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Conditions for the appearance of boundary modes in topological phases of Heisenberg spin ladders NEIL ROBINSON, Brookhaven Natl Lab, ALEXANDER ATLAND, Universität zu Köln, REINHOLD EGGER, HHU Düsseldorf, NKILAS GERGS, Utrecht University, ROBERT KONIK, Brookhaven Natl Lab, WEI LI, LMU München, DIRK SCHURICHT, Utrecht University, ALEXEI TSVELIK, Brookhaven Natl Lab, ANDREAS WEICHSELBAUM, LMU München — We consider the problem of delineating the necessary conditions for the appearance of boundary modes in extended $SU(2)$ Heisenberg spin ladders. Specifically, we study Heisenberg ladders with rung exchange, $J_\perp$, and ring exchange, J_X, that admit a field theoretic description in terms of Majorana fermions in the continuum limit. In this description there are four Majorana fermions, arranged in a triplet and a singlet. This suggests there are four distinct phases, corresponding to the configurations of the signs of the triplet m_t and singlet m_s masses. We label these phases as: Haldane ($m_t > 0, m_s < 0$), rung singlet ($m_t < 0, m_s > 0$), VBS$_+$ ($m_t, m_s > 0$) and VBS$_-$ ($m_t, m_s < 0$). Topologically, we find two of these phases support gapless boundary modes: the Haldane phase (the triplet forms a spin-1/2 degree of freedom at the ends of the ladder) and the VBS$_+$ phase, where all the Majorana fermions have gapless boundary modes. The absence of a gapless boundary mode in the rung singlet phase is surprising; we find that the singlet mode can become gapless if open boundary conditions are replaced with a continuous change in lattice parameters. We suggest a symmetry-allowed modification to the low-energy effective theory which may be responsible for this behavior.

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