Temperature-field scaling of the magnetic free energy of spin-liquid candidate RuCl3 up to 65T

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Introduction

Kitaev's analysis [2] of a particular model of spins on a honeycomb lattice, predicts a spin-liquid state when exchange interactions are strongly spin-anisotropic. Following this theoretical observation, several materials, RuCl3 among them, have been identified as potential hosts of new spin-liquid state. [5] It has been found in neutron studies [6] that RuCl3 indeed feature a brunch of non-spin-wave excitations at low temperatures, consistent with fractionalized excitations of Kitaev's model. [2] Kitaev's analysis suggests robustness of the spin-liquid state, potentially, up to temperatures comparable with exchange energy scale, J~150K in RuCl3. It is therefore extremely interesting to explore magnetic response of RuCl3 in a broad range of temperatures and fields up to the highest available fields. This, in particular ahs a potential to reveal a competition of Zeeman, thermal and exchange energy scales in the spin-liquid state.

Experimental

These measurements use new experimental probe of magnetic anisotropy, resonant torsion magnetometry, specifically adapted for use in pulsed magnetic fields. Detailed description of the new technique can be found in SI section of Ref. [1]. The measurement reports directly the thermodynamic coefficient (second angular derivative of free energy) associated with magnetic anisotropy -- magnetotropic coefficient [3]. Unlike torque, magnetotropic coefficient measurements allow detailed study of magnetic anisotropy very close to crystallographic directions and several orders of magnitude smaller size crystals. Both of these features were critical for success of the current study [1].

We performed measurements of the magnetotropic coefficient up to 65T at dense set of temperatures (Figure 1).

Results and Discussion

Figure 1 shows the full data set obtained in this measurement. See [1] for details. The results obtained in this study suggest that the magnetic free energy of the spin liquid state in RuCl3 exhibits a peculiar B/T scaling, i.e., is scale-invariant.

Acknowledgements

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References

[1] Scale-invariant magnetic anisotropy in RuCl3, K. A. Modic, Ross D. McDonald, B. J. Ramshaw, J. P. C. Ruff, Maja D. Bachmann, You Lai, Johanna C. Palmstrom, David Graf, Mun Chan, F. F. Balakirev, J. B. Betts, G. S. Boebinger, Marcus Schmidt, D. A. Sokolov, Philip J. W. Moll, Arkady Shekhter, in preparation.

[2] A. Kitaev, Annals of Physics 321, 2 (2006).

[3] K. A. Modic, T. E. Smidt, I. Kimchi, N. P. Breznay, A. Biffin, S. Choi, R. D. Johnson, R. Coldea, P. Watkins-Curry, G. T. McCandless, J. Y. Chan, F. Gandara, Z. Islam, A. Vishwanath, A. Shekhter, R. D. McDonald, and J. G. Analytis, Nature Communications 5, 4203 (2014).

[4] K. A. Modic, B. J. Ramshaw, J. B. Betts, N. P. Breznay, J. G. Analytis, R. D. McDonald,
and A. Shekhter, Nature Communications 8, 180 (2017).

[5] J. Chaloupka, G. Jackeli, and G. Khaliullin, Physical Review Letters 110, 097204 (2013).

[6] A. Banerjee, J. Yan, J. Knolle, C. A. Bridges, M. B. Stone, M. D. Lumsden, D. G. Mandrus,
D. A. Tennant, R. Moessner, and S. E. Nagler, Science 356, 1055 (2017).

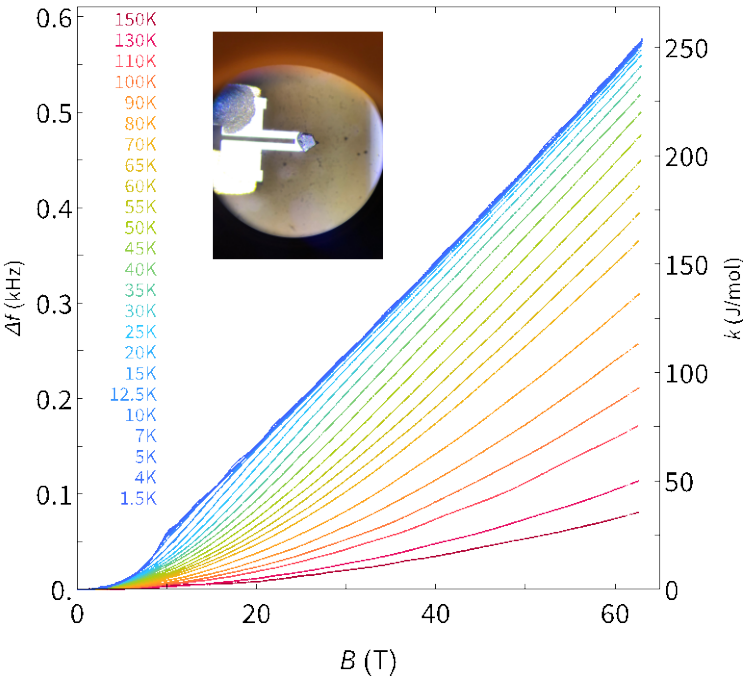

Figure 1. Temperature-field scaling of the magnetotropic coefficient in RuCl3 in a broad field- and temperature range. Left axis indicates the frequency shift of the freely suspended vibrating lever (inset) as field is pulsed. The corresponding value of the magnetotropic coefficient is shown on the right axis.