Spin quadrupole excitations in spin nematics

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The spin nematic state, which is a spin analogue of the nematic liquid crystal, has attracted much attention as a novel quantum spin state emerging in frustrated magnets [1]. As a prototypical model system for the spin nematics, we focus on a spin-1/2 J_1-J_2 Heisenberg chain with ferromagnetic J_1 and antiferromagnetic J_2 in an applied magnetic field. At high magnetic fields, the ground state is a spin nematic liquid state, in which transverse spin correlations are short-ranged due to frustration, while higher-order spin quadrupole correlations are quasi-long-ranged. Longitudinal spin correlations are also quasi-long-ranged. The spin nematic state has been explored in a series of edge-shared cupper oxides, such as $LiCuVO_4$. However, it is difficult to identify the spin nematic state, since magnetic probes are usually insensitive to spin quadrupole correlations, i.e., four-point spin correlations.

In order to gain insight how to characterize the spin nematic state from the viewpoint of excitation dynamics, we study dynamical spin structure factors numerically by dynamical density-matrix renormalization group methods [2, 3]. In the spin nematic regime, we find gapless longitudinal and gapped transverse spin excitation spectra, in accordance with quasi-long-range longitudinal and short-range transverse spin correlations, respectively. These anisotropic behaviors provide indirect evidence for the realization of the spin nematic state and could be examined by inelastic neutron scattering experiments. However, for the direct observation of the spin nematic state, it is highly important to clarify excitation dynamics in the quadrupole channel. Thus we further study dynamical quadrupole structure factors [4]. We observe gapless excitations at $q{=}\pi$, signaling quasi-long-range antiferro-quadrupole correlations. We will present detailed numerical results and discuss how the spectral intensity distribution changes as a function of the magnetic field.

[1] For a review, see K. Penc and A. M. Läuchli, in Introduction to Frustrated Magnetism, ed. C. Lacroix, P. Mendels, and F. Mila (Springer, Berlin, 2011) p. 331.

[2] H. Onishi, J. Phys. Soc. Jpn. **84**, 083702 (2015).

[3] H. Onishi, J. Phys.: Conf. Ser. **592**, 012109 (2015).

[4] H. Onishi, Physica B **536**, 346 (2018).