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## LOW-TEMPERATURE MAGNETISM

# Isostructural magnetic phase transitions and the magnetocaloric effect in Ising ferromagnets

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It is shown that the first-order isostructural magnetic phase transition between antiferromagnetic phases with different magnitudes of the antiferromagnetism vector induced by an external magnetic field in Ising antiferromagnets can be related to entropy. It is found that, depending on the temperature, the entropy jump and the corresponding heat release can change their signs at the phase transition point. In the low-temperature region of the metamagnetic first-order phase transition the entropy jump is positive, while the entropy jump is negative near the triple point for isostructural magnetic phase transitions. © *2014 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4896725]

### 1. Introduction

Two-sublattice Ising antiferromagnets (AFM) are one of several magnetic systems in which first-order phase transitions can occur with a finite (not small) change in the ordering parameter at the transition point.[1,2] In an Ising AFM an external magnetic field induces a phase transition from an AFM state with antiparallel spins in the sublattices to a paramagnetic (PM) state in which the spins are parallel and of the same magnitude. This sort of phase transition can be referred to as metamagnetic,[3–5] but it should be noted that metamagnetic phase transitions are often taken to mean orientational phase transitions from an antiparallel to a parallel orientation of the spins of the sublattices in uniaxial AFM with weak interlattice exchange (smaller than the anisotropy energy).[6–9] In these, the magnetization of a sublattice directed opposite to a magnetic field flips in its entirety to an orientation along the field with conservation of the long-range magnetic ordering in this sublattice (i.e., coherently).[6–11] Ising AFMs are not weakly anisotropic,[12–14] so the spins of the sublattices do not undergo a coherent rotation during a metamagnetic phase transition. In an Ising AFM, this kind of phase transition proceeds by destroying the magnetic ordering in a sublattice whose spin is initially opposite to the field and then a new ordering develops in it with an average spin directed along the field. This process takes place at temperatures below the Neel temperature $T_N$, where the change in the average sublattice spin cannot be regarded as small in magnitude and is comparable in order of magnitude to the saturation magnetization.[15]

Baryakhtar *et al.*[16] used the Landau theory to describe phase transitions in an Ising AFM and showed that a magnetic field can induce an isostructural magnetic first-order phase transition between two AFM states. In this type of first-order phase transition there are no changes in the magnetic structure, but the value of the ordering parameter does change.[17–19] In Ising AFM, during an isostructural magnetic phase transition in a magnetic field, the magnitude of the AFM vector shifts from a large value to a lower value. In the phenomenological theory, the occurrence of isostructural phase transitions is explained by the presence of terms with the 8-th or higher powers of the ordering parameter in the Landau potential.[18] Here the nature of the very strong nonlinearity of the magnetic system is of fundamental importance. It is hard to imagine that in a real magnet, besides pairwise bilinear exchange interactions, there should also be interstitial interactions of fourth, sixth, or higher order in the spin, which would have to be comparable in magnitude to the bilinear exchange term, although this approximation is sometimes used and can be important in some cases.[20–23]

Only the interactions that are bilinear in the spin have been included in a description of Ising AFM isostructural magnetic phase transition.[16] Here it turned out that when the Landau phase transition theory was used, all the coefficients in the expansion of the Landau potential depend on the bilinear exchange parameters. This might create the impression that the strong nonlinearity of the model is associated with bilinear exchange. In this paper we shall show that isostructural phase transitions in Ising AMF are primarily associated with the entropy contribution to free energy. The field dependences of the entropy are derived and the changes and jumps in the entropy during the discontinuous first-order phase transitions and continuous second-order phase

 