

## Anisotropic exchange in LiCu<sub>2</sub>O<sub>2</sub>

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### Abstract

© 2017 American Physical Society. We investigate the magnetic properties of the multiferroic quantum-spin system LiCu<sub>2</sub>O<sub>2</sub> by electron spin resonance (ESR) measurements at X- and Q-band frequencies in a wide temperature range ( $T_{N1} \leq T \leq 300$  K). The observed anisotropies of the  $g$  tensor and the ESR linewidth in untwinned single crystals result from the crystal-electric field and from local exchange geometries acting on the magnetic Cu<sup>2+</sup> ions in the zigzag-ladder-like structure of LiCu<sub>2</sub>O<sub>2</sub>. Supported by a microscopic analysis of the exchange paths involved, we show that both the symmetric anisotropic exchange interaction and the antisymmetric Dzyaloshinskii-Moriya interaction provide the dominant spin-spin relaxation channels in this material.

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### References

- [1] H.-J. Mikeska and A. K. Kolezhuk, *Lect. Notes Phys.* 645, 1 (2004). 9783-5402 10.1007/BFb0119591
- [2] A. V. Chubukov, *Phys. Rev. B* 44, 4693 (1991). PRBMDO 0163-1829 10.1103/PhysRevB.44.4693
- [3] A. K. Kolezhuk, *Phys. Rev. B* 62, R6057 (R) (2000). PRBMDO 0163-1829 10.1103/PhysRevB.62.R6057
- [4] A. K. Kolezhuk and T. Vekua, *Phys. Rev. B* 72, 094424 (2005). PRBMDO 1098-0121 10.1103/PhysRevB.72.094424
- [5] D. V. Dmitriev and V. Ya. Krivnov, *Phys. Rev. B* 77, 024401 (2008). PRBMDO 1098-0121 10.1103/PhysRevB.77.024401
- [6] F. Amiri, G. Sun, H.-J. Mikeska, and T. Vekua, *Phys. Rev. B* 92, 184421 (2015). PRBMDO 1098-0121 10.1103/PhysRevB.92.184421
- [7] T. Hikihara and L. Kecke, T. Momoi and A. Furusaki *Phys. Rev. B* 78, 144404 (2008). PRBMDO 1098-0121 10.1103/PhysRevB.78.144404
- [8] J. Sudan, A. Lüscher, and A. M. Läuchli, *Phys. Rev. B* 80, 140402 (R) (2009). PRBMDO 1098-0121 10.1103/PhysRevB.80.140402
- [9] F. Heidrich-Meisner, I. P. McCulloch, and A. K. Kolezhuk, *Phys. Rev. B* 80, 144417 (2009). PRBMDO 1098-0121 10.1103/PhysRevB.80.144417
- [10] S. Furukawa, M. Sato, Y. Saiga, and S. Onoda, *J. Phys. Soc. Jpn.* 77, 123712 (2008). JUPSAU 0031-9015 10.1143/JPSJ.77.123712
- [11] M. E. Zhitomirsky and H. Tsunetsugu, *Europhys. Lett.* 92, 37001 (2010). EULEEJ 0295-5075 10.1209/0295-5075/92/37001
- [12] S. Nishimoto, S.-L. Drechsler, R. Kuzian, J. Richter, and J. van den Brink, *J. Phys.: Conf. Ser.* 400, 032069 (2012). 1742-6588 10.1088/1742-6596/400/3/032069
- [13] M. Enderle, C. Mukherjee, B. Fåk, R. K. Kremer, J.-M. Broto, H. Rosner, S.-L. Drechsler, J. Richter, J. Malek, A. Prokofiev, W. Assmus, S. Pujol, J.-L. Raggazzoni, H. Rakoto, M. Rheinstädter, and H. M. Rønnow, *Europhys. Lett.* 70, 237 (2005). EULEEJ 0295-5075 10.1209/epl/i2004-10484-x
- [14] M. Hase, H. Kuroe, K. Ozawa, O. Suzuki, H. Kitazawa, G. Kido, and T. Sekine, *Phys. Rev. B* 70, 104426 (2004). PRBMDO 1098-0121 10.1103/PhysRevB.70.104426

- [15] S.-L. Drechsler, N. Tristan, R. Klingeler, B. Büchner, J. Richter, J. Málek, O. Volkova, A. Vasiliev, M. Schmitt, A. Ormeci, C. Loison, W. Schnelle, and H. Rosner, *J. Phys.: Condens. Matter* 19, 145230 (2007). JCOMEL 0953-8984 10.1088/0953-8984/19/14/145230
- [16] M. Boehm, S. Coad, B. Roessli, A. Zheludev, M. Zolliker, P. Böni, D. McK. Paul, H. Eisaki, N. Motoyama, and S. Uchida, *Europhys. Lett.* 43, 77 (1998). EULEEJ 0295-5075 10.1209/epl/i1998-00322-3
- [17] S.-L. Drechsler, O. Volkova, A. N. Vasiliev, N. Tristan, J. Richter, M. Schmitt, H. Rosner, J. Málek, R. Klingeler, A. A. Zvyagin, and B. Büchner, *Phys. Rev. Lett.* 98, 077202 (2007). PRLTAO 0031-9007 10.1103/PhysRevLett.98.077202
- [18] M. G. Banks, R. K. Kremer, C. Hoch, A. Simon, B. Ouladdiaf, J.-M. Broto, H. Rakoto, C. Lee, and M.-H. Whangbo, *Phys. Rev. B* 80, 024404 (2009). PRBMDO 1098-0121 10.1103/PhysRevB.80.024404
- [19] T. Masuda, A. Zheludev, B. Roessli, A. Bush, M. Markina, and A. Vasiliev, *Phys. Rev. B*, 72, 014405 (2005). PRBMDO 1098-0121 10.1103/PhysRevB.72.014405
- [20] S. J. Hibble, C. Malitesta, and P. G. Dickens, *Solid State Ionics* 39, 289 (1990). SSIOD3 0167-2738 10.1016/0167-2738(90)90409-K
- [21] S. J. Hibble, J. Köhler, A. Simon, and S. Paider, *J. Sol. State Chem.* 88, 534 (1990). JSSCBI 0022-4596 10.1016/0022-4596(90)90251-R
- [22] E. C. Fritschij, H. B. Brom, and R. Berger, *Solid State Commun.* 107, 719 (1998). SSCOAA 0038-1098 10.1016/S0038-1098(98)00295-6
- [23] A. M. Vorotynov, A. I. Pankrats, G. A. Petrakovski, K. A. Sablina, W. Paszkowicz, and H. Szymczak, *J. Exp. Theor. Phys.* 86, 1020 (1998). JTPHES 1063-7761 10.1134/1.558548
- [24] B. Roessli, U. Staub, A. Amato, D. Herlach, P. Pattison, K. Sablina, and G. A. Petrakovskii, *Physica B* 296, 306 (2001). PHYBE3 0921-4526 10.1016/S0921-4526(00)00574-3
- [25] S. Zvyagin, G. Cao, Y. Xin, S. McCall, T. Caldwell, W. Moulton, L.-C. Brunel, A. Angerhofer, and J. E. Crow, *Phys. Rev. B* 66, 064424 (2002). PRBMDO 0163-1829 10.1103/PhysRevB.66.064424
- [26] K.-Y. Choi, S. A. Zvyagin, G. Cao, and P. Lemmens, *Phys. Rev. B* 69, 104421 (2004). PRBMDO 1098-0121 10.1103/PhysRevB.69.104421
- [27] T. Masuda, A. Zheludev, A. Bush, M. Markina, and A. Vasiliev, *Phys. Rev. Lett.* 92, 177201 (2004). PRLTAO 0031-9007 10.1103/PhysRevLett.92.177201
- [28] A. A. Gippius, E. N. Morozova, A. S. Moskvina, A. V. Zalessky, A. A. Bush, M. Baenitz, H. Rosner, and S.-L. Drechsler, *Phys. Rev. B* 70, 020406 (2004). PRBMDO 1098-0121 10.1103/PhysRevB.70.020406
- [29] L. Mihály, B. Dóra, A. Ványolos, H. Berger, and L. Forró, *Phys. Rev. Lett.* 97, 067206 (2006). PRLTAO 0031-9007 10.1103/PhysRevLett.97.067206
- [30] S. Park, Y. J. Choi, C. L. Zhang, and S.-W. Cheong, *Phys. Rev. Lett.* 98, 057601 (2007). PRLTAO 0031-9007 10.1103/PhysRevLett.98.057601
- [31] S. Seki, Y. Yamasaki, M. Soda, M. Matsuura, K. Hirota, and Y. Tokura, *Phys. Rev. Lett.* 100, 127201 (2008). PRLTAO 0031-9007 10.1103/PhysRevLett.100.127201
- [32] Y. Yasui, K. Sato, Y. Kobayashi, and M. Sato, *J. Phys. Soc. Jpn.* 78, 084720 (2009). JUPSAU 0031-9015 10.1143/JPSJ.78.084720
- [33] Y. Kobayashi, K. Sato, Y. Yasui, T. Moyoshi, M. Sato, and K. Kakurai, *J. Phys. Soc. Jpn.* 78, 084721 (2009). JUPSAU 0031-9015 10.1143/JPSJ.78.084721
- [34] A. A. Bush, V. N. Glazkov, M. Hagiwara, T. Kashiwagi, S. Kimura, K. Omura, L. A. Prozorova, L. E. Svistov, A. M. Vasiliev, and A. Zheludev, *Phys. Rev B* 85, 054421 (2012). PRBMDO 1098-0121 10.1103/PhysRevB.85.054421
- [35] A. A. Bush, N. Büttgen, A. A. Gippius, V. N. Glazkov, W. Kraetschmer, L. A. Prozorova, L. E. Svistov, A. M. Vasiliev, and A. Zheludev, *Phys. Rev B* 88, 104411 (2013). PRBMDO 1098-0121 10.1103/PhysRevB.88.104411
- [36] R. Berger, P. Önnerud, and R. Tellgren, *J. Alloys and Compounds* 184, 315 (1992). JALCEU 0925-8388 10.1016/0925-8388(92)90505-4
- [37] Y. Qi and A. Du, *Phys. Lett. A* 378, 1417 (2014). PYLAAG 0375-9601 10.1016/j.physleta.2014.03.025
- [38] H.-A. Krug von Nidda, L. E. Svistov, M. V. Eremin, R. M. Eremina, A. Loidl, V. Kataev, A. Validov, A. Prokofiev, and W. Aßmus, *Phys. Rev. B* 65, 134445 (2002). PRBMDO 0163-1829 10.1103/PhysRevB.65.134445
- [39] R. M. Eremina, M. V. Eremin, V. N. Glazkov, H. -A. Krug von Nidda, and A. Loidl, *Phys. Rev. B* 68, 014417 (2003). PRBMDO 0163-1829 10.1103/PhysRevB.68.014417
- [40] A. Abragam and B. Bleaney, *Electron Paramagnetic Resonance of Transition Ions* (Clarendon Press, Oxford, 1970).
- [41] P. W. Anderson and P. R. Weiss, *Rev. Mod. Phys.* 25, 269 (1953). RMPHAT 0034-6861 10.1103/RevModPhys.25.269
- [42] R. Kubo and K. Tomita, *J. Phys. Soc. Jpn.* 9, 888 (1954). JUPSAU 0031-9015 10.1143/JPSJ.9.888

- [43] D. Zakharov, H.-A. Krug von Nidda, A. Loidl, M. Eremin, J. Deisenhofer, and R. Eremina, *Anisotropic exchange in spin chains in NATO Science for Peace and Security Series B: Physics and Biophysics* (Springer, Berlin, Heidelberg, 2008), pp. 193-238.
- [44] R. M. Eremina, T. P. Gavrilova, H.-A. Krug von Nidda, A. Pimenov, J. Deisenhofer, and A. Loidl, *Physics of the Solid State* 50, 283 (2008). PSOSD 1063-7834 10.1134/S106378340802011X
- [45] T. P. Gavrilova, R. M. Eremina, H.-A. Krug von Nidda, J. Deisenhofer, and A. Loidl, *Journal of Optoelectronics and Advanced Materials* 10, 1655 (2008).
- [46] R. M. Eremina, *Magnetic Resonance in Solids. Electronic Journal* 16, 14102 (2014).
- [47] B. Bleaney and K. D. Bowers, *Proc. R. Soc. A* 214, 451 (1952). 1364-5021 10.1098/rspa.1952.0181
- [48] M. Papagno, D. Pacilé, G. Caimi, H. Berger, L. Degiorgi, and M. Grioni, *Phys. Rev. B* 73, 115120 (2006). PRBMDO 1098-0121 10.1103/PhysRevB.73.115120
- [49] R. E. Walstedt and S.-W. Cheong, *Phys. Rev. B* 64, 014404 (2001). PRBMDO 0163-1829 10.1103/PhysRevB.64.014404
- [50] H. Eskes, L. H. Tjeng, and G. A. Sawatzky, *Phys. Rev. B* 41, 288 (1990). PRBMDO 0163-1829 10.1103/PhysRevB.41.288
- [51] M. S. Hybertsen, E. B. Stechel, W. M. C. Foulkes, and M. Schlüter, *Phys. Rev. B* 45, 10032 (1992). PRBMDO 0163-1829 10.1103/PhysRevB.45.10032
- [52] M. V. Eremin, J. Deisenhofer, R. M. Eremina, J. Teyssier, D. vander Marel, and A. Loidl, *Phys. Rev. B* 84, 212407 (2011). PRBMDO 1098-0121 10.1103/PhysRevB.84.212407
- [53] R. Coldea, S. M. Hayden, G. Aeppli, T. G. Perring, C. D. Frost, T. E. Mason, S.-W. Cheong, and Z. Fisk, *Phys. Rev. Lett* 86, 5377 (2001). PRLTAO 0031-9007 10.1103/PhysRevLett.86.5377
- [54] S. Furukawa, M. Sato, and S. Onoda, *Phys. Rev. Lett.* 105, 257205 (2010). PRLTAO 0031-9007 10.1103/PhysRevLett.105.257205
- [55] M. Chen and C. De. Hu, *J. Phys. Soc. Jpn.* 83, 014702 (2014). JUPSAU 0031-9015 10.7566/JPSJ.83.014702
- [56] L. E. Svistov, L. A. Prozorova, A. M. Farutin, A. A. Gippius, K. S. Okhotnikov, A. A. Bush, K. E. Kamentsev, and E. A. Tishchenko, *J. Exp. Theor. Phys.* 108, 1000 (2009). JTPHES 1063-7761 10.1134/S1063776109060119
- [57] J. P. Joshi and S. V. Bhat, *J. Magn. Reson.* 168, 284 (2004). JMARF3 1090-7807 10.1016/j.jmr.2004.03.018
- [58] M. Oshikawa and I. Affleck, *Phys. Rev. B* 65, 134410 (2002). PRBMDO 0163-1829 10.1103/PhysRevB.65.134410
- [59] A. F. Sadykov, A. P. Gerashchenko, Yu. V. Piskunov, V. V. Ogloblichev, A. G. Smolnikov, V. Verkhovskii, A. Yu. Yakubovskii, E. A. Tishchenko, and A. A. Bush, *J. Exp. Theor. Phys.* 115, 666 (2012). 10.1134/S1063776112090105
- [60] Ph. Leininger, M. Rahlenbeck, M. Raichle, B. Bohnenbuck, A. Maljuk, C. T. Lin, B. Keimer, E. Weschke, E. Schierle, S. Seki, Y. Tokura, and J. W. Freeland, *Phys. Rev. B* 81, 085111 (2010). PRBMDO 1098-0121 10.1103/PhysRevB.81.085111
- [61] B. Z. Malkin, *Crystal field and electron in rare-earth ionic paramagnets*. In: *Spectroscopy of solids containing rare-earth ions*, edited by A. A. Kaplyanskii and R. M. Macfarlane (Elsevier Science Publishers, Amsterdam, 1987), p. 13;
- [62] M. V. Eremin and A. A. Kornienko, *phys. stat. sol. (b)* 79, 775 (1977). PSSBBD 0370-1972 10.1002/pssb.2220790244
- [63] R. M. Eremina, M. V. Eremin, V. V. Iglamov, J. Hemberger, H.-A. Krug von Nidda, F. Lichtenberg, and A. Loidl, *Phys. Rev. B* 70, 224428 (2004). PRBMDO 1098-0121 10.1103/PhysRevB.70.224428
- [64] M. V. Eremin, *Theory of the crystal field in dielectrics (in Russian)*, in *Spectroscopy of Crystals*, edited by A. A. Kopyanskii (Nauka, Leningrad, 1989), p. 30.
- [65] H. -Yu Huang, N. A. Bogdanov, L. Siurakshina, P. Fulde, J. van den Brink, and L. Hozoi, *Phys. Rev. B* 84, 235125 (2011). PRBMDO 1098-0121 10.1103/PhysRevB.84.235125