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Investigations of dielectric Van Vleck paramagnets at high magnetic fields and low temperatures

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Abstract

The influence of high magnetic fields on the magnetic properties of dielectric Van Vleck paramagnets is discussed. The dynamics of coupled electron–nuclear spin system is investigated at high magnetic fields and low temperatures.

Keywords: High magnetic field; Nuclear magnetic resonance; Van Vleck paramagnet

1. Introduction

Among different dielectric crystals of rare-earth (RE) compounds the so-called "Van Vleck paramagnets" form a special class. These substances have no magnetic moment in their ground electronic state, but their paramagnetic susceptibility strongly exceeds the diamagnetic one. Van Vleck paramagnetism takes place in crystals containing non-Kramers RE ions, for example, Tm^{3+}. The isotope ^{169}Tm (100% natural abundance) has a nuclear spin equal to $\frac{1}{2}$ so the compounds of this element possess both electronic and nuclear magnetism. The so-called "enhanced" nuclear magnetic resonance is the main method of investigation for the Van Vleck paramagnets (see, for example, Refs. [1,2]). Almost all investigations have been carried out at magnetic fields where the Zeeman energy of an ion can be considered as a perturbation. In Ref. [3], we proposed that dielectric Van Vleck paramagnets at high magnetic fields (above 5 T) could be used for the nuclear dynamic polarization. In Ref. [4], the high-frequency electron paramagnetic resonance and resonant far-infrared absorption were observed for the first time at high magnetic fields in thulium ethylsulphate $Tm(C_2H_5SO_4)_3 \cdot 9H_2O$(TmES) crystals. These investigations showed that new, essential information about Van Vleck paramagnets can be obtained at high magnetic fields.

It is natural to expect that at high magnetic fields the dynamics of the nuclear spin system will also exhibit new features. Foremost it is connected with the drastic change of ion wave functions due to the applied high magnetic field. In the present work we consider the electron–nuclear spin system of Tm^{3+} ion in TmES.

2. Electron–nuclear states at high magnetic fields

Owing to its ground multiplet of $^3H_6$ manifold, the system under consideration can be described by the effective Hamiltonian

$$H = H_{cr} + H_{eZ} + H_{nZ} + H_{hf}, \quad (1)$$

where H_{cr} represents the influence of electric crystal field (the explicit form for it can be found in Ref. [1]), H_{eZ} and H_{nZ} stand for the electron and nuclear Zeeman interactions, respectively, H_{hf} describes the hyperfine interaction. The effects of electron–phonon interaction are not taken into account here for simplicity. The numerical procedure of diagonalization of the Hamiltonian (1) allows us to find all magnetic quantities for Tm^{3+} ions in TmES crystal in the dependence on the strength of the applied magnetic field and the orientation of this field with respect to crystallographic axes (angle θ).

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