Quantum renormalization effect in one-dimensional Heisenberg antiferromagnets

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The dispersion relation of the lowest magnetic excitations and the temperature dependence of the inverse magnetic correlation length were determined using inelastic pulsed neutron scattering experiments on the following one-dimensional (1D) Heisenberg antiferromagnets: $CsVCl_3$ ($S = 3/2$), $CsVBr_3$ ($S = 3/2$), $CsCrCl_3$ ($S = 2$), and $CsNiCl_3$ ($S = 1$). It is well known that the ground state for a 1D Heisenberg antiferromagnet with $S = 1/2$ is a degenerated singlet spin state, rather than the Néel state (Bethe conjecture) [1]. Thus, the lowest magnetic excitations from the Bethe state are renormalized from the classical spin-wave state excited from the Néel state, where the enhancement of excitation energies in comparison with those of a classical system is defined by the quantum renormalization factor R; here, $R = \pi/2$ for $S = 1/2$ [2]. Since Haldane predicted another singlet ground state with a spin gap (Haldane gap) [3], the existence of the spin gap as well as the quantum renormalization for $S = 1$ have been investigated. On the other hand, it is well recognized that a system with $S = 5/2$ behaves classically, however, between $S = 1$ and $S = 5/2$, there is a lack of consistent experimental data to confirm the quantum dynamics. We determined the S-dependence of the quantum renormalization factor using only inelastic neutron scattering data [4]. In order to discuss the quantum renormalization effect quantitatively, the value of the exchange constant J should be determined, because magnetic excitation energies observed by an inelastic neutron scattering experiment is proportional to RJ. The static spin correlation function $S(q)$ was deduced by integrating the dynamical structure factor $S(q, \omega)$ over ω, and then the temperature dependence of the inverse magnetic correlation length $\kappa(T)$ can be obtained from $S(q)$. The exchange constant J can be determined because $\kappa(T)$ is described as a function of J for any S by a quantum theory [5]. Therefore, the quantum renormalization factor R for each spin system can be determined only from inelastic pulsed neutron scattering experiments. We demonstrated that the S-dependent quantum renormalization effect, which is consistent with quantum Monte Carlo calculations [6].

[1] H. A. Bethe, Z. Phys. 71 (1931) 205.
[2] J. des Cloizeaux and J. J. Pearson, Phys. Rev. 128 (1962) 2131.
[3] F. D. M. Haldane, Phys. Lett. A 93 (1983) 464; Phys. Rev. Lett. 50 (1983) 1153.
[4] S. Itoh, T. Yokoo, S. Yano, D. Kawana, H. Tanaka and Y. Endoh, submitted to J. Phys. Soc. Jpn.
[5] N. Hatano and M. Suzuki, J. Phys. Soc. Jpn. 62 (1993) 1346.
[6] S. Yamamoto, Phys. Rev. Lett. 75 (1995) 3348.