Experimental report

11/01/2024

Proposal: **5-51-596** **Council:** 4/2023

Title: Study of Field-Induced Magnetization in a New Iron-Based Superconductor Using Polarized Neutron Diffraction

Research area: Physics

This proposal is a new proposal

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Samples: Yttrium Iron Germanium

Instrument	Requested days	Allocated days	From	To
D3 High field >1T	6	8	14/06/2023	22/06/2023
ORIENTEXPRESS	0	1	13/06/2023	14/06/2023

Abstract:

Ferromagnetic and antiferromagnetic spin fluctuations tend to mediate superconducting pairing with different symmetry. In contrast to the widely-studied AFM fluctuations, FM fluctuations are largely unexplored due to the limited candidate compounds. Recently, our inelastic neutron scattering measurements have observed the coexistence of in-plane FM and stripe-type AFM spin fluctuations in a newly-synthesized iron germanium superconductor YFe2Ge2. The FM spin fluctuations were found to be stronger in the low energy regime, suggesting the possibility of unconventional pairing mechanism. The field-induced magnetization measurement using polarized neutron diffraction has been adopted to probe the pairing symmetry in many superconductors, including cuprates, iron pnictides and Sr2RuO4. On purpose of revealing the SC ground state in YFe2Ge2, we thereby plan to extract the field-induced magnetization and track its temperature dependence across Tc in our high-quality, bulk-superconducting sample. The success of the experiment will provide crucial information on the pairing symmetry in YFe2Ge2.

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Scientific Background

Determining the pairing symmetry of electrons in unconventional superconductors is critical for understanding the mechanism of superconductivity. Enormous previous research efforts have been made on cuprates and iron-based superconductors studying singlet pairing with *d*- or $s_{\pm}$-wave symmetry and the closely related antiferromagnetic spin fluctuations [1,2]. However, triplet pairing superconductivity, which is typically mediated by ferromagnetic fluctuations, is largely unexplored, despite its significance in superconducting spintronics and quantum computing [3-5], due to a limited number of candidate compounds [6].

Our recent neutron scattering measurements showed the presence of in-plane ferromagnetic and stripe-type antiferromagnetic spin fluctuations in the newly discovered iron-germanium superconductor YFe_2Ge_2 [7] (Fig. 1(a,b)). The ferromagnetic spin fluctuations were found to be stronger in the low energy regime, suggesting the possibility of unconventional pairing mechanism. However, the superconducting ground state of YFe_2Ge_2 remains unclear.

Field-induced magnetization measurements using polarized neutron diffraction can provide important information about the pairing symmetry of superconductors. This method was first developed by Shull and Wedgwood [8], and has been used successfully to study pairing symmetry in cuprates, iron pnictides, and Sr_2RuO_4 superconductors [9-12]. Induced by an external field, magnetization along the field direction can be derived from the 'flipping ratio' defined as the ratio of cross sections for initial neutron spin polarization states parallel or anti-parallel to the applied field (without analyzing the final spin state). A suppression in magnetization across the superconducting transition temperature (T_c) indicates singlet pairing (S=0) (Fig. 1(c)), while unchanged magnetization suggests triplet pairing (S=1).

Experiment Results

The superconductivity of YFe_2Ge_2 is extremely sensitive to defects/disorders, and fabricating bulk superconducting YFe_2Ge_2 single crystals is not trivial [13]. Recently, we have successfully synthesized high-quality single-crystalline YFe_2Ge_2 using the chemical vapor transport method. The single crystal has bulk superconductivity with high residual resistivity ratio (RRR) = ρ(300K)/ρ(2K) ~ 300 (Fig. 2(b)). Superconducting transitions were confirmed by resistivity, ac susceptibility, and heat capacity measurements (Fig. 2(b-d)).

In this experiment, one piece of bulk-superconducting YFe_2Ge_2 single crystal in dimension 3mm×6mm×1mm (with a total mass of 100 micrograms) was aligned in the tetragonal (H, H, L) scattering plane (Fig. 2(a)). Dilution refrigerator was used to reach the superconducting state. The magnetization is found to grow linearly with external field (Fig. 3). The temperature evolution of field-induced magnetization was further tracked across T_c at low-|**Q**| Bragg peak position (0, 0, 2) and (1, 1, 0). The data is currently under analysis to provide deeper insight on the pairing symmetry in YFe_2Ge_2.

References

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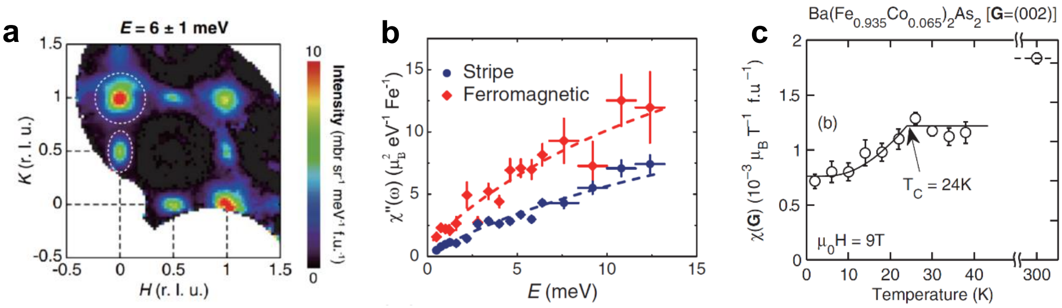

Fig. 1 **(a)** A contour plot of the spin excitations in the (H, K, 0.5) plane (1-Fe notation) in YFe_2Ge_2 at 4 K, with FM and stripe spin fluctuations indicated by dashed circle and ellipsoid respectively. **(b)** Momentum-integrated local susceptibility in YFe_2Ge_2. (**a**) and (**b**) is adopted from Ref. [7]. (**c**) Field-induced magnetization in $Ba(Fe,Co)_2As_2$ reduces below T_c consistent with the singlet pairing [11].

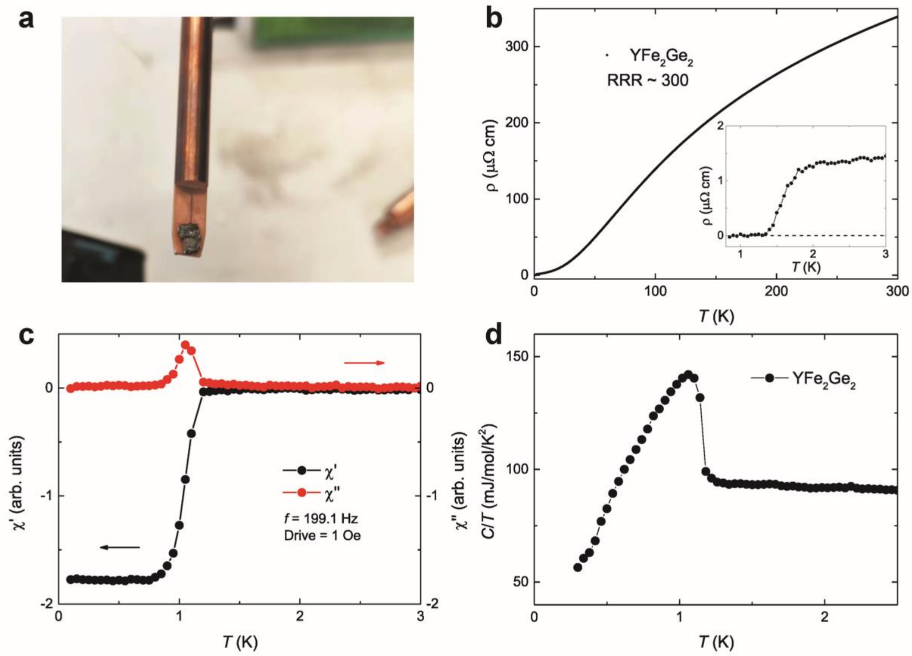

Fig. 2 **(a)** Photo of the YFe_2Ge_2 single crystal. **(b-d)** The resistivity, ac susceptibility and heat capacity in YFe_2Ge_2 around the superconducting phase transition, demonstrating the high quality of the sample and its bulk superconductivity.

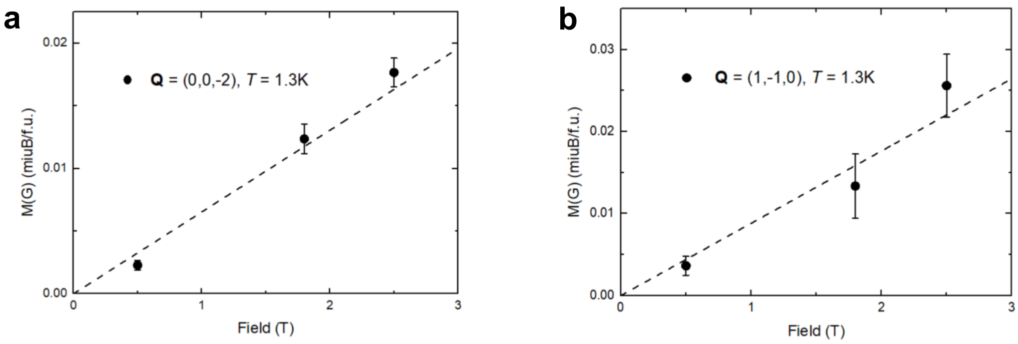

Fig. 3 Field-induced magnetization in YFe_2Ge_2 superconductor at **(a)** (0, 0, 2) and **(b)** (1, 1, 0) (equivalent position).