MAGNETISM AND SUPERCONDUCTIVITY IN $CeMIn_5$ (M = Rh, Co) SINGLE CRYSTALS *

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We report on the magnetic and superconducting properties of single crystals of the alloys $CeRh_{1-x}Co_xIn_5$ ($x = 0.0, 0.25, 0.5, 1.0$). For $x \leq 0.5$ we do not find any signature of superconductivity down to 1.6 K. The previously observed metamagnetic transition in $CeRhIn_5$ at 20 kOe is also present for small Co doping ($x = 0.25$), but disappears for $x = 0.5$. In the superconducting state, $CeCoIn_5$ shows hysteresis in the magnetisation versus field measurements which is typical of a type II superconductor, with the pinning predominantly controlled by surface and geometrical factors.

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1. Introduction

The new class of heavy fermion superconductors $CeMIn_5$ (M = Rh, Co) have attracted considerable attention due to their relatively high superconducting transition temperatures. The magnetism and superconductivity lie in very close proximity in these compounds and thereby provide a unique opportunity to investigate the role of magnetic interactions in the formation of the superconducting ground state. The compound $CeRhIn_5$ has been found to be a moderate heavy fermion with the linear term in the specific heat about 400 mJ/ mol-K [1]. It orders magnetically at 3.8 K with a c-modulated incommensurate spiral structure. $CeRhIn_5$ is also characterised by a metamagnetic transition below 3 K when a magnetic field of 20 kOe is applied parallel to the a–b plane [2]. Beyond a hydrostatic pressure of 16 kbar, a superconducting ground state emerges below 2.1 K with a sudden disappearance of the 3.8 K magnetic ordering. $CeCoIn_5$ shows superconductivity at 2.3 K in the ambient pressure condition [4].

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In order to investigate the evolution of the ground state properties under chemical pressure we have studied the magnetisation and transport properties of single crystals of the solid solutions $CeRh_{1-x}Co_xIn_5$ ($x = 0$, 0.25, 0.5 and 1). Coexistence of magnetism and superconductivity has been recently reported for the alloys $CeRh_{1-x}Co_xIn_5$ for $0.4 \leq x \leq 0.6$ [3]. The single crystals were prepared by a flux growth technique using excess indium flux [4]. Powder X-ray diffraction measurements on this tetragonal system of compounds show that with the replacement of Rh by Co, there is a contraction of the lattice parameters in the basal plane (a, b), while the lattice parameter in the c-direction increases. The lattice parameters (in Å) are found to be: (a, c) = (4.652, 7.542), (4.646, 7.545), (4.636, 7.546) and (4.620, 7.560) for $x =$ B0.0, 0.25, 0.5 and 1.0, respectively. The magnetisation measurements were carried out using an Oxford Instruments vibrating sample magnetometer and the resistivity was measured by a standard four-probe method.

2. Results and discussions

Figure 1 shows the magnetisation *vs.* field at 1.8 K for $x = 0.0$, 0.25 and 0.5 with the field parallel to the a-b plane of the single crystals. The magnetisation for all the compositions shows quasi-linear behaviour without any signature of saturation. For the composition $x = 0.0$, the step like anomaly around 20 kOe is due to the occurrence of a metamagnetic transition [2].

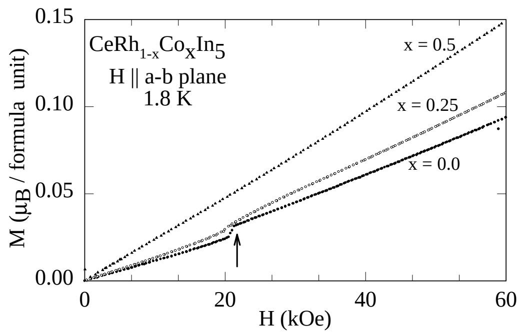

Fig. 1. Magnetisation (M) as a function of magnetic field (H) applied parallel to the a–b plane at 1.8 K for the compositions $CeRh_{1-x}Co_xIn_5$ ($x = 0$, 0.25, 0.5). The arrow marks the metamagnetic transitions.

In our measurement, this metamagnetic behaviour around 20 kOe is also present for the $x = 0.25$ compound, but the anomaly is rather weak when compared to the pure Rh compound. This anomaly ultimately disappears completely for the $x = 0.5$ composition. The free electron mediated indirect exchange term is dependent on the inter atomic spacing. Therefore, the increase in the lattice parameters in the c-direction with x can change the magnetic interactions and thus modify the metamagnetic behaviour. We have measured the magnetisation carefully around the metamagnetic transition point with different field ramping rates. We have not observed any hysteresis around the transition point within the accuracy of our measurements. This signifies that the metamagnetic transition is not a first order like transition. The magnetisation measurements in the direction parallel to the c-axis show a monotonously increasing behaviour without any signature of metamagnetic behaviour in any of these compositions.

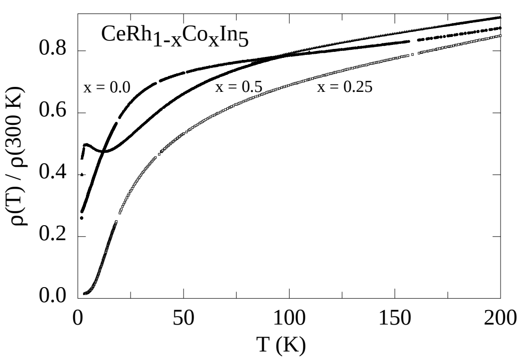

Fig. 2. Electrical resistivity (ρ) as a function of temperature (T) in the a–b plane for CeRh$_{1-x}$Co$_x$In$_5$ ($x = 0$, 0.25, 0.5). The $x = 0.5$ data shows Kondo-like minimum around $T = 15$ K.

We have also measured the resistivity and magnetic susceptibility as a function of temperature for these CeRh$_{1-x}$Co$_x$In$_5$ compounds. For the compositions $x \leq 0.5$ we do not see any signature of superconductivity down to 1.6 K. The resistivity *vs.* temperature behaviour changes significantly with the Co substitution (see figure 2). For $x = 0$ and 0.25, a monotonous fall of resistivity below 100 K is observed, whereas for $x = 0.5$ there is a distinctive Kondo-like minimum around 15 K, followed by a drop at lower temperatures. The $x = 1$ compound is also characterised by a shallow Kondo minimum but at a much higher temperature (150 K) [1]. This clearly indicates that the system increasingly shows *single ion Kondo behavior* with the substitution of Rh by Co. The high pressure resistivity measurements on CeRhIn$_5$ show a gradual occurrence of Kondo-like minimum with increasing hydrostatic pressure [1]. Therefore, the observed changes in the resistivity behaviour with x are consistent with the application of chemical pressure.

We have investigated the low field behaviour of the magnetisation of $CeCoIn_5$ in its superconducting state (see figure 3). The magnetisation loops below the superconducting transition temperature of 2.3 K show hysteresis behaviour typical of a type II superconductor. The value of the lower critical field, calculated from the magnetisation data for fields in the a-b plane, is found to be around 25 Oe at 1.5 K. The most interesting observation in the low field measurements is the *signature of flux jumps* in the magnetisation data. These flux jumps are only observed while the field is ramped up. The flux jumps are also seen in the measurements parallel to the c-axis (data not shown here). In addition, the flux jumps are almost absent in the magnetisation data below 1.7 K. This indicates that there is some difference in the pinning mechanism above and below 1.7 K. The magnetisation loops are also asymmetric with respect to the $M = 0$ axis (see figure 3). This and the observation of flux jumps suggest that the magnetisation behaviour at low field is dominated by surface and geometrical barriers rather than bulk pinning (at least for $T \geq 1.7$ K).

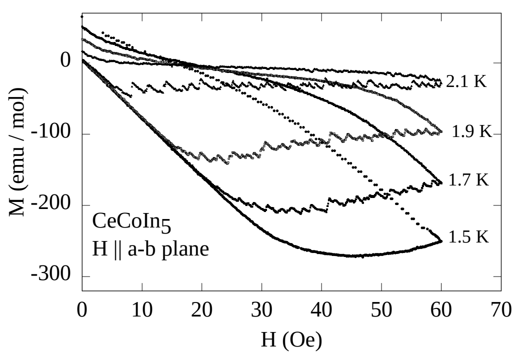

Fig. 3. Low field magnetisation (M) *vs.* magnetic field (H) loops of $CeCoIn_5$ at different temperatures with field along the a–b plane.

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