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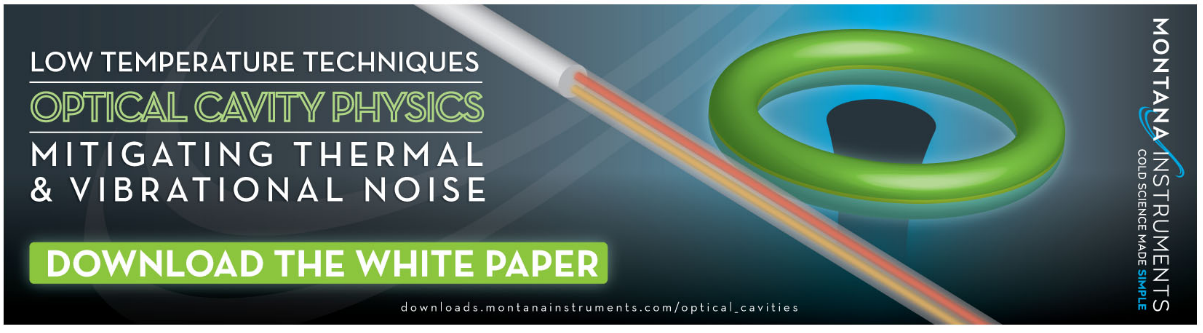

Change in the entropy during a first-order phase transition induced by a magnetic field in an isotropic non-Heisenberg ferromagnet

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We describe a first-order phase transition in an isotropic non-Heisenberg ferromagnet induced by a magnetic field with a fourth-order spin exchange interaction at temperatures above the Curie point. The field behavior of the magnetization is analyzed and the temperature dependences of the critical fields of the stability of the paramagnetic and ferromagnetic phases as well as the critical field of the phase transition between them are determined. It is shown that this first-order phase transition has a finite amplitude of the magnetization jump and can occur in small magnetic fields. An *H–T* phase diagram is presented. It is found that the amplitude of the phase jump during the magnetic field-induced transition from the paramagnetic to the ferromagnetic phase can exceed the magnitude of the entropy change of an isotropic Heisenberg ferromagnet by two orders of magnitude when it is magnetized at the Curie point. It is shown that the expansion of the free energy model up to the 6th power in magnetization can only qualitatively describe the entropy behavior in the phase transition between the paramagnetic and ferromagnetic phases. *Published by AIP Publishing.*
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1. Introduction

It is known[1,2] that a magnetic field can induce a type-I phase transition (PT-I) from a paramagnetic (PM) to a ferromagnetic (FM) phase. Aside from a jump in magnetization, experimental evidence shows that during a PT-I, an anomalous magnetocaloric effect[3–10] can also be observed.

As an example, PT-Is can be induced with a magnetic field in strongly anisotropic Van-Vleck FMs with competing exchange and single-ion anisotropies.[11] However, Van-Vleck FMs with a large easy plane single-ion anisotropy constant, show a decrease in the temperature of the tricritical point,[12,13] above which the PT-I does not occur and all of the properties related to the critical magnetization (including the entropy jumps) will have a low-temperature character.

The magnetic field can induce a PT-I in antiferromagnets,[14–16] also with accompanying magnetization jumps. These can be metamagnetic PT-Is, when the jump changes the direction of the average magnetization of one of the sublattices that was originally oriented opposite to the magnetic field. This PT-I, along with the magnetic isostructural PT-I caused by the nonlinearity of the entropic nature,[17] are both low-temperature transitions. And even though these PTs show an entropy field dependence,[18,19] these materials are of little use for refrigeration[20] at room temperatures. It is worth noting that the magnetocaloric effect in Van-Vleck paramagnets in a constant magnetic field discussed in Ref. 21, also has a low-temperature character.

If a FM exhibits a significantly large non-Heisenberg interaction,[22–24] a magnetic field can induce a high-temperature PT-I, near the FM Curie point. This FM behavior is considered in works,[25,26] where the PT-I is described using a Landau potential up to 6th power in magnetization (Landau–Ginzburg–Devonshire model[27,28]) where the coefficient for the 4th power of the order parameter shows a large change near the Curie point, that is possible due to the presence of non-Heisenberg exchange interactions (EI) of the 4th order in spin.[29]

Non-Heisenberg four-spin EIs can be a result of spin-spin interactions.[30] However, in systems with a strong magnetoelastic coupling, the fourth order term in spin in the effective Hamiltonian is due to approximations in the action of the magnetoelastic field.[31] For example, the magnetoelastic coupling in manganties is strong.[32] The magnetic field in manganties induces a PT-I and as a result, a large magnetocaloric effect is observed.[33] Evidently, the large magnetoelasticity and the nonlinearity it causes in manganite films forms the foundation for the observed anomalous magnetocaloric effect.[34]

Below, we investigate the behavior of non-Heisenberg FMs with four-spin exchange in a magnetic field near the Curie point. It will be shown that the non-Heisenberg four-spin EI, leads to an interesting scenario where the PT between the PM and FM phases occurs in low (i.e., experimentally accessible) magnetic fields, while the magnetization jump appears to be finite (not small). The interaction