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LOW TEMPERATURE PHASE TRANSITIONS IN THE HEAVY ELECTRON COMPOUND YbSb

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ABSTRACT : Using Mössbauer spectroscopy on ^{170}Yb, we detected two low temperature phase transitions in the heavy electron pnictide YbSb. Below $T_N = 0.32K$ antiferromagnetic ordering of Yb^{3+} develops, and between 0.32K and 5K a phase exists whose nature is yet undetermined. Magneto-transport measurements confirm the heavy electron properties and the 5K phase transition.

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The cubic pnictides YbP and YbAs are heavy electron materials /1/ which show Kondo-frustrated magnetic ordering at very low temperatures ($T_N \simeq 0.4K$ and C.6K) /2,3/. Using Mössbauer absorption spectroscopy on $^{170}Yb(I_e=2, I_g=0, E=84$ keV) we investigated the isoelectronic compound YbSb and we found that it undergoes two phase transitions, at 5K and at 0.32K. The 5K phase transition was confirmed by magneto-transport measurements.

1) Observation of antiferromagnetic ordering in YbSb

The Mössbauer spectrum at T=0.045K in zero external field is a poorly resolved five line hyperfine spectrum due to a magnetic hyperfine field of 63T. This demonstrates the presence of a spontaneous Yb^{3+} moment of $0.63\mu_B$, i.e. of magnetic ordering of the Yb^{3+} ions. The hyperfine field remains constant up to 0.2K, and then decreases to 50T at 0.3K; 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 5.8T parallel to the direction of propagation of the γ-rays; they are shown in figure 1. At T=0.045K (fig.1a) the angle $\varphi=\left(\vec{H}_{ext},\vec{H}_{hf}\right)$ obtained is close to 70° as in YbAs /3/ and the hyperfine field is 72T. This indicates that the magnetic structure has first rotated towards a direction almost perpendicular to $\vec{H}_{ext}$ 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: $H_{exch}=H_{ext}/2\cos\varphi \simeq 8T$. The magnetic moment derived from the H_{hf} value is $0.72\mu_B$, about 10% bigger than its value in zero external field.

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 Yb^{3+} in cubic symmetry: $\Gamma_7 (1.72\mu_B)$, $\Gamma_6 (1.33\mu_B)$ or Γ_8 $(2.1\mu_B)$; the value of T_N (0.32K) is much lower than the exchange energy $\mu_B H_{exch} \simeq 10K$; 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 0.4K and 4.2K, the Mössbauer spectrum consists of an unresolved broad line (FWHM≃7mm/s) with a slight asymmetry; above 5K the spectrum is a narrow line (FWHM=3mm/s). As shown in the inset of fig.3, the linewidth changes abruptly between 4K and 5K, which strongly suggests the existence of a phase transition at $T_t \simeq 5K$. The lack of resolution of the zero field spectra between 0.4K and 4.2K 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 5.8T provide some additional information. The spectrum at 10K (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 1.4K spectrum (fig.1b) shows that the angle φ is non zero in the intermediate phase: the best fit yields $\varphi=76°$ and $H_{hf}=39.4T$ ($\mu=0.39\mu_B$). 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 antiferromagnetic 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 parallel and transverse magnetoresistance measurements have been performed in YbSb in fields up to 6T. The temperature dependence of the Hall constant R_H and of the magnetic resistivity are typical of heavy electron systems. R_H presents a maximum at about 60K and, below 60K, drops rapidly (see fig.2) as expected for

Kondo lattice systems below the onset temperature for coherence. The magnetoresistance ratio $\rho(H)/\rho(H=0)$ is close to 1, which is much bigger than in normal metals. In fig.3 we show the variation of the Hall resistivity ρ_{xy} versus the external magnetic field for various temperatures in the range 1.3K-8.2K. The transition at 5K is inferred by the drastic change between the curves obtained at 4.2K and at 5.3K.

In conclusion we observed two low temperature phase transitions in YbSb. Below T_N=0.32K, a Kondo-frustrated antiferromagnetic ordering of the Yb^{3+} ions sets in. In the region 0.32K<T<5K, 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. As an antiferroquadrupolar ordering can only occur if the Γ_8 quartet is the ground state or if it is very close to a doublet (Γ_6 or Γ_7) ground state, experiments probing crystal field excitations could help elucidate the nature of the intermediate phase in YbSb.

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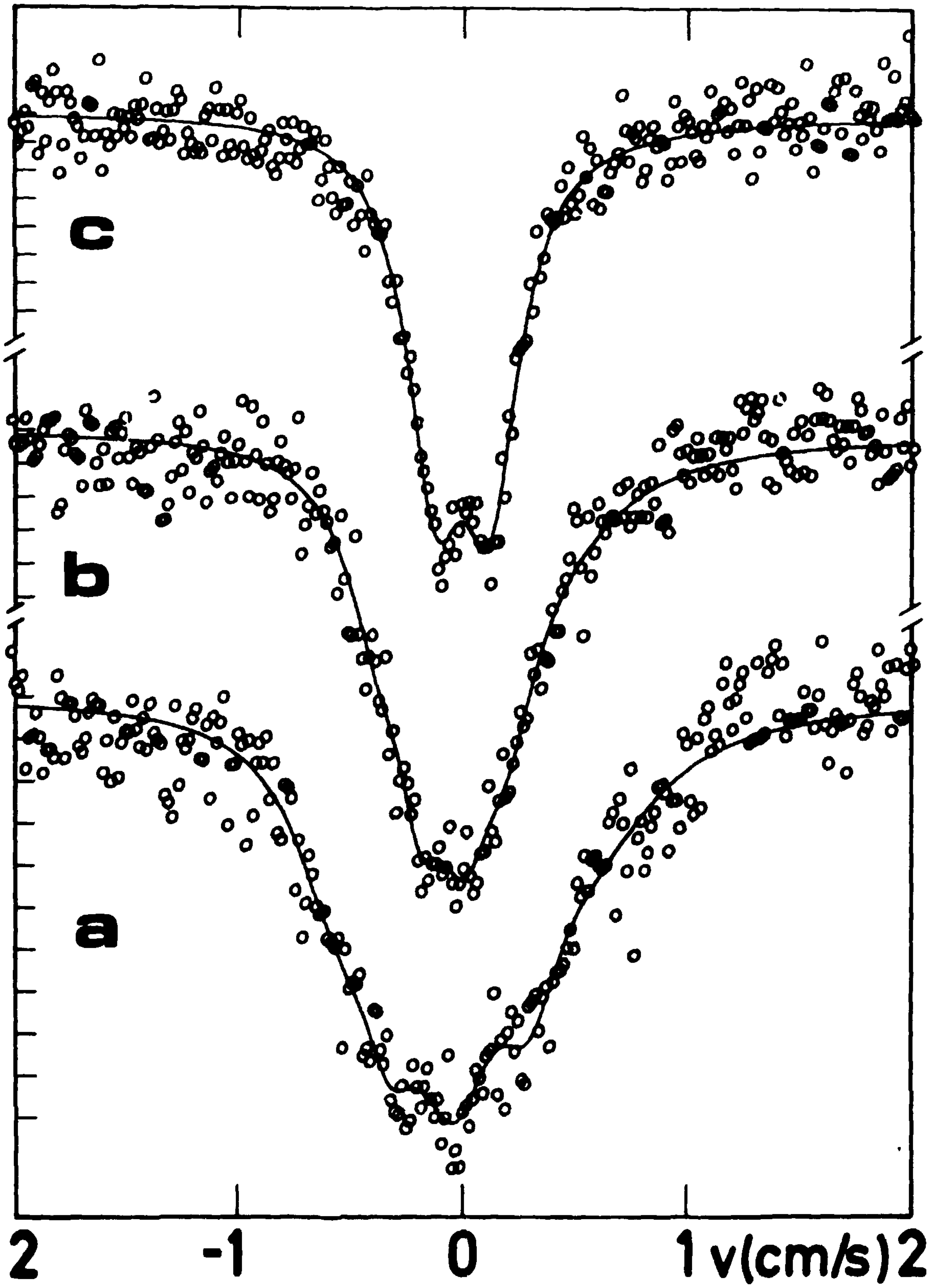
Figure captions

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

Fig.2 : Thermal variation of the Hall constant R_H.

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).


c
b
a
-2
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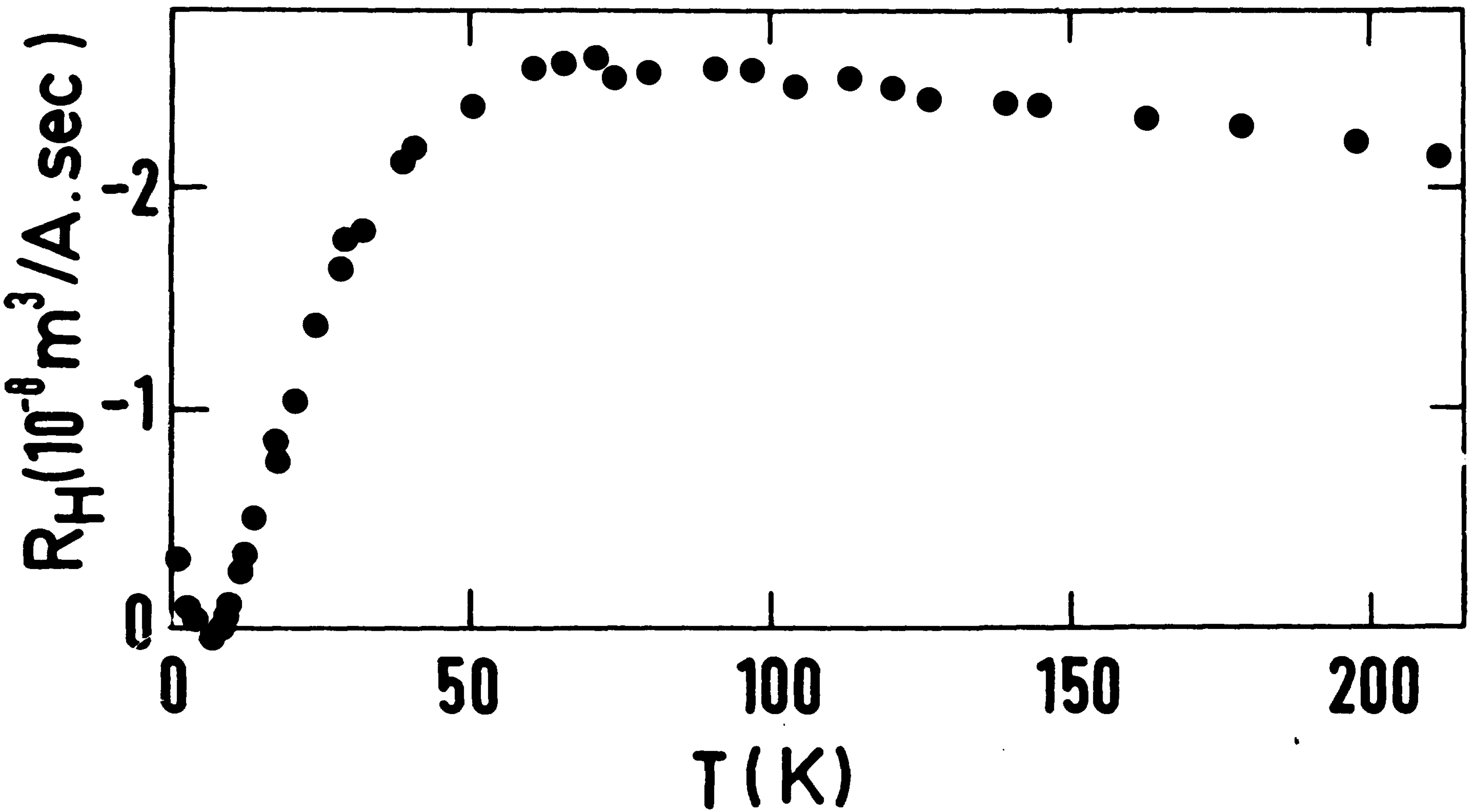

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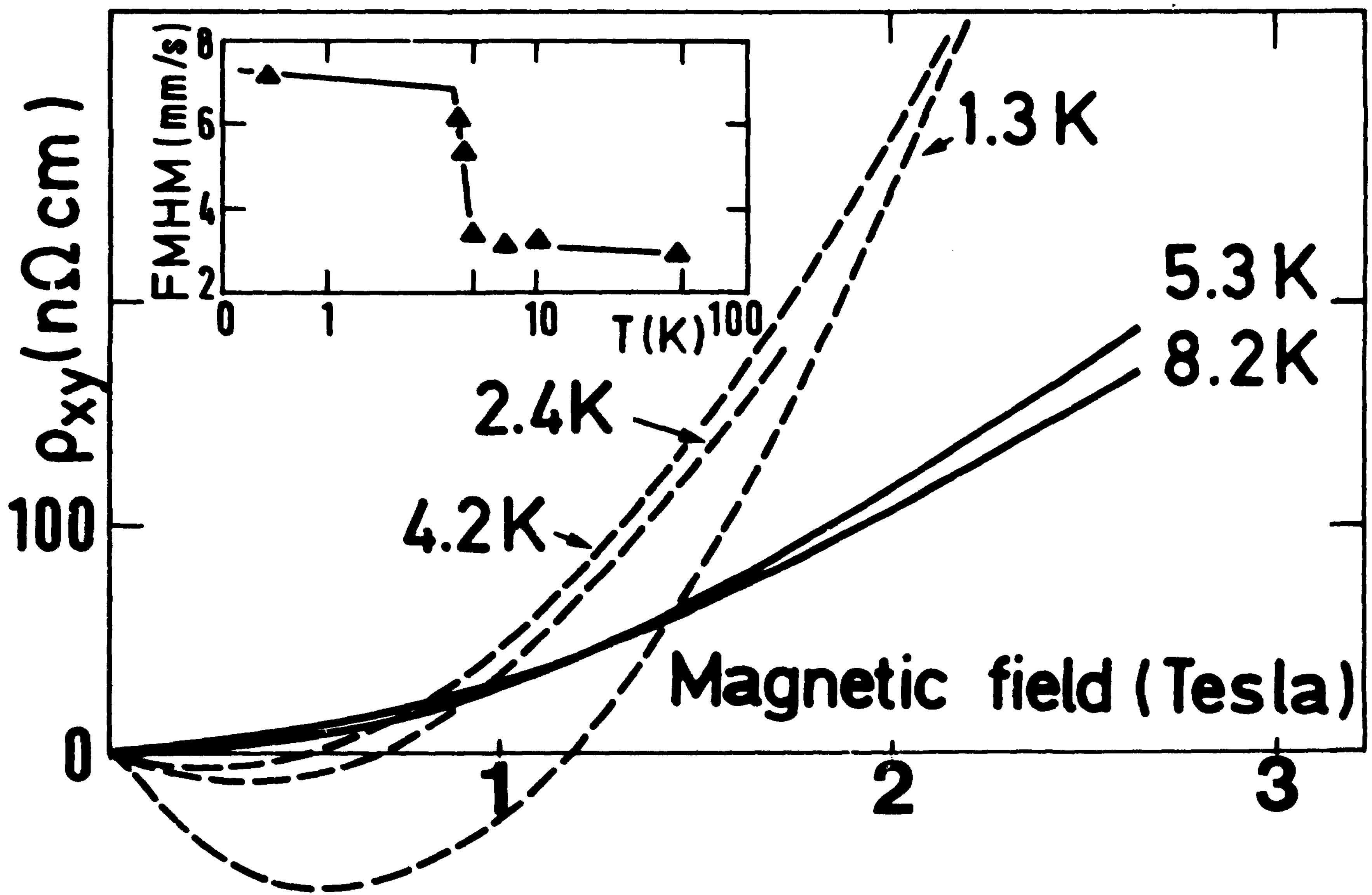

FMHM (mm/s)
8
6
4
2
0
1
10
100
T(K)
1.3 K
5.3 K
8.2 K
2.4K
4.2K
ρxy (nΩ cm)
100
0
Magnetic field (Tesla)
1
2
3