Accepted Manuscript

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PII: S0378-4371(17)30080-8
DOI: http://dx.doi.org/10.1016/j.physa.2017.01.070
Reference: PHYSA 17963

To appear in: *Physica A*

Received date: 28 November 2016

Please cite this article as: M. Shahri Naseri, S. Mahdavifar, The magnetic properties of spin-1/2 two-leg ladders with dimerized legs and trimerized modulation of rung exchange, *Physica A* (2017), http://dx.doi.org/10.1016/j.physa.2017.01.070

The magnetic properties of spin-1/2 two-leg ladders with dimerized legs and trimerized modulation of rung exchange

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(Dated: November 28, 2016)

The zero-temperature magnetic properties of spin-1/2 two-leg ladders with staggered and columnar dimerized legs and trimerized modulated rung exchange is studied using the numerical Lanczos method. A clear picture of the influence of different dimerizations on the appearance of magnetization plateaus is provided. It is found that the magnetization curve of the staggered ladders exhibits two plateaus at values $1/3M_{sat}$ and $2/3M_{sat}$, and columnar ladders have an additional plateau at half of the saturation. The width of plateaus in staggered ladders is independent of dimerization on legs but in columnar ladders depends. The width of mid-plateau increases by enhancing the dimerized parameter on legs but others behave inversely. In addition, the effect of the dimerized parameter is studied on other functions as the energy gap, the on-rung spin-spin correlation and dimer order parameter.

PACS numbers: 75.10.Jm; 75.10.Pq

I. INTRODUCTION

Low-dimensional quantum magnets have been at the canon of intensive researches. In particular, quantum spin ladders have attracted much interest for a long time. This is partly because sophisticated theoretical analysis, such as exact solutions, can be applied to one dimensional systems. It has been also recognized that the effect of quantum fluctuations is more significant than in higher dimensional systems, resulting in many interesting phenomena. On the other hand, progress in experimental techniques has increased the opportunity to observe physics of spin-ladder systems[1].

The spin S=1/2 two-leg ladders represent one, particular subclass of low-dimensional quantum magnets which also has attracted a lot of interest for a number of reasons. On the one hand, there was remarkable progress in recent years in the fabrication of such ladder compounds as well as with the opened wide perspectives for use of low-dimensional magnetic materials in modern nanoscale technologies[2]. The spin-ladder models pose interesting theoretical problems since the excitation spectrum of a two-leg antiferromagnetic ladder is gapped[3–6] and therefore, in presence of a magnetic field, these systems reveal an extremely complex behavior, dominated by quantum effects. These systems exhibit a variety of interesting phenomena such as the appearance of plateau in magnetization curves that has received a lot of attention both theoretically and experimentally[7-32]. The necessary quantization condition for appearance of plateau in ladder systems is[12]

$$PNS(1- < M >) \in z, \tag{1}$$

where P, N and S stand respectively for the periodicity of the ground state, the number of coupled chains and the total spin per site. $< M >$ denotes the normalized magnetization to its saturation value.

Therefore search for the gapped phases emerging from different sources and study of ordered phases and quantum phase transitions associated with the dynamical generation of new gaps is an important direction in theoretical studies of quantum spin systems. Particular realization of such scenario appears in the case where the spin-exchange coupling constants are spatially modulated[33,34].

The effect of the dimerization on legs in a two-leg ladder with uniform rungs is also investigated[11,22]. Theoretical studies pointed out the phase diagram of a ladder with dimerized legs can exibit vanishing spin gaps depending on the manner in which the array of couplings is realized.

In this work, we compare two types of different arrays of ladders: staggered and columnar. Our purpose is the study of the ground state magnetic properties of the spin $S = 1/2$ two-leg ladders with dimerized legs and trimer modulated rung exchanges. We analyze these models by means of the numerical Lanczos method. The layout of the paper is organized as follows. In Section II, we introduce the models and the effective Hamiltonian will be obtained in the limit where the rung exchange is dominate. A numerical analyzed for finite systems is given using Lanczos algorithm in Section III. We end the paper with Section IV which contains our conclusions.

II. THE MODEL

Here we consider the spin $S = 1/2$ two-leg ladder which contains two dimerized antiferromagnetic spin chains interacting through a Hamiltonian

$$\begin{aligned}\widehat{H} &= \sum_{n,\alpha} J_{n,\alpha}\mathbf{S}_{n,\alpha}.\mathbf{S}_{n+1,\alpha} + \sum_{n} J(n)\mathbf{S}_{n,1}.\mathbf{S}_{n,2} \\ &- H\sum_{n,\alpha} s^z_{n,\alpha},\end{aligned} \tag{2}$$