The growth of magnetization minerals with a rise in temperature

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ABSTRACT

Magnetic properties of iron sulfides in a metastable phase state were investigated. During heating of iron sulfides of the composition $Fe_{0.901}S$ up to ~150°C, a magnetization increase was observed. It was shown that the observed effect is not the known γ- transition and that it results from the redistribution of vacancies of iron ions in basal planes of the crystal structure of the NiAs type. A theoretical model was proposed which explains qualitatively this effect.

Keywords: molecular-field model, exchange interactions, magnetization, magnetic field.

INTRODUCTION

Chalcogenides are of some interest from the point of view of studying vacancies. The number of vacancies in their structure is determined by the composition, namely the formula unit. For example, the formula for pyrrhotite is represented as Fe_{1-n} S, where n is the number of vacancies, that is, the average number of vacancies per one iron atom (the density of vacancies). In addition, chalcogenides can be used to study the ordering of vacancies in a structure, with a long-range magnetic order. Magnetic properties in nonstoichiometric ferrimagnets are closely related to the distribution of cation vacancies in the structure [Schwars and Vaughan, 1972, Onufrienok, 2005, Makovicky, 2006, Mashukov et al., 2007]. For example, in the structure of pyrrhotite, a ferromagnet spin ordering is realized in the basal planes and an antiferromagnet order is realized in the neighboring planes.

In natural minerals of the composition $Fe_{0.875}S$—$Fe_{0.909}S$ (pyrrhotines), the temperature dependence of magnetization exhibits a series of specific features. For instance, the γ- transition manifests itself in a sharp change of magnetization at temperatures 220-280°C (Schwars and Vaughan, 1972). Low temperature (T = 45 K) changes of magnetization were observed in synthetic iron sulfides (Zvegintsev et al., 1982). In ferrimagnetic iron sulfides, one observes the so-called temperature magnetic hysteresis, i.e., the difference between the magnetization before and after thermal treatment. Such a behavior of magnetization is determined not only by the γ transition but also by other, hitherto still little studied, phenomena (Onufrienock et al., 1981).

The magnetization of a ferrimagnets often behaves strangely when it is heated. It can, for example, increase over a certain temperature range, with no changes in the structure occurring. For example, Zvegintsev and Onufrienok (1981), Onufrienock and Zvegintzev (1981), Onufrienok (1991), Rickard and Luther (2007) described the anomalous magnetization behavior during growth temperatures for various reasons, related to crystallization and exchange interactions. Natural pyrrhotite $FeS_{1.14}$ is a heavily-doped [Onufrienok et al., 1982, Wang and Salveson, 2005, Dorogina, et al., 2015] ferrimagnet semiconductor with a distorted NiAs structure, in which successive planes perpendicular to the c-axis are occupied exclusively by iron atoms with their magnetic moments antiferromagnetically aligned. The iron vacancies are ordered in every second plane forming a superstructure (Kuzmin and Onufrienok, 1983, Lilies and de Villiers, 2012) and making the compound ferrimagnetic. As a result of X-ray studies, it is established that the crystal structure remains hexagonal of the NiAs type (Ward, 1970, Koto, et al. 1975, Morimoto, et al. 1975, Onufrienok 2013). Since antiferromagnetic spin ordering is realized in adjacent basal planes, the effect of increasing magnetization on the ordering of vacancies in even (odd) basis planes is practically obvious, but this is not noted in these experiments. We note that the total magnetic moment consists of the sum of the moments of the sublattices.