SOLITARY WAVES IN QUANTUM SPIN CHAINS

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One of the most prominent examples of a solitary wave in a quantum spin chain is an $S=1/2$ AFM chain perturbed by an alternating $g$-tensor and/or the Dzyaloshinskii-Moriya interaction; this situation is realized experimentally in several spin chain systems [1]. In the presence of such interactions, application of a uniform external field $H$ induces an effective transverse staggered field $h \sim H$, which leads to the opening of an energy gap $\Delta \sim H^{2/3}$. The gapped phase can be effectively described by the quantum sine-Gordon field theory recently developed by Oshikawa and Affleck [2]. A rich excitation spectrum has been predicted. Our study was a detailed investigation of the elementary excitation spectrum in the molecular magnet copper pyrimidine dinitrate (Cu-PM). It has been recently identified as an $S=1/2$ antiferromagnetic chain system with a field-induced spin gap, and appears to be the best realization of the quantum sine-Gordon spin chain model known to date. The excitation spectrum was studied using a high-field tunable-frequency submillimeter wave electron spin resonance (ESR) spectrometer, recently developed at the NHMFL [3].

![Fig.1](https://via.placeholder.com/150)

Fig.1 The frequency-field diagram of the ESR modes in Cu-PM. Symbols denote experimental results and lines correspond to contributions from specific excitations as predicted by the sine-Gordon quantum field theory: the mode S corresponds to soliton excitations, the modes B1-B3 correspond to breather excitations.

The complete frequency-field diagram of magnetic excitations in Cu-PM is presented in Fig.1. Ten ESR modes were resolved in the low-temperature spectrum, and their excitation diagram was systematically studied in a broad frequency-field range. For the first time, the field-induced gap in Cu-PM has been observed directly. We showed that the size of the gap was determined by excitation energy of the first breather (mode B1, Fig. 1). By comparing the entire set of data with theoretical predictions, we have provided clear experimental evidence for a number of excitations: one soliton (S), three breathers (B1-B3) and several soliton-breather bound excitations (C1-C3) have been observed. The origin of the modes U1-U3 is still unclear. Thus, for the first time a complete set of excitations predicted by the sine-Gordon quantum field theory in a quantum spin chain has been confirmed experimentally. This work has been published; please see S.A. Zvyagin et al., Phys. Rev. Lett. 93, 027201 (2004).