Low-temperature magnetic properties of classical frustrated spin chain

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The classical spin chain with the ferromagnetic nearest-neighbor interaction J_1 and the antiferromagnetic next-nearest-neighbor interaction J_2 (F-AF model) in the external magnetic field h is studied. The F-AF chain is the minimal one for the description of magnetic properties of recently synthesized edge-shared cuprate chain compounds. We have investigated the low-temperature magnetization curve of this model near the transition point between the ferromagnetic and the helical phases when $J_2/|J_1 = 1/4$. We consider the magnetization in the scaling limit when $h \to 0$, $T \to 0$ but the value $h/T^{4/3}$ is fixed. It is shown that the calculation of the partition function in the scaling limit reduces to the eigenvalue problem of the Schrödinger equation of the special form for the quantum particle. It is argued that the magnetization of the classical model in the ferromagnetic part of the phase diagram including the transition point defines the universal scaling function which is valid for the quantum model as well. Explicit analytical formulae for the magnetization are given in the limiting cases of low and high magnetic fields. We have studied the influence of the easy-axis anisotropy of the exchange interactions on the behavior of the magnetic susceptibility at the transition point. It is shown that even weak anisotropy essentially changes this behavior. In the low-temperature limit the susceptibility diverges exponentially in contrast with the isotropic case where the divergence is of a power-like type. Such behavior of the susceptibility takes place in the quantum F-AF model and the corresponding thermal gap has the same functional form as the classical one. This fact confirms the close relation between the low-temperature magnetic properties of the classical and the quantum F-AF chains.