MAGNETIC FORM FACTOR OF URhGe*

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The magnetic form factor of ferromagnetic superconductor URhGe has been measured with the use of polarized neutrons. In spite of rather peculiar state of the $5f$ electrons in this compound reflected in their itinerant behavior, strongly reduced uranium magnetic moments of 0.4 μ_B and in some cases also superconductivity at low temperatures, we found a magnetic form factor that does not deviate substantially from that one of the free U^{3+} ion calculated in a dipole approximation.

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1. Introduction

URhGe has recently attracted great interest because of coexistence of ferromagnetism and superconductivity at low temperatures [1]. It forms in the orthorhombic TiNiSi type of structure in which U atoms form chains running along the a axis. Bulk measurements on single crystal indicate a ferromagnetic order below 9.6 K [2], with the easy plane type anisotropy. URhGe also exhibits an enhanced low-temperature specific-heat coefficient γ of 160 mJ/molK^2 [3]. Strongly reduced uranium magnetic moments of about 0.4 μ_B were found to be confined to the b–c plane [2] or parallel to the c axis [1]. At 0.25 K [1] transition to superconducting state was found that coexists with ferromagnetism. However, the appearance of such transition depends on the quality of crystal.

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In this contribution we report on magnetic-form-factor measurements performed on a URhGe crystal using polarized neutrons.

2. Experimental

The crystal has been grown from a stoichiometric melt by means of a modified tetra-arc Czochralski technique. The scattering experiment was performed at 2 K on a single crystal in magnetic fields of up to 6 T applied about 38 degrees away from the c axis using the 5C1 spectrometer installed at CEA Saclay. The incident wavelength was 0.85 Å and the polarization degree 92%.

3. Results and discussion

During the experiment we have recorded 210 flipping ratios (108 inequivalent ones) $R = (1+\gamma)^2/(1-\gamma)^2$, with $\gamma = F_{\rm M}/F_{\rm N}$ and $F_{\rm M}$ and $F_{\rm N}$ being magnetic and nuclear structure factors, respectively. However, some of the R values with too high error bars were discarded. This resulted in a set of 80 experimental R values used in direct fits to formula $\mu f = \mu[\langle j_0\rangle + C_2\langle j_2\rangle]$, where C_2 coefficient is related to the ratio between the spin and orbital contribution and j_n are averages of spherical Bessel functions. In the dipole approximation, the values of C_2 are 1.75 and 1.5 for free U^{3+} and U^{4+} ions, respectively. Better approximations give values 1.803 and 1.644 [4].

We performed refinement considering the extinction correction, non-zero moments on both, U and Rh ions, free direction of U moments and free C_2 coefficient supposing both ionic states for U and arrived to a magnetic form factor that is very close to those expected for free U^{3+} or U^{4+} ions. In Fig. 1 magnetic amplitudes μf as a function of $\sin\theta/\lambda$ recorded for URhGe at 2 K and 6 T are shown together with the best fit. The refined C_2 coefficient supposing U^{3+} ionic state amounts to 1.68 ± 0.05. This indicates that the orbital contribution (oriented antiparallel to the spin part) to the total magnetic moment of 0.41 ± 0.01 $\mu_{\rm B}$/U is very important in URhGe that is in qualitative agreement with theoretical calculations [5]. It is also consistent with values determined from magnetic bulk measurements and unpolarized neutron experiment [2]. On Rh atoms a much smaller moment of 0.023 ± 0.008 $\mu_{\rm B}$/Rh has been found. The magnetism in URhGe is clearly of $5f$ origin. Inclusion or removal of Rh moments from the fit does not change significantly its quality in terms of χ^2, which is always slightly below 3.

From the fit it follows that the direction of ferromagnetically aligned U moment is not 60 degrees away from the c axis as was indicated in [2] nor along the c axis as was reported in [1] but approximately 18 degrees

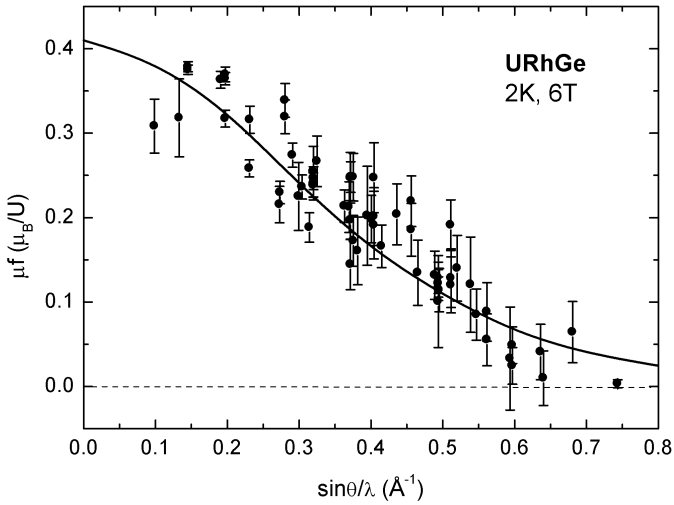

Fig. 1. Experimental and calculated U magnetic form factor in URhGe at 2 K and 6 T. The calculation is performed using dipolar approximation.

away from the c axis, however, still being confined to the b–c plane. At this moment we can argue that a relatively small magnetocrystalline anisotropy energy within the b–c plane that amounts according to magnetic bulk measurements to about 10 K is responsible for these controversial findings.

Despite the rather anomalous physical properties of URhGe the magnetic form factor is found strongly resembling free U^{3+} and U^{4+} ion values. Within the error bars we were not able to distinguish between them due to their strong similarity. Moreover, even C_2 value does not help to resolve the uncertainty. Such a situation has been met in many other U based compounds including the superconducting ferromagnet UGe_2 [6] that exhibits under pressure similar physical properties. This fact may indicate that the $5f$ electrons responsible for both the magnetism and superconductivity do not participate in both phenomena simultaneously but are separated either in space or time. Clearly, more effort in this field is needed.

4. Conclusions

In conclusion, uranium magnetic form factor in URhGe has been determined at 2 K and 6 T using polarized neutron beam. Within the dipolar approximation it resembles very strongly theoretical $5f$ form factors of the free U^{3+} or U^{4+} ions. The strongly reduced value of U moments of 0.41 ± 0.01 μ_B/U is therefore not only a consequence of spin and orbital part cancellation.

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REFERENCES

[1] D. Aoki, A. Huxley, E. Ressouche, D. Braithwaite, J. Flouquet, J. P. Brison, E. Lhotel, C. Paulsen, *Nature* **413**, 613 (2001).

[2] I.H. Hagmusa, K.Prokeš, Y. Echizen, T. Takabatake, T. Fujita, J.C.P. Klaasse, E. Bruck, V. Sechovský, F.R. de Boer, *Physica B* **281-282**, 223 (2000).

[3] K. Prokeš, T. Tahara, Y. Echizen, T. Takabatake, T. Fujita, I.H. Hagmusa, J.C.P. Klaasse, E.Bruck, F.R. de Boer, M. Diviš, V. Sechovský, *Physica B* **311**, 220 (2002).

[4] J.X. Boucherle, D. Givord, J. Schweizer, *J. Phys. C* **7**, 199 (1982).

[5] M. Diviš, L. M. Sandratskii, M. Richter, P. Mohn, P. Novák, *J. Alloy. Compnd.* **337**, 48 (2002).

[6] K. Kuhawara, H. Sagayama,K. Iwasa, M. Kohgi, Y. Haga, Y. Ōnuki, K. Kakurai, M. Nishi, K. Nakajima, N. Aso, Y. Uwatoko, *Physica B* **312-313**, 106 (2002).