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Magnetotransport studies of the low-carrier-density semimetal CeP

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Abstract

The transverse magnetoresistance is measured up to 32 T for the field direction [0 0 1] as well as some other directions and the magnetic phase diagram is derived for each direction. The Hall resistivity is measured up to 26 T for the field direction [0 0 1]. Results indicate strong magnetic anisotropy and an appreciable change of the electronic structure at a magnetic phase transition. © 2000 Elsevier Science B.V. All rights reserved.

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CeP with the simple NaCl structure is a compensated semimetal with a low carrier density, in which electron and hole carriers originate from Ce 5d and P 3p states, respectively. It is also magnetic due to Ce 4 f localized moments. The strong interplay between the two subsystems, the carriers and local moments, gives rise to various intriguing phenomena (for a review see Ref. [1]).

The crystal-field ground state in the paramagnetic phase is Γ_7 with Γ_8 at about 150 K [2]. As the temperature is lowered, CeP exhibits two major transitions [3], which we shall call $F(\Gamma_8)$ and $AF(\Gamma_7)$. At the $F(\Gamma_8)$ transition, ferromagnetic double (0 0 1) layers appear periodically in the sea of paramagnetic ions [4]. The Ce ions in the ferromagnetic layers have a large moment of about 2 μ_B and hence they are believed to be in the Γ_8 state despite the large crystal-field splitting. The $AF(\Gamma_7)$ transition occurs at a lower temperature, when a type-I-like antiferromagnetic order with a Γ_7 compatible moment of 0.7 μ_B develops among the remaining ions with the ferromagnetic Γ_8 double layers intact [4]. Further, a series of metamagnetic transitions occurs with increasing fields in the ordered phases [5,6], which may be attributed to the change in the interval between the ferromagnetic double layers. In this work, we study those anomalous magnetic behaviors through magnetotransport measurements.

Fig. 1(a) shows transverse magnetoresistance (MR) traces at 20 K for four different field directions. For $H//[0\,0\,1](\theta = 0)$, the transverse MR is similar to the longitudinal MR [6], except an upturn above about 20 T. The upturn becomes steeper at lower temperatures and can be approximated by H^2 below 5 K. This behavior is consistent with a compensated metal in the high-field limit. The largest resistivity drop at 6.4 T is due to the $F(\Gamma_8)$ transition, while the other anomalies with hysteresis at higher fields are due to the series of metamagnetic transitions. All the transitions shift to higher fields as the field is tilted from [0 0 1]. Fig. 1(b) compares the phase diagrams thus determined for the four field directions. Note that the vertical axis is $H \cos\theta$, which is the [0 0 1] component of the applied field. The four phase diagrams look surprisingly similar, which indicates that the local moment in the Γ_8 layers sees only the [0 0 1] component

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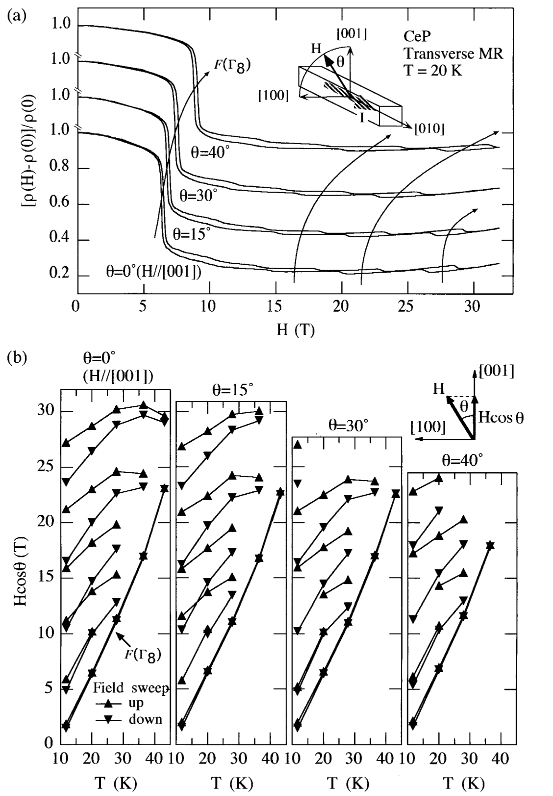

Fig. 1. (a) Transverse magnetoresistance in CeP at 20 K as a function of the field direction. The angular dependence of the $F(\Gamma_8)$ and some other transitions is indicated by arrows. (b) Comparison between magnetic phase diagrams for different field directions. Note that the vertical axis $H\cos\theta$ is the [0 0 1] component of the field.

of the applied field. The strongly anisotropic Γ_8 state contrasts sharply with the Γ_7 state appearing below the $AF(\Gamma_7)$ transition. The Γ_7 moments exhibit a spin-flop transition [4], which is typical of a weakly anisotropic system. The extreme uniaxial anisotropy of the Γ_8 states is reminiscent of CeSb, in which the origin of the anisotropy was identified as the anisotropic mixing interaction between the p-valence band and the Ce 4f state [7]. The present result indicates that the same mechanism is operative in the Γ_8 layers in CeP despite the much larger crystal-field splitting in CeP.

Fig. 2 shows Hall resistivity traces for various temperatures. The Hall constant ($R_H = \rho_H/H$) is -0.045 cm^3/C at 25 K and 1 T, which is in good agreement with a previous report [8]. Assuming the single carrier model, the carrier density is evaluated to be 0.007 electron/Ce. This figure seems a fair estimate, compared with the carrier density in CeSb, which was accurately determined from

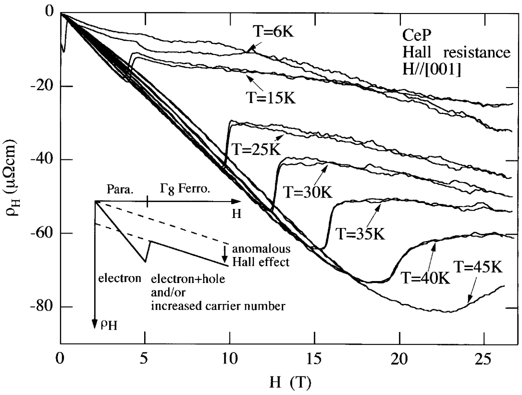

Fig. 2. Hall resistivity ρ_H with $H//[0\,0\,1]$ in CeP at various temperatures. The interpretation of the data is schematically given in the inset.

de Haas–van Alphen measurements to be 0.021 electron/Ce [9]. An intensive application of the single carrier model, however, may not be adequate in analyzing further details of the data. The Hall constant shows temperature- as well as field-dependence even in the paramagnetic phase (see traces for $T = 15$ K and above). Although the temperature dependence was previously attributed to change in the carrier number [8], it may be necessary to consider contributions from hole carriers and the anomalous Hall effect to account for those variations. The most prominent feature in Fig. 2 is the reduction of the absolute value of the Hall resistivity at the $F(\Gamma_8)$ transition and the smaller slope above the transition. The smaller slope may be attributed to an increase in the carrier density and/or enhanced hole mobility. This interpretation fits in with the magnetic polaron model which Kasuya et al. proposed to explain anomalous properties in CeP [8]. An extrapolation from the Hall resistivity above the $F(\Gamma_8)$ transition does not seem to go to the origin of the graph. The offset may be due to the anomalous Hall effect.

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