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Evidence of a Low Energy Anisotropy in $GdCoIn_5$

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Abstract We investigate the effects of an applied magnetic field on the magnetic properties of the antiferromagnet $GdCoIn_5$. The prominent anisotropy observed in the susceptibility below T_N is rapidly suppressed by a field of just a few Tesla. Further evidence of this low energy-scale is obtained from magnetoresistance and magnetostriction experiments. The lattice length, particularly, shows a sudden change below 2 T when the magnetic field is applied perpendicular to the crystallographic $\hat{c}$-axis.

Keywords Rare earth magnetism · Antiferromagnetic transition · Anisotropy

1 Introduction

$GdCoIn_5$ is a member of the extensively studied 115 family of compounds $RTIn_5$ (R = rare earth, T = Co, Rh, Ir). Different experiments [1] show a second-order phase transition to an antiferromagnetic state at $T_N = 30$ K. Magnetic ground states are also observed in several other members of the 115 family [2–5]. In general, these magnetic states are influenced by the crystal electric field (CEF) produced by the surrounding ions [6]. In this sense, one expects a different situation for $GdCoIn_5$ since the half-filled $4f$ orbital of the Gd^{3+} ion has zero orbital momentum which makes the CEF effects much less important. This would imply, for instance, that anisotropy in the magnetic properties should be negligible. Nonetheless, very recently, [1] we have shown that an important anisotropy is observed in the magnetic susceptibility below T_N. The susceptibility indeed shows an easy magnetic axis along the basal ab-plane of the tetragonal crystal structure.

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Here, we show that the magnetic anisotropy of $GdCoIn_5$ has a small characteristic energy-scale: the magnetic susceptibility becomes mostly isotropic under an applied field B of a few Tesla. This is further confirmed by some singularities observed in the magnetoresistance and magnetostriction around 2 T when $B \perp [001]$.

2 Experimental Details

Single crystalline samples of $GdCoIn_5$ were grown by the self-flux technique as described elsewhere [1]. The magnetization M was measured in a Quantum Design MPMS magnetometer. A high-resolution capacitive dilatometer [7] was used in the magnetostriction experiments, while a standard four probe setup was used in the magnetoresistance experiments.

3 Results

Figure 1 shows the temperature dependence of the magnetic static susceptibility ($\chi = M/B$) parallel and perpendicular to the [001] direction in an applied magnetic field $B = 1$ T (lower panel) and $B = 5$ T (upper panel). The transition to the antiferromagnetic state is detected as a peak in both directions ($T_N \approx 30$ K). At $B = 1$ T, the anisotropy observed below T_N is typical of an antiferromagnet with ordered moments lying perpendicular to [001]. Remarkably, however, this pronounced anisotropy is significantly reduced at $B = 5$ T. A quantitative estimate of this field-induced "isotropization" is shown in the inset of Fig. 1. It depicts the susceptibility difference between its value at T_N and its minimum value below T_N, in both directions. While $\Delta\chi_{001}$ is very small and field independent, $\Delta\chi_{100}$ is quite large at low fields but it rapidly decreases above $B \sim 2$ T.

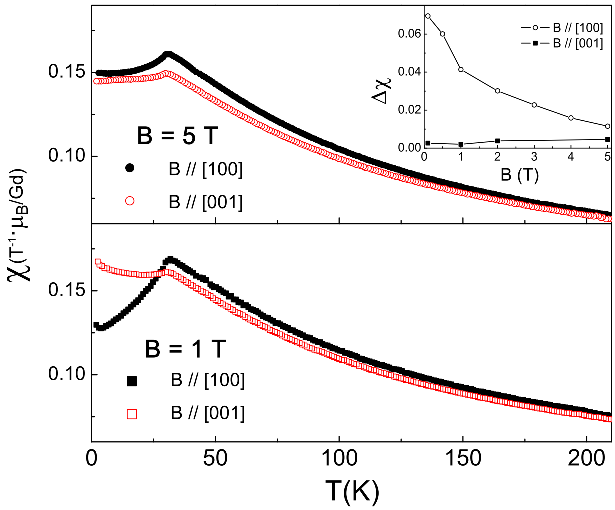

Fig. 1 Temperature dependence of the magnetic susceptibility along the [100] and [001] directions in an applied field $B = 1$ T (*lower panel*) and $B = 5$ T (*upper panel*). *Inset* susceptibility difference between its value at T_N and its minimum value below T_N (Color figure online)

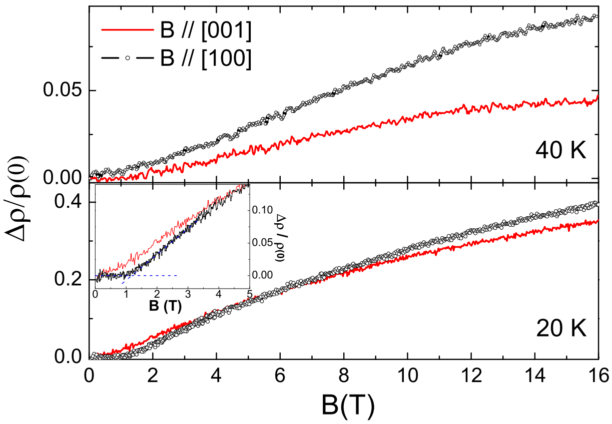

Fig. 2 Magnetoresistance as function of a magnetic field applied along the [100] and [001] directions at $T = 20$ K (*lower panel*) and $T = 40$ K (*upper panel*). *Inset* Low field magnetoresistance at 20 K. *Dashed lines* are guides to the eye (Color figure online)

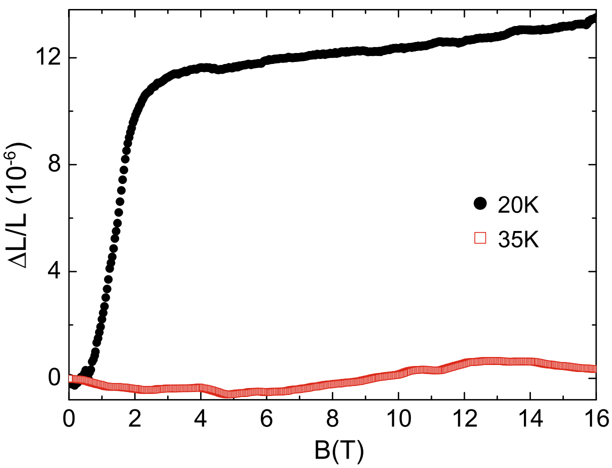

Fig. 3 Longitudinal magnetostriction along [100] at $T = 20$ K and $T = 35$ K (Color figure online)

Another evidence of this low energy-scale comes from the ab-plane magnetoresistance $\Delta\rho\,(B)/\rho\,(0)$. Figure 2 displays $\Delta\rho\,(B)/\rho\,(0)$ at two different temperatures, above ($T = 40$ K) and below ($T = 20$ K) the ordering temperature and for B along the [100] and [001] directions. The magnetoresistance is positive as expected for predominant antiferromagnetic correlations and it is progressively reduced above T_N. The inset of Fig. 2 shows a detailed view of the low field magnetoresistance at 20 K. It can be seen that when $B \parallel [100]$, $\Delta\rho\,(B)/\rho\,(0)$ is zero for $B \lesssim 1$ T. The effect disappears above T_N.

But the most notable evidence of a low energy-scale is obtained from magnetostriction. Figure 3 shows the field dependence of the longitudinal magnetostriction along the [100] direction at two different temperatures. Below T_N, the lattice length shows an abrupt increase around 2 T (see the curve at 20 K). This effect becomes less important as the temperature is raised and it finally disappears at T_N. Above T_N the magnetostriction is much smaller and shows a smooth field dependence (see the curve at 35 K). On the other hand, no peculiarities in the striction is observed when the magnetic field points in the [001] direction.

Dipolar interactions would be the simplest assumption to explain this anisotropy. In fact, this hypothesis gives a good explanation of the observed magnetic order in $GdRhIn_5$ [8]. The same argument should apply to the whole Gd_m M_n In_{3m+2n} (n = 0,1; m =1,2) series. However, dipolar interactions cannot account for the magnetic order observed in Gd_2IrIn_8 [9]. For that reason, we argue that the observed anisotropy can arise instead, from a direction-dependent magnetic coupling [10] mediated by the Gd 5d orbitals (J. I. Facio's unpublished data).

The magnetic energy associated with an applied magnetic field $B \approx 2$ T is enough to suppress the magnetic anisotropy and, eventually, to induce a change in the relative orientation of neighboring magnetic moments (i.e., a change in the magnetic correlations) which causes the observed magnetostriction [11].

4 Conclusions

Even though the antiferromagnetic state of $GdCoIn_5$ is very robust against an applied magnetic field [1], different experiments like magnetic susceptibility, resistivity, and magnetostriction show evidence of a low energy-scale below T_N. The anisotropy associated with this energy-scale can be due to direction-dependent magnetic interactions.

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References

1. D. Betancourth, J. I. Facio, P. Pedrazzini, C. B. R. Jesus, P. G. Pagliuso, V. Vildosola, P. S. Cornaglia, D. J. García, V. F. Correa, J. Magn. Magn. Mater. (2014). doi:10.1016/j.jmmm.2014.09.024
2. Y. Isikawa, D. Kato, A. Mitsuda, T. Mizushima, T. Kuwai, J. Magn. Magn. Mater. **272–276**, 635 (2004)
3. Y. Inada, M. Hedo, T. Fujiwara, T. Sadamasa, Y. Uwatoko, Physica B **378–380**, 421 (2006)
4. J. Hudis, R. Hu, C.L. Broholm, V.F. Mitrović, C. Petrovic, J. Magn. Magn. Mater. **307**, 301 (2006)
5. H.T. Huy, S. Noguchi, N. Van Hieu, X. Shao, T. Sugimoto, T. Ishida, J. Magn. Magn. Mater. **321**, 2425 (2009)
6. N. Van Hieu, T. Takeuchi, H. Shishido, C. Tonohiro, T. Yamada, H. Nakashima, K. Sugiyama, R. Settai, T.D. Matsuda, Y. Haga, M. Hagiwara, K. Kindo, S. Araki, Y. Nozue, Y. Ōnuki, J. Phys. Soc. Jpn. **76**, 064702 (2007)
7. G.M. Schmiedeshoff, A.W. Lounsbury, D.J. Luna, S.J. Tracy, A.J. Schramm, S.W. Tozer, V.F. Correa, S.T. Hannahs, T.P. Murphy, E.C. Palm, A.H. Lacerda, S.L. Bud'ko, P.C. Canfield, J.L. Smith, J.C. Lashley, J.C. Cooley, Rev. Sci. Instrum. **77**, 123907 (2006)
8. E. Granado, B. Uchoa, A. Malachias, R. Lora-Serrano, P.G. Pagliuso, H. Jr Westfahl, Phys. Rev. B. **74**(21), 214428 (2006)
9. E. Granado, P.G. Pagliuso, C. Giles, R. Lora-Serrano, F. Yokaichiya, J.L. Sarrao, Phys. Rev. B. **69**(14), 144411 (2004)
10. G. Jackeli, G. Khaliullin, Phys. Rev. Lett. **102**(1), 017205 (2009)
11. E. Callen, H.B. Callen, Phys. Rev. **139**(2A), A455 (1965)