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MAGNETIC PROPERTIES OF DILUTE RANDOM MAGNETIC ANISOTROPY SYSTEMS (Dy \(_{x}Y_{1-x}\))\(_{2}\) Al\(_{2}\)

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Abstract. The magnetic phase diagram for the RMA system Dy\(_{x}Y_{1-x}\)\(_{2}\) Al\(_{2}\) is determined. For \(x \leq 0.30\) a PM/SG phase exists. No long range magnetic order appears, yet the initial susceptibility diverges at and below the PM/CSG transition. Scaling analysis indicates phase transitions, and the critical exponents \(\beta, \gamma, \delta, \Delta\) and \(\phi\) and \(\beta_s, \gamma_s\) and \(\delta_s\) have been determined.

1. Introduction

Interest in random magnetic anisotropy (RMA) magnets stems from predictions [1-3] that no ferromagnetic order (if exchange is \(J_o > 0\)) is possible below \(d = 4\); yet an infinite susceptibility (or very large, \(\chi \propto (J_o / D_0)^4\), where \(D_0\) is the uniaxial strength RMA) is expected below a certain temperature \(T_c\). Depending on \(D_0\) two kinds of magnetic order are possible: at \(T < T_{SG}\), anisotropy is strong and the system becomes a SG, while for \(T_{SG} < T < T_c\) it becomes a “coherent spin glass” (CSG), with quasiferromagnetic domains but without spontaneous magnetization [3].

We have studied the crystalline systems Dy\(_{x}Y_{1-x}\)\(_{2}\) (\(x \leq 0.45\)) and found RMA behaviour, a fact never observed in crystalline cubic Laves phases. Two kinds of measurements were performed: magnetization up to 5 T and down to 1.7 K using a SQUID, and AC susceptibility at 15 Hz and 35 mOe, down to 2.2 K.

2. Theoretical background

We will outline the scaling or critical behaviour of initial susceptibility, \(x_0\), SG order parameter, \(q\), nonlinear susceptibility, \(x_{nl}\), magnetization, \(M\), and spin relaxation time, \(T_s\). For \(D_0 \to \infty\) (Ising) an AT line of instability \(H = H_{AT}t^{\phi/2}\) is expected (\(\phi = 3\)) [4]. When anisotropy is weak transverse spin freezing is possible, along a GT phase transition line \(H = H_{GT}t^{\phi/2}\) (\(\phi = 1\)) [5].

Aharony and Pytte [2] deduced an equation of state which predicts \(M = 0\) for \(T < T_{SG}\) or \(T_c\). Therefore, for low \(H\), isotherms have the form, \(M \sim H^{1/6}\) (\(T = T_c\)) and \(M \sim H^{1/4}\) (\(T < T_c\)) and the initial susceptibility scales as \(x_0 \sim t^{-\gamma}\) for \(T > T_c\), where \(t = (T - T_c) / T_c\). Similar results were also obtained using MFA [6].

When the CSG phase no longer occurs, it is \(x_{nl}\) which diverges at \(T_{SG}\),

\[
x_{nl} \equiv M / H - x_0 = \beta f H^{2/\gamma_s} / (t^{\phi_s} / H),
\]

or

\[
H^{2/\gamma_s} g (t^{2/\phi_s} / H). \quad (1)
\]

with \(t \equiv (T_{SG} - T) / T_{SG}\). For \(t > 0\), we have \(x_{nl} \sim H^2\)

while \(x_{nl} \sim H^{2/\gamma_s}\) for \(T = T_{SG}\). The order parameter \(q\) is obtained from \(x_0\) using Fisher equation, \(x_0 = C (1 - q) / [T - \theta (1 - q)]\), where \(\theta \propto J_0\).

3. Experimental results and discussion

In figure 1 we show the thermal dependence of \(x_{AC}\) (real part) for the CSG systems, where two anomalies at \(T_c\) and \(T_{SG}\) appear (for \(x \leq 0.30\) there is only one at \(T_{SG}\) (Tab. I)). Evidently, the concentration of the nominal \(x = 0.40\) sample is lower than that of the \(x = 0.38\) sample. The phase diagram is shown in figure 2, \(x = 0.30\) being a tricritical point. From \(x_{AC}\) and the Fisher equation we were able to determine \(q(T)\), that shows a \(\beta_s\) exponent near to MFA, \(\beta_s = 1\) (Tab. I). Transition lines in plane \((H, T)\) have been

![Fig. 1. - Thermal variation of initial AC susceptibility, \(x_{AC}\). All concentrations are nominal, except for \(x = 0.38\).](http://dx.doi.org/10.1051/jphyscol:19888559)

<table>
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<th>(x)</th>
<th>(T_{SG}) (K)</th>
<th>(T_c) (K)</th>
<th>(q)</th>
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<th>(\gamma)</th>
<th>(\delta)</th>
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<td>1</td>
<td>1.0</td>
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(\(\ast\)) At 1.6 K; (-) exponent not determined; (*) magnetization not critical; (a) renormalization group.
observed. For the SG systems \((0.10 \leq x \leq 0.30)\) a shift of a broad magnetization cusp with applied field is observed, following a GT line \((\varphi = 1)\), showing irreversibility between FC and ZFC magnetizations. For CSG systems the PM/CSG line is of AT type \((\varphi = 3)\).

**Scaling analysis:** in figure 3 we plot \(M^2\) vs. \(H/M\) for \(x = 0.38\), in general no spontaneous magnetization is found below \(T_c\) or \(T_{SG}\). It is difficult to determine if \(x_0\) diverges or attains the demagnetizing limit, although \((\text{Fig. 3})\) for \(x > 0.30\), \(x_0\) attains such limit.

**Fig. 2.** Magnetic phase diagram; \((\circ) = \chi'_{AC}, (\Delta) =\) magnetization.

**Fig. 3.** Arrott plot of \(M^2\) vs. \(H/M\) (D.L. = demagnetizing limit).

**Fig. 4.** Log-log plot of \(M\) vs. \(H\) in SG regime.

In figure 4 we show the power law relation between \(M\) and \(H\), in the SG regime. This behaviour is also observed at \(T = T_{SG}\) or \(T_c\) and in the CSG regime \((\delta = 2.33, \delta_1 = 5)\). Notice in table I that the AP values, \(\delta = 2.33\) and \(\delta_1 = 5\) agree well with our best characterized sample, \(x = 0.38\).

Although there is no spontaneous magnetization below \(T_c\) or \(T_{SG}\) is was suggested [7] that a crossover with \(H\) from SG to ferromagnet can exist. In fact we observe scaling \(M^2 \sim t^{\delta} \) in non-zero field for the CSG systems but not for the SG ones. A divergent susceptibility \(x_0 \sim t^{-\gamma_6}\) was observed for \(T > T_c\) (CSG) \((\gamma_6\) in Tab. I).

**Non-linear susceptibility:** for small \(H\) and at \(T_{SG}\), \(x_{nl} / H^2\) diverges indicating true PM/SG or CSG/SG phase transitions. According to (1), \(x_{nl} \sim t^{-\gamma_6}\) for \(t > 0\) at \(H \to 0\), as observed in figure 5 \((\gamma_6\) in Tab. I). Equations (1) predict that \(x_{nl} \sim H^{2/\delta_4}\) at \(T = T_{SG}\); values for \(\delta_4\) are given in table I.

We should mention that critical slowing down of the spin-spin relaxation time, \(T_2 \sim t^{-\lambda_4}\), has been observed at \(T_{SG}\) and \(T_c\). Table I summarize the critical exponents, including the MFA values.

**Acknowledgments**

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