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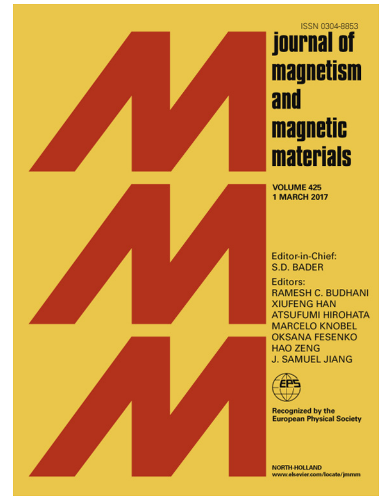

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Plateau on Temperature Dependence of Magnetization of Nanostructured Rare Earth Titanates

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Abstract

Magnetic properties of nanocomposite materials containing particles of rare earth titanates of $R_2Ti_2O_7$ type, where R is a rare earth ion, including "spin ice" materials are investigated. The descending branches of hysteresis loop have been studied in detail in temperature range from 2 to 50 K. It has been shown that nanocomposites with $Yb_2Ti_2O_7$, $Dy_2Ti_2O_7$ and $Er_2Ti_2O_7$ particles have one intersection point of the descending branches in some temperature range unlike many other nanocomposites. It is shown that magnetization has only weak temperature dependence near this point. It has been obtained that nanocomposites with $Pr_2Ti_2O_7$ and $Nd_2Ti_2O_7$ particles have no hysteresis loop. All above findings point out to unusual magnetic structures of the studied samples.

Keywords: rare earth titanates, nanostructured materials, hysteresis loops, temperature dependencies of magnetization.

1. Introduction

Investigation of low temperature magnetic properties of rare earth titanates constitutes a valuable and fashionable task. Most interest attracts the problem of "spin ice" stated for several titanates with pyrochlore structure, which consists of corner-sharing tetrahedras. The analogy between the problem of the frustrated Ising antiferromagnet on a pyrochlore lattice and Pauling's water ice problem was drawn by R. Anderson [1]. Frustrated interactions between neighbouring ions prevent them from completely freezing secure spin degrees of freedom even at absolute zero. As a consequence, a macroscopically degenerate ground state manifold obeying the "ice rule" - two spins point into each tetrahedra, and two out - is formed in such systems. A spin flip out of the ice rule manifold creates a magnetic excitation that may fractionalize to produce defects, which behave as magnetic monopoles. Note here, that although the monopoles are always created as a pair, their mutual interaction is so weak, that under proper conditions each monopole can be considered as a free quasiparticle [2].

Two different types of spin ice are discussed in literature, namely, classical spin ice ($Dy_2Ti_2O_7$, $Ho_2Ti_2O_7$) and quantum spin ice (possibly $Yb_2Ti_2O_7$) [3-6]. Bulk magnetization of the heavy rare earth titanate pyrochlores—a series of model frustrated magnets. J. Phys.: Condens. Matter 12 (2000) 483–495]. Low temperature magnetic properties of pyrochlore titanates could be described by using a concept of (classical or quantum) diffusion of monopoles. In Ref. [7] magnetic anisotropy of the spin ice compound $Dy_2Ti_2O_7$ has been carefully studied and it was found that at high enough magnetic fields the saturated moment exhibits a breaking of the ice-rule: the obtained data agree rather with the value expected for a three-in-one-out spin configuration. Experiments demonstrated a clear plateau of a constant magnetization versus the applied magnetic field in $Dy_2Ti_2O_7$ followed by a sharp jump of the magnetization below the freezing temperature T = 0.5 - 1 K [8]. Such magnetization curves correspond to a breaking of the spin ice state and testify a frustration of the spins on the Kagome layers [7]. Thus, below the spin freezing temperature, even the slowest sweeps fail to yield the equilibrium magnetization curve [9]. AC susceptibility and DC magnetic relaxation measurements of $Dy_2Ti_2O_7$ have been performed in work [10]. It has been shown that the spin dynamics of $Dy_2Ti_2O_7$ is well described by using two relaxation times. Below 0.5 K, both relaxation times show a clear deviation from the thermal activated dynamics toward temperature independent relaxation, suggesting a quantum dynamics.

Strong spin fluctuations in $Yb_2Ti_2O_7$ was studied in Ref. [11] and the full set of Hamiltonian parameters was extracted from neutron scattering experiments. The authors concluded that $Yb_2Ti_2O_7$ is the quantum spin liquid candidate. The electronic properties of $R_2Ti_2O_7$ (R = Sm and Gd) titanates are investigated by first-principles density functional theory calculations [12]. The ground-state phase diagram of a spin-1 Kagome antiferromagnetic Heisenberg model is determined in Ref. [13]. A system of spins on the sites of a three-dimensional pyrochlore lattice with a predominant effective *xy* exchange is discussed in work [14]. The phase diagrams were obtained and a weak magnetic moment along the local <111> direction was predicted. The magnetization and differential susceptibility of $Dy_2Ti_2O_7$ measured in the range 2-20 K are consistent with the assumption of a nearly pure $J_z = \pm$