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LOW TEMPERATURE PHASE TRANSITIONS IN THE HEAVY ELECTRON COMPOUND YbSb

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Abstract. - Using Mössbauer spectroscopy on ¹⁷⁰Yb, we detected two low temperature phase transitions in the heavy electron pnictide YbSb. Below $T_N = 0.32$ K antiferromagnetic ordering of Yb³⁺ develops, and between 0.32 K and 5 K a phase exists whose nature is yet undetermined. Magneto-transport measurements confirm the heavy electron properties and the 5 K phase transition.

The cubic pnictides YbP and YbAs are heavy electron materials [1] which show Kondo-frustrated magnetic ordering at very low temperatures ($T_N \simeq 0.4$ K and 0.6 K) [2, 3]. Using Mössbauer absorption spectroscopy on ¹⁷⁰Yb ($I_E = 2$, $I_G = 0$, $E = 84$ keV) we investigated the isoelectronic compound YbSb and we found that it undergoes two phase transitions, at 5 K and at 0.32 K. The 5 K phase transition was confirmed by magneto-transport measurements.

1. Observation of antiferromagnetic ordering in YbSb

The Mössbauer spectrum at $T = 0.045$ K in zero external field is a poorly resolved five line hyperfine spectrum due to a magnetic hyperfine field of 63 T. This demonstrates the presence of a spontaneous Yb³⁺ moment of $0.63 \mu_B$, i.e. of magnetic ordering of the Yb³⁺ ions. The hyperfine field remains constant up to 0.2 K, and then decreases to 50 T at 0.3 K; by extrapolation we estimate that the magnetic transition occurs at (0.32 ± 0.02) K. Spectra were taken with an external magnetic field H_{ext} of 5.8 T parallel to the direction of propagation of the γ -rays; they are shown in figure 1. At $T = 0.045$ K (Fig. 1a) the angle $\varphi = (\mathbf{H}_{ext}, \mathbf{H}_{hf})$ obtained is close to 70° as in YbAs [3] and the hyperfine field is 72 T. This indicates that the magnetic structure has first rotated towards a direction almost perpendicular to \mathbf{H}_{ext} when applying the external magnetic field, i.e. that the spontaneous structure is antiferromagnetic. In a simple model assuming two magnetic sublattices [3], one can estimate the exchange field by: $H_{exch} = H_{ext} / 2 \cos \varphi \simeq 8$ T. The magnetic moment derived from the H_{hf} value is $0.72 \mu_B$, about 10 % bigger than its value in zero external field.

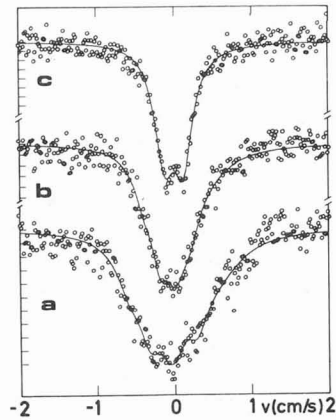


Fig. 1.- Mössbauer spectra in YbSb with an external magnetic field of 5.8 T: (a) $T = 0.045$ K; (b) $T = 1.4$ K; (c) $T = 10$ K.

These features are characteristic of a Kondo-frustrated magnetic ordering very similar to that observed in YbP [2] and YbAs [3]: the mean value of the spontaneous saturated electronic moment, $0.66 \mu_B$, is reduced with respect to that of any of the possible crystal field ground-states of Yb³⁺ in cubic symmetry: Γ_7 ($1.72 \mu_B$), Γ_6 ($1.33 \mu_B$) or Γ_8 ($2.1 \mu_B$); the value of T_N (0.32 K) is much lower than the exchange energy

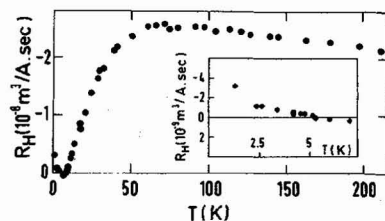


Fig. 2. - Thermal variation of the initial Hall constant R_H (measured for $H < 0.1$ T).

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$\mu_B H_{\text{exch}} \simeq 10$ K; finally, the enhancement of the saturated electronic moment under external field reflects the fact that the Kondo compensation is partially destroyed by a magnetic field. YbSb is then a magnetic heavy electron material.

2. Observation of a second phase transition in YbSb

Between 0.4 K and 4.2 K, the Mössbauer spectrum consists of an unresolved broad line (FWHM $\simeq 7$ mm/s) with a slight asymmetry; above 5 K the spectrum is a narrow line (FWHM = 3 mm/s). As shown in the inset of figure 3, the linewidth changes abruptly between 4 K and 5 K, which strongly suggests the existence of a phase transition at $T_i \simeq 5$ K. The lack of resolution of the zero field spectra between 0.4 K and 4.2 K makes it difficult to fit them in an unambiguous way: a pure quadrupolar hyperfine interaction accounts well for the lineshape (suggesting a structural and/or an electronic quadrupolar transition), as does a magnetic hyperfine interaction corresponding to an electronic moment of ca. $0.4 \mu_B$ (implying a magnetic transition to a phase that might present a complicated structure as observed in CeSb [4]). Measurements with an external field of 5.8 T provide some additional information. The spectrum at 10 K (Fig. 1c) is a 2-line spectrum, which means that $\varphi = 0$, i.e. the external field has aligned the induced paramagnetic moments ($0.26 \mu_B$) along its direction. On the contrary, the 1.4 K spectrum (Fig. 1b) shows that the angle φ is non zero in the intermediate phase: the best fit yields $\varphi = 76^\circ$ and $H_{\text{hf}} = 39.4$ T ($\mu = 0.39 \mu_B$).

This demonstrates that there exists an antiferromagnetic coupling between Yb^{3+} moments in this phase. But this fact does not necessarily imply that the zero field intermediate phase is magnetically ordered. We recall that in CeB_6 , observation of an antiferromag-

netic structure induced by an external magnetic field has been assigned to an antiferroquadrupolar ordering of the Ce^{3+} ions in zero magnetic field [5].

3. Magneto-transport measurements in YbSb

Resistivity, Hall constant and magneto-resistance measurements have been performed on polycrystals in fields up to 6 T between 1.3 K and 300 K. The temperature dependence of the magnetic resistivity and of the initial Hall constant R_H are typical of heavy electron systems. We reserve a more detailed study of the resistivity for a longer publication and we present only the results concerning the initial Hall constant R_H (measured in the range $H < 0.1$ T where the Hall resistivity is linear in H) displayed in figure 2: R_H presents a maximum at about 60 K and, below 60 K, drops rapidly as expected for Kondo lattice systems below the onset temperature for coherence. The magneto-resistance ratio $[\rho(H) - \rho(H=0)] / \rho(H=0)$ is close to 1, which is much bigger than in normal metals. In figure 3 we show the field dependence of the Hall resistivity ρ_{xy} for various temperatures in the range 1.3 K-8.2 K. The transition at 5 K is inferred by the drastic change of the $\rho_{xy}(H)$ curve between 4.2 K and 5.3 K. In particular, the sign of the initial Hall constant changes at about 5.1 K, as shown in the inset of figure 2.

In conclusion we observed two low temperature phase transitions in YbSb. Below $T_N = 0.32$ K, a Kondo-frustrated antiferromagnetic ordering of the Yb^{3+} ions sets in. In the region $0.32 \text{ K} < T < 5$ K, YbSb presents a phase which shows a canted antiferromagnetic structure in the presence of an external magnetic field; this could be due to either antiferromagnetic or antiferroquadrupolar spontaneous ordering.

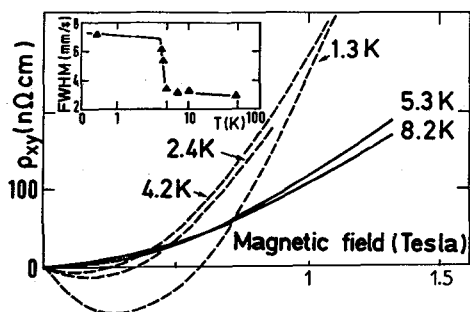


Fig. 3. - Hall resistivity ρ_{xy} versus magnetic field at various temperatures. The inset shows the thermal variation of the Mössbauer linewidth (the line is a guide to the eye).

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