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Suppression of the Mass Enhancement in CeB_6 in High Magnetic Fields

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The effective mass of the itinerant electrons in the Kondo lattice system CeB_6 is found to be strongly field dependent. Measurements of the de Haas-van Alphen effect at temperatures down to 60 mK in steady magnetic fields up to 22 T show a change of more than 100% in the cyclotron effective mass, decreasing with increasing field. The origin of the effect is not known but it is noted that a field of about 10 T corresponds to the energy scales in the system.

1. INTRODUCTION

CeB_6 is a typical Kondo lattice system. The Kondo temperature is estimated to be 1-8 K [1]. At T_Q=3.2 K [2] an antiferro-quadrupolar order sets in [3] (refered to as phase II) and at T_N=2.4 K a complex antiferromagnetic phase is formed (phase III). In an external field of more than 2 T the antiferromagnetic phase is destroyed and the system enters phase II again. The field induces a staggered moment due to a different susceptibility on the +Q and -Q sites, in addition to a uniform moment of about 1 μ_B/Ce at 8 T. Here de Haas-van Alphen (dHvA) measurements are presented, performed in steady fields up to 22 T and at temperatures between 60 mK and 1 K. Thus the range of measurement belongs to the phase II of the system.

The Fermi surface of CeB_6 was investigated by van Deursen et al.[4]. The dHvA frequency branches found for this compound are very similar to the main branches found for LaB_6, though about 10% larger. On the other hand the effective mass measured for this branch along [100] differs by an order of magnitude: 0.61 m_e for LaB_6 and 6+/-2 m_e for CeB_6. However, from the electronic specific heat coefficient γ an effective mass of about 60 m_e would be expected for the latter. Here we show that this apparent discrepancy is mainly due to a unique field dependence of the cyclotron effective mass.

2. EXPERIMENT

The dHvA experiments were performed in the 25T polyhelix magnet of the Grenoble High Magnetic Field Facility. A dilution refrigerator was mounted with the mixing chamber in the field center. The sample was fixed with cotton wool in a compensated set of pick-up coils inside the mixing chamber. The standard large-amplitude low-frequency modulation technique was used to detect the signals.

3. RESULTS

With the field along [100] one strong frequency at 8680 T was detected. No beat structure was observed and the frequency was constant to 0.5% with changes in field and temperature. At a number of fixed field values the amplitude A of this frequency was measured as a function of temperature. It was found that this temperature dependence shows no deviations from the usual Lifshitz-Kosevich formula [5]

$$A \sim X/\sinh X; \quad X = \alpha m^* T/B$$

where $\alpha=2\pi^2 k_B m_e/e\hbar$, T is the temperature and B the magnetic field. However, the effective mass m* found in this procedure depends strongly on the applied field B. At 21.4 T a mass 8.7+/- 0.4 m_e is found. This mass increases towards lower fields to a value of 17.3+/-1.2 m_e at 12.8 T. More detailed results will be published elsewhere.

4. DISCUSSION

The observed field dependence partly resolves the above noted disagreement between dHvA and specific heat effective mass. In order to made a comparison between and m* we assume that the Fermi surfaces of LaB_6 and CeB_6 are of the same form and dimension, ignoring the 10% difference in orbit size. Thus we assume that the f-electron is localized, disturbing the geometry of the Fermi surface only slightly through hybridization and exchange effects and its non spherical charge distribution. Further it is assumed that the full magnetic moment observed in high fields is due to this localized f electron and that there is only a small, in this experiment unresolved, exchange splitting of the Fermi surface. Thus we assume that the itinerant states are occupied twice.

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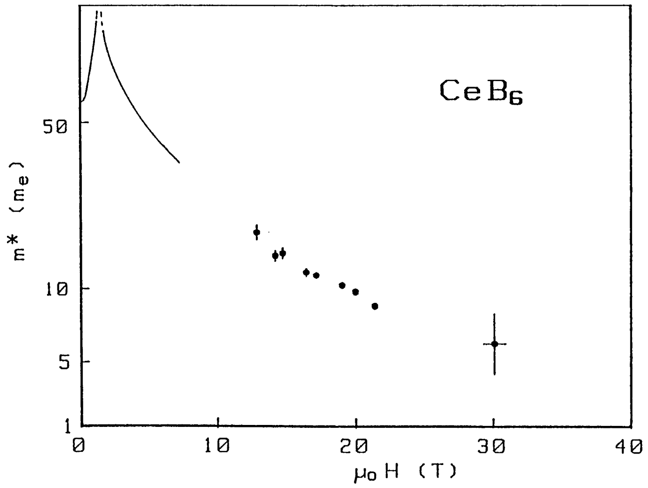

Fig. 1. The cyclotron effective mass of the electrons of the 8680 T orbit for the field along [100]. The point at about 30 T is from Ref.4. The curve represents the field dependence of the effective mass corresponding to the electronic specific heat,as explained in the text. The masses are given on logarithmic scale in order to facilitate comparison.

These two assumptions correspond with the situation encountered in CeSb [6]. The latter is a well known local moment system and it is by no means obvious that these two assumptions must hold for CeB_6. However, if we relax on one of the assumptions, we are faced with many problems in interpreting the dHvA frequencies in terms of a Fermi surface. Recently the specific heat of CeB_6 was measured in fields up to 8 T [7]. After an initial rise to about double its zero field value the electronic specific heat coefficient γ decreases strongly above 1.5 T. The maximum at 1.5 T is related to the phase III to II magnetic phase transition. There is apparently some sample dependence in the specific heat. Values for γ range from 0.225 to 0.30 $J/moleK^2$. Taking some average value the field dependence of γ is translated with the above described Fermi surface model to a field dependence of m*. This is shown by the curve in Fig.1, together with the present dHvA results and the mass at above 30 T from pulsed field measurements [4]. In order to facilitate comparison the mass data are presented on a logaritmic scale. From this semi-quantitative comparison we find that the major part of the discrepancy between γ and m* is due to the field dependence of these quantities. Further experiments to investigate the Fermi surface and measure m* and γ on the same sample in the same field are planned.

The energy scales in CeB_6: T_Q, T_N and T_K are all low and smaller than $\mu_B B$ in a field of 20T. Thus it is expected that the field strongly modifies the fluctuations giving rise to the large electronic specific heat. Here it is directly observed that the large γ value and its field dependence correspond to a large and field dependent effective mass of the itinerant electrons.

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