Experimental Report

07/03/2014

Proposal: **4-01-1206** **Council:** 4/2012

Title: Paramagnon in a KxFe2-ySe2 superconductor

This proposal is a new proposal

Researh Area: Physics

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Samples: KFeSe

Instrument	Req. Days	All. Days	From	To
IN8	8	7	26/10/2012	02/11/2012

Abstract:

A recent time-of-flight experiment on a superconducting KxFe2-ySe2 sample revealed not only spin resonance mode at 14 meV around the (0.5,0.25,0) wave vector, but also a ring-like low energy (LE) mode at 9 meV which connects the equivalent resonance positions in the HK0 scattering plane. This feature does not show a temperature dependence upon entering the superconducting state. We suspect that this new excitation is a paramagnon resulting from the nesting of the electron pockets at M point. In order to confirm its magnetic character we propose to study its temperature dependence in the normal state and its dispersion with the out-of-plane wave vector.

Experimental report for proposal No. 4-01-1206

Introduction.

The recently discovered family of alkali iron selenide superconductors $A_xFe_{2-y}Se_2$ show a comparatively high superconducting (SC) transition temperature of $T_c = 31\,\mathrm{K}$ on the one hand [1], and a strong antiferromagnetic order ($T_N > 500\,\mathrm{K}$) on the other hand [2]. It was shown by multiple experimental probes that both ground states originate from chemically different, spatially separated phases. The former presumably has $A_{0.3}Fe_2Se_2$ stoichiometry [4], whereas the latter was found to have $A_2Fe_4Se_5$ stoichiometry, exhibiting an $\sqrt{5}\times\sqrt{5}$ iron vacancy superstructure [2]. This magnetic phase is insulating, whereas the SC/metallic phase shows a distinctly different Fermi surface compared to its 122 iron arsenide analogues, consisting mainly of large electron pockets at the M point $[\mathbf{Q} = (\frac{1}{2}, 0)]$ [5].

The unconventional nature of superconductivity was recently revealed when observing spin fluctuations peaked at $\mathbf{Q}_{res} = (\frac{1}{2}\,\frac{1}{4})$ in the normal state, which get redistributed into a resonant mode excitation at $\hbar\omega_{res} = 14\,\mathrm{meV}$ in the SC state [6]. Below $\hbar\omega_{res}$ a spin gap with zero intensity should exist. However, in a recent time-of-flight spectroscopy study on a $K_{0.77}Fe_{1.85}Se_2$ sample an additional low energy mode around $\hbar\omega_2 = 9\,\mathrm{meV}$ was observed in both normal state and superconducting state [7]. In reciprocal space the intensity forms a ring centered at $M(\frac{1}{2}\,\frac{1}{2})$ and passing through the wave vectors of the resonant mode at $\mathbf{Q}_{res} = (\frac{1}{2}\,\frac{1}{4})$. Goal of the proposed experiment was to investigate whether this feature is magnetic by measuring the temperature dependence and L-dependence of its intensity. Before the date of the experiment the same investigation was already conducted at the Puma spectrometer (FRM2, Garching) on a $K_{0.77}Fe_{1.85}Se_2$ sample by our group (see Ref. 7). It revealed the LE mode to be a phonon, since the intensity increases upon warming to $T = 100\,\mathrm{K}$. Therefore, we decided to concentrate on measuring the spectrum at the resonance position at $\mathbf{Q}_{res} = (\frac{1}{2}\,\frac{1}{4})$ in the superconducting and in the normal state, which is part of a study, that has been initiated in a previous experiment at In8 [8]. Being previously restricted to energies below 16 meV due to kinematical constraints, we decided to measure in the $(H\; H/2\; L)$ scattering plane. Since the resonance signal has no L-dependence, we can freely alter the L-component and reach energy transfers up to $E = 36\,\mathrm{meV}$. The sample was $Rb_{0.8}Fe_{1.6}Se_2$, as previously used. The final wave vector was chosen to $k_f = 4.1\,\mathrm{\mathring{A}}^{-1}$. The sample environment comprised a standard orange cryostat.

Results of Experiment

It was planned to measure the spin fluctuations at $\mathbf{Q}_{res} = (\frac{1}{2}\,\frac{1}{4})$ by performing momentum scans in the normal (at $T = 35\,\mathrm{K}$) and in the SC state (at $T = 1.5\,\mathrm{K}$). The trajectory were slightly off the scattering plane, progressing with a step of $d\mathbf{Q} = (0.018\; 0.003\; \Delta L)$. By this we wanted to avoid contaminations from spin waves associated with the block-AFM $\sqrt{5}\times\sqrt{5}$ ordering of $Rb_2Fe_4Se_5$, that are emerging from the superstructure peaks at the nearby wave vectors $(0.3, 0.1)$ and $(0.7, 0.1)$. Nonetheless, in the discussion here the trajectory will be treated as if it goes along $(\Delta H\; \Delta H/2\; \Delta L)$. The stepsize along the c direction ΔL can be chosen freely. This freedom was important in order to avoid possible contaminations on both sides of the center at $(\frac{1}{2}\,\frac{1}{4}\,L)$.

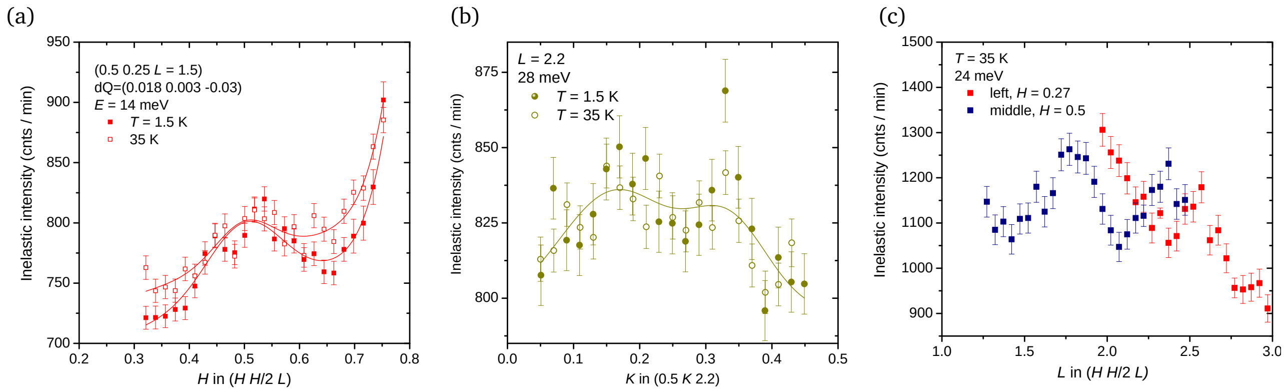

Fig. 1: (a) Momentum scan with a step size of $d\mathbf{Q} = (0.018\; 0.003\; -0.03)$ through $\mathbf{Q}_{res} = (\frac{1}{2}\,\frac{1}{4}\,L = 1.5)$ at $E = 14\,\mathrm{meV}$ in both SC and normal state. **(b)** Momentum scan along $d\mathbf{Q} = (\frac{1}{2}\; K\; 2.2)$ at $E = 28\,\mathrm{meV}$ in both SC and normal state. **(c)** Momentum scan along L in $(H_0\; H_0/2\; L)$ for $H_0 = 0.27$ (left) and $H_0 = 0.5$ (middle). All solid lines are fits with one or more Gaussian functions.

A typical momentum scan is shown in Fig. 1 (a) for $E = 14\,\mathrm{meV}$. The peak in the middle at $H = 0.5$ are the spin fluctuations which get enhanced when cooling below T_c. However, on the right side is a spurion that creates a slopy background, which makes it difficult to determine the amplitude of the magnetic peak by fitting it with a Gaussian. The momentum scans for other energies were even more contaminated which made it impossible to observe clearly the spin excitations. This became clear when mapping the inelastic intensity over the $(H\; H/2\; L)$ scattering plane as shown in Figure 1 (c) for $E = 24\,\mathrm{meV}$. Low statistics momentum scans along L were done for certain $H = H_0$. Especially the center of the spin fluctuations at $H_0 = 0.5$ shows strong contaminations for almost all L values. By doing similar scans for other energies we could find some positions that were "clean". Figure 1 (b) shows a momentum scan along $(\frac{1}{2}\; K\; 2.2)$ at $E = 28\,\mathrm{meV}$ that was feasible by means of the 3D mode at the instrument. It shows a broad peak centered at $K = \frac{1}{4}$ that could also be fitted with two incommensurate Gaussian profiles. Incommensurate excitations at the resonance were also observed in pnictides

($Ba(Fe_{1-x}Ni_x)_2As_2$ [9]) and in 11 selenides ($FeTe_{1-x}Se_x$ [10]). Therefore, a closer inspection of this incommensurability would be desirable to see if it is a general property of the pnictides.

At higher energies the magnetic intensity was measured along the ($\Delta H\ \Delta H/2\ \Delta L$) trajectory. Figure 2 (a) shows scans in the SC and in the normal state plus a scan at a very high temperature ($T = 150$ K), where spin fluctuations are expected to vanish. Unfortunately, there is a concavely shaped background, which renders it impossible to determine the magnetic intensity. However, the flat intensity difference between SC and normal state in Fig. 2 (b) shows that there is no resonant enhancement anymore. The presence of spin fluctuations is established from the intensity difference with the $T = 150$ K data, that shows a peak in the center. Unfortunately, the concave background in the raw momentum scans persisted for energies up to $E = 36$ meV. A reason could be the overlap with the spin waves from $(0.3, 0.1)$ that are now reaching into region of the trajectory.

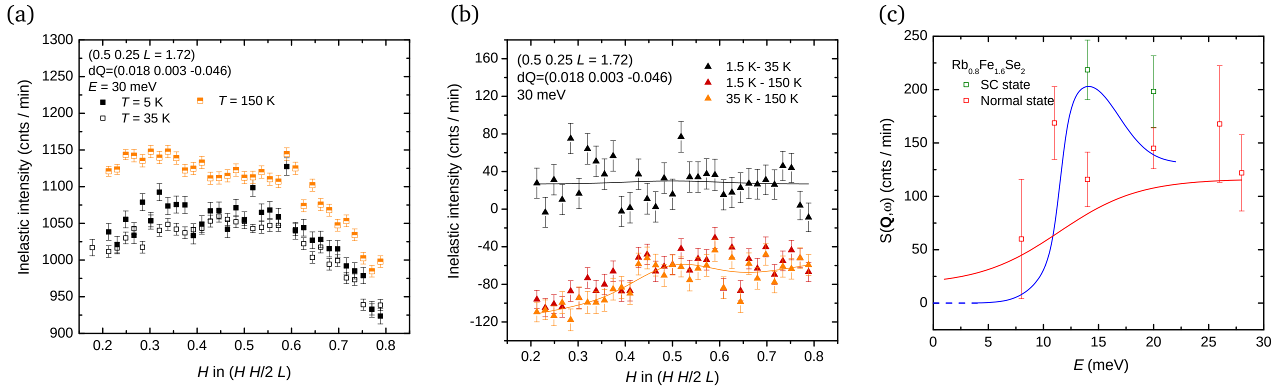

Fig. 2: (a) Momentum scan with a step size of $d\mathbf{Q} = (0.018\ 0.003\ -0.048)$ through $\mathbf{Q}_{\rm res} = (\frac{1}{2}\ \frac{1}{4}\ 1.72)$ at $E = 30$ meV in the SC ($T = 1.5$ K) and in the normal state ($T = 35$ K and $T = 150$ K). **(b)** Intensity difference of the momentum scans in panel (a). **(c)** Amplitude of the Gaussian fits to the momentum scans, centered at $\mathbf{Q}_{\rm res} = (0.5\ 0.25\ L)$ *vs.* energy. The solid lines are taken from the previous study covering the energy range below 16 meV.

Summary

Panel (c) of Figure 2 shows the amplitude of the Gaussian fits to the momentum scans through $\mathbf{Q}_{\rm res} = (\frac{1}{2}\ \frac{1}{4}\ L)$ *vs.* energy for both normal state and superconducting state, that are corrected for the Fe^{2+} magnetic form factor. The solid lines are taken from the previous study covering the energy range below 16 meV [8]. The data points collected in this study agree with these lines within statistical uncertainty. Both data sets will be combined which will be a first comprehensive assessment of the absolute intensities in both SC and normal state *vs.* energy for $Rb_{0.8}Fe_{1.6}Se_2$.

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