Giant anisotropy of the magnetoresistance in few-layer α-$RuCl_3$ tunnel junctions

M. Massicotte[1,2], S. Dehlavi[1], X. Liu[3], J. L. Hart[4], E. Garnaoui[1], P. Lampen-Kelley[5], J. Q. Yan[5], D. Mandrus[5], S. E. Nagler[6], K. Watanabe[7], T. Taniguchi[7], B. Reulet[1], J. J. Cha[4], H.-Y. Kee[3], J. A. Quilliam[1]

[1] *Institut quantique, Département de physique, Université de Sherbrooke, Sherbrooke, QC, J1K 2R1, Canada*
[2] *Institut Interdisciplinaire d'Innovation Technologique, Laboratoire Nanotechnologies Nanosystèmes – CNRS, Département de génie électrique et génie informatique, Université de Sherbrooke, Sherbrooke, J1K 2R1, Canada*
[3] *Department of Physics, University of Toronto, Toronto, Ontario, M5S 1A7, Canada*
[4] *Department of Materials Science and Engineering, Cornell University, Ithaca, New York 14853, USA*
[5] *Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA and Department of Materials Science and Engineering, University of Tennessee, Knoxville, TN 37996*
[6] *Neutron Scattering Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA and Department of Physics and Astronomy, The University of Tennessee, Knoxville, Tennessee 37996, USA*
[7] *National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan*
mathieu.massicotte@usherbrooke.ca

The magnetic insulator α-$RuCl_3$ is proximate to a quantum spin liquid (QSL) [1] described by the Kitaev model [2]. A promising route to realizing a true Kitaev QSL in α-$RuCl_3$ is to reduce its dimensionality via mechanical exfoliation. In addition to enhancing magnetic fluctuations [3], exfoliating α-$RuCl_3$ opens the door to manipulating its magnetic state by coupling it to other two-dimensional materials [4]. However, measuring the magnetic properties of such small samples represents a great technical challenge. Moreover, to harness the technological potential of this predicted Kitaev QSL phase and its non-Abelian anyonic excitations, an electrical probing technique is highly desirable but limited by the insulating nature of the material.

Here, we present angle-dependent tunneling magnetoresistance (TMR) measurements on ultrathin α-$RuCl_3$ crystals with various layer numbers (Fig. 1) to probe their magnetic, electronic and crystal structure. We observe a giant change in resistance – as large as ~ 2500 % – when the magnetic field rotates either within or out of the α-$RuCl_3$ plane. This is a manifestation of the anisotropic spin interactions arising from the strong spin-orbit coupling in this material. Using TMR as a probe, we track the magnetic phase diagram of α-$RuCl_3$ as a function of temperature, applied magnetic field and its angle relative to the crystallographic axes. Our results show that few-layer α-$RuCl_3$ hosts a zigzag antiferromagnetic order with a Néel temperature of ~ 14 K, higher than the ~ 7 K measured in bulk samples with a rhombohedral stacking [5]. We explain this surprising result by showing that exfoliated flakes maintain a monoclinic structure at low temperature, while bulk α-$RuCl_3$ is believed to undergo a monoclinic-to-rhombohedral phase transition. This conclusion is supported by our scanning transmission microscopy study of isolated flakes. Our study provides a deeper understanding of how the magnetic properties of α-$RuCl_3$ depend on its stacking order and layer number, which helps lay the groundwork for the van der Waals engineering of exotic magnetic phases such as QSL.

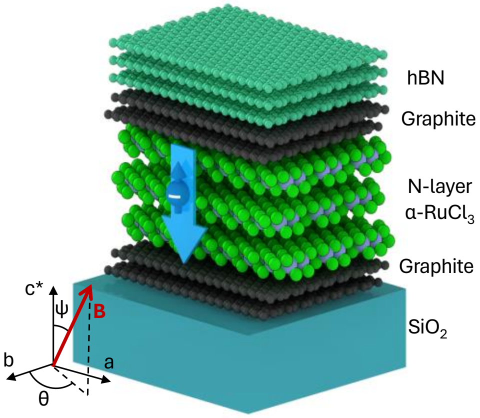

Fig.1. Schematic representation of a graphite/α-$RuCl_3$/graphite magnetic tunnel junction.

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