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Magnetocaloric effect at the first-order magnetic phase transitions

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Abstract

On the basis of a thermodynamic approach, the magnetocaloric effect (MCE) arising at the first-order transition in heavy rare earth metals Tb, Dy, Er and $Tb_{0.5}Dy_{0.5}$ alloy and in $Fe_{0.49}Rh_{0.51}$ and $Gd_5Si_{1.7}Ge_{2.3}$ is considered. The main contributions to the MCE (exchange, magnetoelastic, anisotropic and magnetic energy) were calculated in the temperature interval corresponding to the first-order transition. It is shown that the model adequately describes the MCE and gives results, which are in accord with the direct experimental measurements.

Keywords: Magnetically ordered materials

1. Introduction

In recent years, the interest in the magnetocaloric effect (MCE) has considerably grown. This is connected first of all with its possible practical application in magnetic refrigerators, where a magnetic material is used as a working body. Magnetic refrigerators can replace conventional refrigerators working on gas-vapor cycles because they provide an environmentally clean and energy-saving operation. The task of searching and developing effective magnetic working bodies with high magnetocaloric characteristics is one of the central tasks in the creation of magnetic refrigeration devices. It was established that the highest values of the MCE is observed near the magnetic phase transitions, in particular, near the first-order transitions accompanied by structural phase transitions, where magnetization and other magnetic characteristics of the material can be changed drastically by changing the temperature or external magnetic field. High MCE values were observed, in particular, in the $Gd_5(Si–Ge)_4$ compounds with the first-order transitions being accompanied by structural changes [1,2] and in $MnFeP_{1-x}As_x$ compounds [3]. It was shown that the nature of such transitions, for example, in the $Gd_5(Si–Ge)_4$ compounds is related with field-induced reversible breaking of covalent bonds between Si and Ge atoms [4]. The task of investigating the nature of the “magnetic-structural” first-order phase transitions and MCE arising under such transitions is very important from the point of view of development of materials with outstanding magnetocaloric properties, which can be used as an effective magnetic working body. However, today there are no works which consider possible contributions to the magnetocaloric effect and the magnetic entropy change at the first-order transitions and their relative role in the effect. In this article, the possible presence of such contributions is considered on the basis of a thermodynamical approach applied to the rare earth metals Tb, Dy, Er and $Tb_{0.5}Dy_{0.5}$, $Fe_{0.49}Rh_{0.51}$ and $Gd_5Si_{1.7}Ge_{2.3}$ alloys, where first-order transitions of different nature are observed.

2. Thermodynamic model

Consider a magnetic material in which one magnetic phase (for example, antiferromagnetic) can be transformed to another (for example, ferromagnetic) by the field-induced

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