Reichl, W. Wegscheider, S. Das Sarma, L. M. K. Vandersypen, Nature, 548 (2017) 70.
[4] A. Mazurenko, C. S. Chiu, G. Ji, M. F. Parsons, M. Kanász-Nagy, R. Schmidt, F. Grusdt, E. Demler, D. Greif, M. Greiner, Nature, 545 (2017) 462.
[5] S. Mishra, **G. Catarina**, F. Wu, R. Ortiz, D. Jacob, K. Eimre, J. Ma, C. A. Pignedoli, X. Feng, P. Ruffieux, J. Fernández-Rossier, R. Fasel, Nature, 598 (2021) 287.

Figures

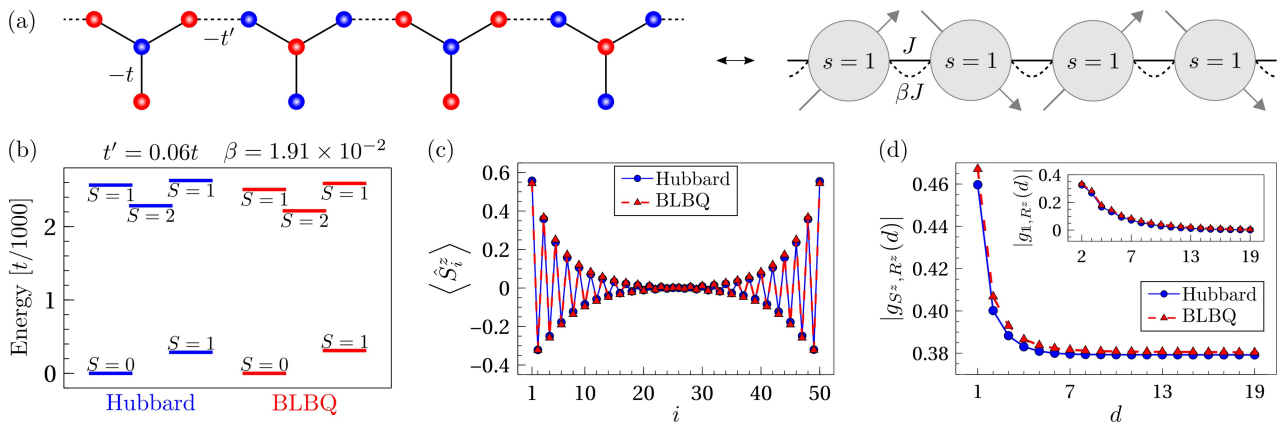

Figure 1: (a) Sketch of the general mapping between a 1D Hubbard lattice, with hoppings t and t', and an antiferromagnetic spin-1 chain, with bilinear (J) and biquadratic (βJ) exchange couplings (BLBQ model), where N four-site fermionic structures are mapped into N s=1 spins. (b) Comparison between the lowest-energy levels of N=10 four-site Hubbard and spin-1 BLBQ chains, with the corresponding total spin S indicated. Hubbard model results were obtained at half filling, for a Hubbard repulsion U=t, with t'=0.06t. BLBQ model parameters J=2.51×10^{-3}t and β=1.91×10^{-2} were fixed by matching the low-energy spectra of N=2 chains. (c) Average magnetization and (d) string order parameters, obtained for the lowest-energy state with $|S,S_z\rangle$=$|1,+1\rangle$ of N=50 four-site Hubbard and spin-1 BLBQ chains, using the same model parameters as in (b). The agreement between both models is apparent. The observation of spin-1/2 edge fractionalization (c), vanishing pure-string (d, inset) and nonvanishing spin-string (d) correlators are indicative of the spin-1 Haldane phase.