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MAGNETISM

Mean-Field Theory as Applied to the Ising Model with Mobile Impurities and to the Three-State Potts Model

S. V. Semkin and V. P. Smagin

Vladivostok State University of Economics and Service, ul. Gogolya 41, Vladivostok, 690014 Russia
e-mail: Li15@rambler.ru

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Abstract—The mean-field theory has been considered as applied to the system of magnetic and nonmagnetic atoms at thermal equilibrium. The phase diagrams and the dependence of the magnetization on the density of magnetic atoms have been found in the Ising model with mobile nonmagnetic impurities. In the same approximation, the phase transition in the three-state Potts model has been studied.

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1. INTRODUCTION

The magnetic properties of diluted and disordered magnets have been the subject of theoretical and experimental investigations for many years [1–4]. In our previous works [5–7], we proposed a number of self-consistent methods for the calculation of the magnetization and critical points of pure and diluted magnets. These methods are based on averaging over the local exchange fields. The technique of averaging over the local exchange fields can be also used for the analysis of the behavior of the alloy of two types of magnetic atoms [8] and for the analysis of systems in which the exchange integral is a continuous function of the interatomic distance [9, 10].

In this work, we consider the self-consistent equations as applied to a diluted magnet with mobile impurities. The effects associated with the mobility of the impurities can be conditionally divided into two groups. The first group includes the dynamic (nonequilibrium) phenomena, e.g., a change in the properties of a rapidly cooled diluted magnet with time or the dynamics of impurity redistribution under the action of the external magnetic field. Such dynamic processes gradually lead to establishing the thermodynamic equilibrium in the system. The second group of effects is associated with the influence of different internal and external parameters (temperature, external magnetic field, impurity density, etc.) on the properties of the equilibrium state. For the known reasons, investigation of the properties of the equilibrium state, although associated with considerable difficulties [11], is still simpler than the investigation of nonequilibrium (relaxation) processes.

In [12], the technique of averaging over the exchange fields, as applied to the Ising model with mobile impurities, was used for the analysis of the equilibrium states of the alloy of magnetic and nonmagnetic atoms in a zero external magnetic field. In this work, we consider a simpler self-consistent approximation for the same model, i.e., the mean-field theory method, but take into account the effect of the external magnetic field on the equilibrium state. In addition, we show that the three-state Potts model [13] can be analyzed in the same approximation.

2. ISING MODEL WITH MOBILE IMPURITIES

We consider a crystal lattice with the coordination number q, the sites of which can be occupied by magnetic and nonmagnetic atoms (atoms of types 1 and 2, respectively). Each magnetic atom has the Ising spin $s_i = \pm 1$ so that the energy of exchange interaction between two magnetic atoms with the spins s_i and s_j is $-Js_is_j$, if the atoms are situated in the adjacent sites, and zero otherwise.

Similarly to what is common in the investigation of binary alloys [13], we assume that, in the system there are interatomic Coulomb forces, the range of which is limited to the first coordination sphere. We denote the potential of these forces as $-U_{\alpha\beta}$, α, $\beta = 1, 2$. Let us assume that each lattice site is described by the variable $\sigma_i = s_i$ when the site is occupied by a magnetic atom and $\sigma_i = 0$ when it is occupied by a nonmagnetic atom. Then, the exchange interaction energy E_{ex} and the Coulomb energy E_{Coulomb} can be expressed as the sums over all ordered pairs of the adjacent sites:

$$E_{ex} = -\sum_{(i,j)} J\sigma_i\sigma_j,$$

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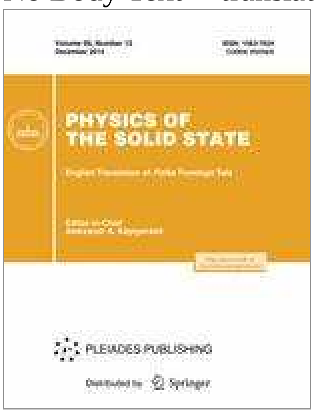

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