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SLOW CROSSOVER AND OBSERVATION OF A SECOND ENERGY SCALE IN YbAl_3 *

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YbAl_3 is an intermediate valent compound with a large Kondo temperature T_K and moderately low conduction electron density. Because of this, YbAl_3 is a prime candidate for the observation of effects caused by low conduction electron density, where coherence sets in below T_{coh} rather than T_K ($T_{\text{coh}} \ll T_K$). For the first time, we have directly observed the cross over between the energy scales by the application of a magnetic field above $B^* \approx 40$ T ($\approx k_B T_{\text{coh}} / \mu_B$). We also observe a reduction in the effective masses above B^* that is consistent with the energy scale crossover.

PACS numbers: 75.30.Mb, 75.20.Hr, 71.27.+a, 71.28.+d

1. Introduction

YbAl_3 is an intermediate valent (IV) compound with a Kondo temperature T_K in excess of 500 K and a moderately low conduction electron density of $n_c \sim 0.5/\text{atom}$ [1]. Recent theoretical studies [2,3] of the Anderson Lattice Model (ALM) suggest that the thermodynamic properties can differ in at least two ways from the predictions of the Anderson Impurity Model

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(AIM). As the background conduction electron density n_c decreases, theory predicts [3] a new low temperature scale T_{coh} for the onset of Fermi liquid coherence with $T_{\text{coh}} \ll T_K$ along with a crossover from low temperature Fermi liquid behavior to high temperature local moment behavior slower than predicted for the AIM [2]. We report data on YbAl_3 which shows that an applied field of 40 T causes an energy scale crossover from T_{coh} to T_K and a reduction in the effective masses relative to the low field values [4].

2. Results

Thermodynamic measurements have been reported elsewhere [1]. First, the crossover from low temperature Fermi liquid behavior to high temperature local moment behavior is slower than predicted for the AIM. Second, anomalies (relative to the AIM) occur below 30–40 K, which is the temperature scale T_{coh} for the onset of coherent Fermi liquid T^2 behavior in the resistivity. We believe that these effects are generic to IV compounds, as a slow crossover exists in a number of YbXCu_4 compounds [5] and a small coherence scale is observed in CePd_3 [6]. The occurrence of the slow crossover **and** the low energy scale in YbAl_3 and other IV compounds correlates with a low background conduction electron density [1].

The magnetization and dHvA effect were measured up to 60 T as described elsewhere [1]. Fig. 1 shows the magnetization as a function of applied magnetic field at temperatures above and below $T_{\text{coh}} \approx 40$ K. The solid lines are linear fits to the data in the magnetic field range $10 \text{ T} < B < 35 \text{ T}$. The difference between the linear fits and the raw data is shown in the inset. At both temperatures, the data display linear behavior for $B < 40$ T. Above

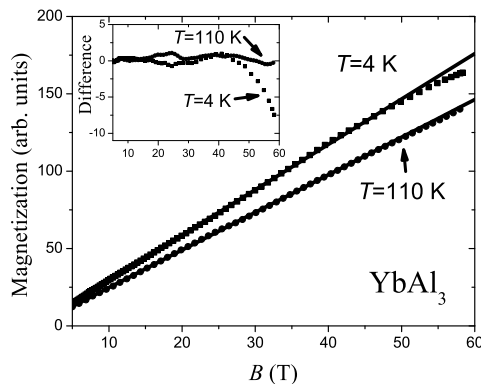


Fig. 1. Magnetization measurements in pulsed magnetic fields to 60 T at 4 K and 110 K. The solid lines are fits to the data below 35 T. The inset shows the difference between the measured values and the linear fit.

40 T, there is a clear change in slope for the 4 K data while the 110 K data retains its linearity. As the slope is simply the magnetic susceptibility χ , there is clearly a reduction in χ above 40 T at 4 K. A detailed examination of the temperature dependence of the low field ($B < 35$ T) data is in good agreement with SQUID measurements which show two maximum in $\chi(T)$ indicative of two energy scales, while the high field ($B > 40$ T) data shows a single maximum which is consistent with a single energy scale T_K [1].

Fig. 2 shows results for the dHvA measurements for $B||$ (111). As can be seen, all four branches (labelled β , η , α and ε) observed in previous low field ($B < 17$ T) measurements [4] are also observed in the 60 T pulsed field measurements. The frequencies F as given in Fig. 2 are found to be relatively unchanged compared to the values found in low fields, indicative of no fundamental change occurring in the shape of the Fermi surface at B^* . The effective masses m^* , however, are all found to be reduced up to a factor of three and are found to be independent of field above B^* . This reduction in m^* is consistent with the drastic change in the energy scales as one finds that m^* should scale as the inverse of the relevant energy scale.

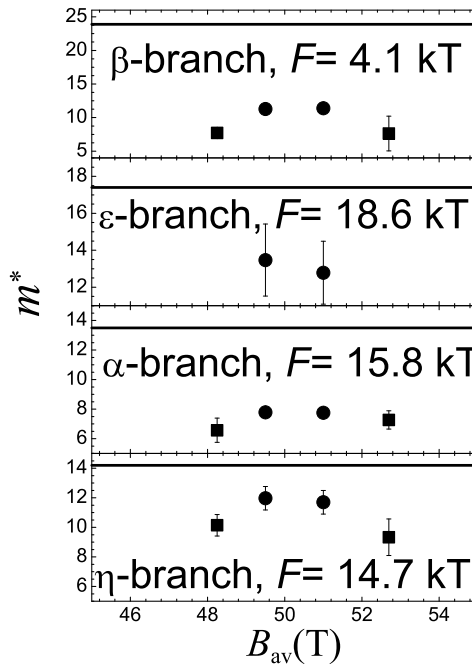


Fig. 2. Effective masses m^* versus average applied magnetic field B_{av} for $B||$ (111) in $YbAl_3$. Four branches are observed with labelling and frequencies F the same as in Ref. [4]. The different symbols represent measurements on two separate crystals. The solid lines show the values of m^* measured for $B < 17$ T from Ref. [4].

YbAl_3 is an IV compound with a moderately low conduction electron density which is found to have two energy scales $T_{\text{coh}} \approx 40$ K and $T_{\text{K}} \approx 600$ K. For $T \ll T_{\text{coh}}$ we find that the magnetization “crosses” over from the zero field energy scale T_{coh} to the high temperature energy scale T_{K} at a magnetic field $B^* \approx 40$ T ($\approx k_{\text{B}}T_{\text{coh}}/\mu_{\text{B}}$) with little change in the shape of the Fermi surface however the effective masses are all reduced relative to their low field values [4]. This is the first direct observation of the crossover between the T_{coh} and T_{K} energy scales as a function of magnetic field in an IV compound.

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