Experimental report

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Proposal: **4-01-1498** **Council:** 4/2016

Title: Inelastic neutron scattering studyon YbFe2Al10

Research area: Physics

This proposal is a new proposal

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Samples: YbFe2Al10, LaFe2Al10

Instrument	Requested days	Allocated days	From	To
IN4	4	4	24/11/2016	28/11/2016

Abstract:

CeT2Al10 compounds exhibit a Kondo insulator (T=Fe) to an unconventional long-range magnetic order (T=Ru, Os). Recently P. Khuntia et. al. measured magnetization, specific heat, and NMR on YbFe2Al10. The dc susceptibility at low temperatures is strongly enhanced in weak magnetic fields accompanied by a -lnT divergence of the low-T specific heat coefficient in zero field, which points to a ground state of correlated electrons. The system displays valence fluctuating behavior in the low to intermediate temperature range, whereas above 400 K, Yb3+ carries a full and stable moment and Fe carries a moment of about 3.1 μB. The enhanced value of the Sommerfeld Wilson ratio and the spin-lattice relaxation rate suggest the presence of ferromagnetic correlations. 27Al (1/T1T) simultaneously tracks the valence fluctuations from the 4f Yb ions in the high T range and the field dependent Kondo-like correlations among small Fe 3d moments (0.5 μB) at low T, which evolve out of an Yb 4f admixed conduction band. We want to perform inelastic neutron scattering using IN4 to understand the low energy and high energy spin dynamics governing the underlying magnetism of the YbFe2Al10 compound.

Inelastic neutron scattering study on $YbFe_2Al_{10}$

Abstract: Recently P. Khuntia et. al. [PRL2014] measured magnetization, specific heat, and NMR on $YbFe_2Al_{10}$. The dc susceptibility at low temperatures is strongly enhanced in weak magnetic fields accompanied by a -lnT divergence of the low-T specific heat coefficient in zero field, which points to a ground state of correlated electrons. In the present IN4 experiment, we have investigated the magnetic response of $YbFe_2Al_{10}$. We have also measured the magnetic susceptibility (Fig.1), between 1.2 K and 800 K, of our $YbFe_2Al_{10}$ polycrystalline sample used in the IN4 experiment, which revealed a broad maximum near 100 K, indicating mixed valence behavior of Yb ion (i.e. dynamic fluctuations of 4f electron between $4f^{13}$ and $4f^{14}$ configurations). Further high temperature susceptibility exhibits a Curie-Weiss behavior between 300 K and 800 K. Our IN4 data indicate a broad magnetic excitation near 30 meV, which is in agreement with the T_K=300K (~26meV).

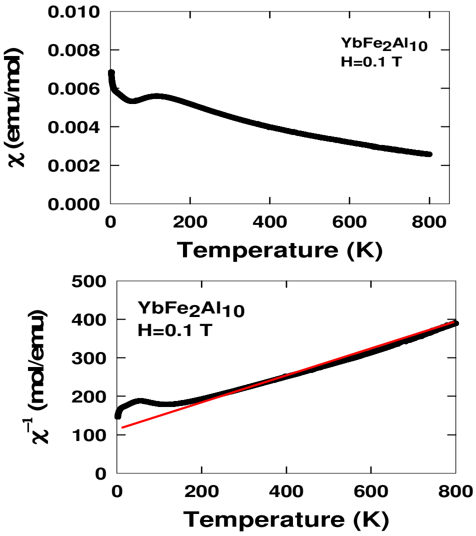

Figure 1: Temperature dependent χ of $YbFe_2Al_{10}$ sample used in our IN4 experiment.

Introduction: Yb or Ce based *f*-electron compounds display a rich variety of physics properties, including an enormous increase of the quasiparticle effective mass, a Kondo insulating state, and unconventional superconductivity [1]. Over the last two decades these properties have attracted considerable interest in condensed matter physics. The qualitative representation of both HF and the Kondo insulating state is based on the knowledge that ground state results from a competition between Kondo and Ruderman-Kittel-Kasuya-Yosida (RKKY) interactions [2]. If the RKKY interaction dominates, the system orders magnetically. However, if the Kondo interaction dominates, theory predicts that hybridization between localized *f*-electron and conduction carrier states should lead to the opening of a charge gap (or pseudogap) at the Fermi energy [3]. Though this picture is not in dispute, the well-defined predictions of the hybridization scenario have so far escaped direct experimental verification. One of the key predictions is a simple scaling relationship between the magnitude of the direct energy gap Δ in the excitation spectrum and the enhancement of the effective mass of charge carriers in the coherent regime [4]. Several HF materials, such as $CeAl_3$ [5], show no evidence of such a gap, whereas in prototypical compounds such as UPt_3 and URu_2Si_2 the gap is attributed to a magnetic ground state [6-8].
Caged type Ce-based compounds with the general formula CeT_2Al_{10} (T = Fe, Ru and Os) have attracted considerable attention due to Kondo semiconducting paramagnetic ground state (down to 40 mK) observed in $CeFe_2Al_{10}$ [9], and the anomalously high antiferromagnetic (AFM) ordering temperature with spin gap formation at low temperatures in the Kondo semimetals $CeRu_2Al_{10}$ and $CeOs_2Al_{10}$ [10]. AFM ordering of these Ce compounds is found to occur at higher temperature than in the Gd compound, which rules out the magnetic order being caused by simple RKKY interactions. According to the de Gennes scaling, T_N for a Gd compound is expected to be 100 times larger than for the Ce counterpart if we neglect the crystal field effect and possible differences in the Fermi surface. Charge density wave like instability is found in optical conductivity measurements for CeT_2Al_{10} (T = Ru, Os) which develops along the *b*-axis at temperatures slightly higher than T_N. It was suggested that this electronic instability induces the AFM order [11]. The formation of long-range magnetic ordering out of the Kondo semiconducting/semimetallic state itself is unexpected and these are the first examples of this mysterious coexistence of electronic ground states. These compounds also reveal robust anisotropy in magnetic and transport properties, which has been elucidated on the basis of single-ion crystal electric field anisotropy in the presence of strongly anisotropic hybridization between localized 4*f*-electron and conduction electrons. Recently J. Kawabata et.al. [12] suggested the suppression of T_N is well correlated with that of gap energy as a function of electron/hole doping. They

have therefore concluded that the presence of the hybridization gap is in fact necessary for the AFM order at unusually high T_N in $CeOs_2Al_{10}$.

Recently P. Khuntia et. al. [13] have performed magnetization, specific heat, and NMR investigations on $YbFe_2Al_{10}$ over a wide range of temperatures and magnetic fields. The dc magnetic susceptibility at low temperatures is strongly enhanced in weak magnetic fields accompanied by a -lnT divergence of the low-T specific heat coefficient in zero field, which is ascribed to a ground state of correlated electrons. The system displays valence fluctuating behavior in the low to intermediate temperature range, whereas above 400 K, Yb^{3+} carries a full and stable moment and Fe carries a moment of about 3.1 μ_B**.** The enhanced value of the Sommerfeld Wilson ratio and the dynamic scaling of spin lattice relaxation rate with static susceptibility suggest the presence of ferromagnetic correlations. *($1/T_1T$)* from ^{27}Al NMR *simultaneously tracks the valence fluctuations from the 4f -Yb ions in the high T range and the field dependent Kondo-like correlations among small Fe 3d moments (0.5 μ_B) at low T, which evolve out of an Yb 4f admixed conduction band.*

Results of Inelastic Neutron Scattering Experiment (INS) on IN4

Considering electron-hole symmetry between Ce (1 4f-electron) and Yb (1 4f-hole), it would be interesting to investigate the spin dynamic of $YbFe_2Al_{10}$ to compare it with the existing results of $CeFe_2Al_{10}$ [9, 14]. In order to understand the low energy and high energy spin dynamics governing the underlying magnetism of $YbFe_2Al_{10}$, both from Yb and Fe magnetism, we have investigated inelastic neutron scattering response in $YbFe_2Al_{10}$ using two wavelengths λ=1.11 Å and 2.22 Å on the IN4 spectrometer. We also measured the nonmagnetic phonon reference compound $LaFe_2Al_{10}$ for comparison. We have characterized our sample using magnetic susceptibility measurements between 1.2 K and 800 K and the results are shown in Fig.1. The magnetic susceptibility exhibits a maximum near 100 K, giving single ion Kondo temperature $T_K=3*T^{max}{}_{\chi}$=300K (26meV). Based on the magnetic susceptibility data we should expect an inelastic peak near T_K according to the scaling between TK and INS peak position proposed by Adroja et al [15].

Fig. 2 shows color coded scattering intensity maps, Energy transfer (E) versus momentum transfer (Q) from $YbFe_2Al_{10}$ at two temperatures for λ=1.11 Å (left side) and 2.22 Å (right side). It can be seen from these maps that at 1.5 K and at low energy there is no clear sign of magnetic scattering at low Q, while the high energy response show a presence of magnetic scattering near 30 meV at 1.5 K. At high temperature (280 K and 150 K) the phonon scattering increases and magnetic scattering decreases. It seems the magnetic scattering near 30 meV is transferred to the quasi-elastic line. This type of response was also observed in $CeFe_2Al_{10}$ [9, 14].

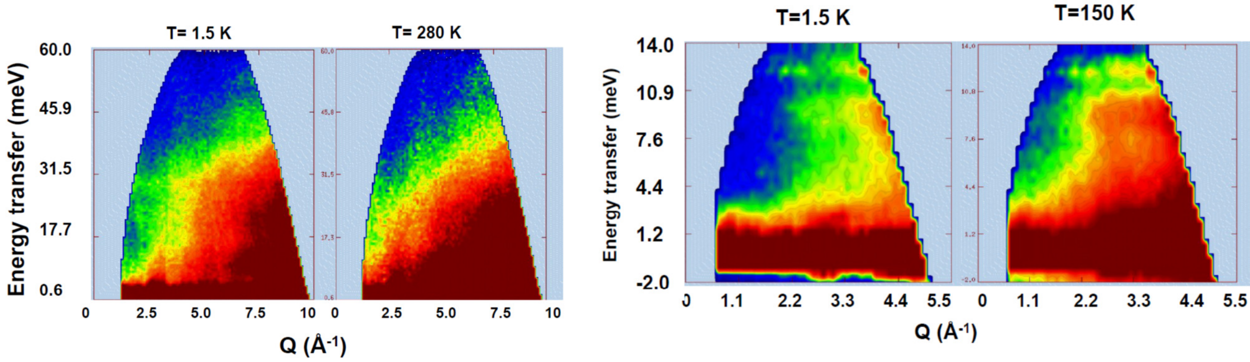

Fig.2 Color coded scattering intensity maps, Energy transfer (E) versus momentum transfer (Q) from $YbFe_2Al_{10}$ at two temperatures for λ=1.11 Å (left) and 2.22 Å (right).

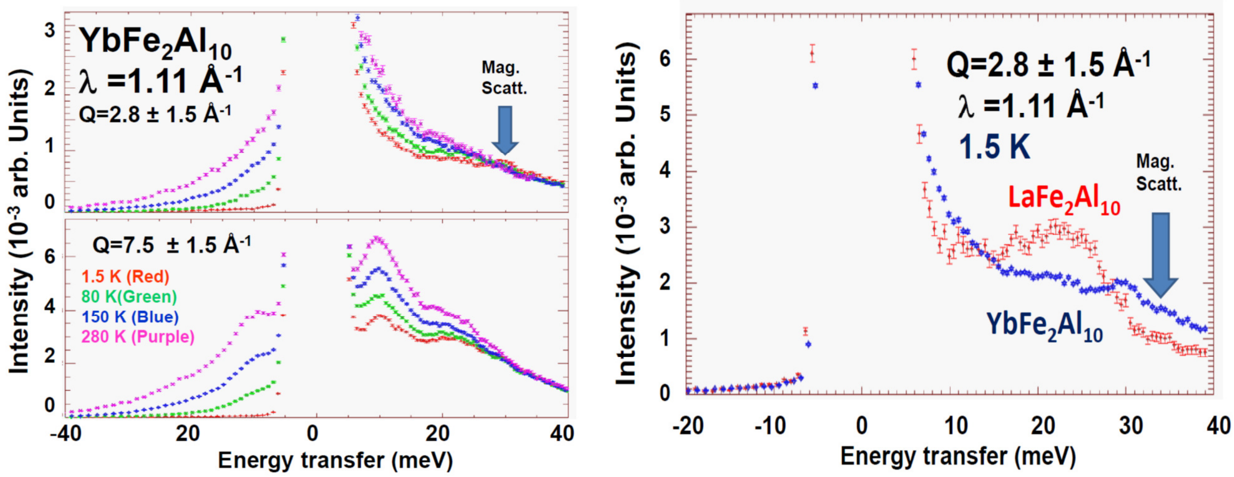

Fig.3 The energy cuts from $YbFe_2Al_{10}$ at various temperatures (top left) for low-Q and (bottom left) at high-Q. (Right) The energy cuts from $YbFe_2Al_{10}$ and $LaFe_2Al_{10}$ at low-Q, at 1.5 K. The Magnetic scattering in $YbFe_2Al_{10}$ can be seen near 30 meV.

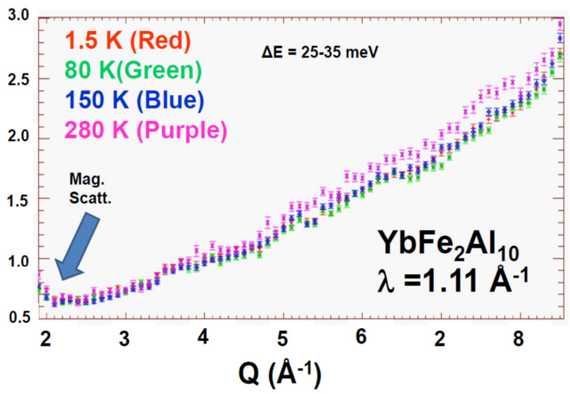

Fig.4 The energy integrated, between 25 and 35 meV, Q-dependence of the scattering intensity from $YbFe_2Al_{10}$ at various temperatures.

Fig. 3 (left) shows the energy cuts at various temperatures at low-Q (top) and at high-Q (bottom). It can be seen from the low-Q cuts that we have a clear sign of magnetic scattering at 1.5 K near 30meV. While increasing temperature scattering near 30 meV decreases at low-Q (Fig.3 top), while the scattering near 30 meV at high-Q increases, which confirmed that the 30 meV peaks at low-Q is coming from the magnetic scattering. As the position of the peak is very close to T_K value, which indicates that it is coming from the Yb ions. A very similar peak, but at low energy 12 meV, has been observed in $CeFe_2Al_{10}$ [9]. The fig. 4 shows the energy integrated, between 25 and 35 meV, Q-cuts at various temperatures, which reveal an upturn at low Q that supports the magnetic nature of 30 meV, peak. As we have not seen any other sign of magnetic scattering than 30meV peak at 1.5 K and also up to 280 K, it is unlikely that the Fe ion exhibits any magnetism in this temperature range. Further, our susceptibility of $YbFe_2Al_{10}$ exhibits a Curie-Weiss behavior between 300 K and 800 K, also supports that in our sample the Fe ions are non-magnetic. A detailed analysis of the data is in progress and will be published as a full paper in near future.

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