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SPIN WAVES IN HEISENBERG TWO-DIMENSIONAL ANTIFERROMAGNETS $S = 1/2$ WITH SKYRMIONS

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Quantum consideration of skyrmions and elementary spin excitations in a two-dimensional Heisenberg antiferromagnet is given. We have shown that spin fluctuations considerably renormalize the local order parameter, skyrmion energy and average radius of thermally excited skyrmions. While this renormalization at low temperatures $T \ll J$, where J is the nearest-neighbor exchange constant, results only in a reducing of the exponential divergence of r_0 at $T \to 0$, at high temperatures $T \sim J$ it leads to a linear temperature dependence of $1/r_0$. © 1997 Elsevier Science Ltd

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The magnetic behavior and spin dynamics of the cuprate superconductors and their parent compounds have been extensively studied during the last few years. It is well established that their properties are strongly influenced by two-dimensional (2D) critical fluctuations and the undoped materials can be modeled by a nearest-neighbour $S = 1/2$ quantum Heisenberg antiferromagnet (QHAF) on a square lattice with a large isotropic exchange coupling constant ($J = 1580$ K in La_2CuO_4 [1]). Considerable progress has been made in understanding of the low temperature properties of 2D QHAF by a mapping to a classical nonlinear sigma model with parameters renormalized by the quantum fluctuations [2–4]. The staggered magnetization, spin stiffness constant ρ_s and spin wave velocity c were calculated in a spin wave theory at $T = 0$. Using this method Chakravarty, Halperin and Nelson (CHN) were able to obtain the correlation length and the spin-correlation functions with no adjustable parameters [2]. The CHN results for the renormalized classical (RC) regime were improved by Hasenfratz and Niedermayer (HN) [5] using the chiral perturbation theory and by Chubukov *et al.* [6] with the $1/N$ expansion method on antiferromagnets with an N-component order parameter. The predicted exponential temperature dependence of the spin correlation length ξ was found in a fairly good agreement with neutron-scattering measurements in a pure La_2CuO_4 at $T < 600$ K [1, 7]. At the same time the authors could not avoid a fitting of the ρ_s value. In this paper we want to show that a different approach based on a self-consistent quantum consideration of 2D QHAF with skyrmions can predict similar magnetic properties. In particular, in a simplest local mean field approximation we obtain with no adjustable parameters an average radius of thermally excited skyrmions, which can be identified with the spin correlation length ξ. At low temperatures $T \ll J$ its temperature dependence is almost the same as in the CHN–HN theory for the RC regime with the *fitted* ρ_s. Moreover, at the temperatures $T > 0.4J$ the inverse average radius of skyrmions increases linearly with temperature being rather close to the result of Chubukov *et al.* [6] obtained for $1/\xi$ in a quantum critical (QC) region.

A general static solution for spin textures called skyrmions in 2D Heisenberg ferromagnets were obtained by Belavin and Polyakov [8] from a classical nonlinear sigma model. A number of qualitative and experimental arguments in favor of an important role of skyrmions in unusual magnetic properties of layered magnets was given later by Waldner [9]. Recent attempts to explain some peculiarities of the spin dynamics in layered antiferromagnets, including weekly doped cuprates, by the influence of skyrmions show a renewed interest to this problem [10]. It seems, however, that an adaptation of the classical description of skyrmions is not sufficient in the case $S = 1/2$. We use from the very beginning a quantum consideration, which gives an opportunity both to take into account the quantum fluctuations to