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Electronic transport in $Ce_3Bi_4Pt_3$: evidence for a temperature-dependent hybridization gap

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Abstract

We present an analysis of transport data from $Ce_3Bi_4Pt_3$ to determine the energy gap temperature dependence $E_g(T)$. $E_g(T)$ is a decreasing function of temperature. This result is consistent with the gap being a product of many-body correlations in which $E_g(T)$ is scaled by the Kondo energy scale T_K.

$Ce_3Bi_4Pt_3$ is a narrow-gap Kondo insulator [1] in which the energy gap results from band hybridization driven by many-body effects. Mean-field treatments [2, 3] of the Anderson lattice Hamiltonian suggest that the gap should be a decreasing function of temperature scaled by T_K. In this note we present the results of an analysis of the energy gap $E_g(T)$ as determined from the resistivity ρ and thermoelectric power S of $Ce_3Bi_4Pt_3$. The analysis indicates that E_g is strongly temperature-dependent above 50 K, dropping close to zero at 300 K. As the gap shrinks above 100 K, single-impurity Kondo (SIK) scattering becomes evident in the resistivity. Upon comparing $E_g(T)$ with bulk modulus B and pressure-dependent $E_g(P)$ data, a single energy scale (T_K) appears to govern both $E_g(T)$ and the thermal expansion β.

The ρ and S of $Ce_3Bi_4Pt_3$ are plotted in Fig. 1. With a temperature-independent gap and electron-phonon (EP) scattering, both data sets would appear as straight lines in Fig. 1; in both cases, the slope, and therefore E_g, drops with increasing temperature. Some curvature is also expected because this material is an extremely degenerate semiconductor (i.e., $E_g \sim k_B T$). Therefore, a careful quantitative analysis employing degenerate semiconductor statistics [4] is required to determine $E_g(T)$. We model the system as involving two wide parabolic bands separated by $E_g(T)$; this is a reasonable assumption for the lower and upper hybridized bands away from the Brillouin zone edge. In addition, we assume that EP scattering predominates. The results of a degenerate semiconductor analysis with these assumptions are presented in Fig. 2, along with a mean-field prediction [3]. $E_g(T)$ is a decreasing function of temperature, as expected for a gap produced by many-body effects. Further, the gaps determined from ρ and S are equivalent; this is an indication that the assumption concerning scattering is valid since ρ and S are affected by EP scattering in fundamentally different ways. Above 100 K the uncertainty in the gap determined from S increases, but it still consistent with a shrinking gap. Despite considerable scatter in E_g above 100 K as determined from ρ, the gap appears to saturate to $E_g = 70$ K. This is an artifact of the assumption that only EP scattering is present. It suggests that SIK scattering develops as the gap shrinks with increasing temperature.

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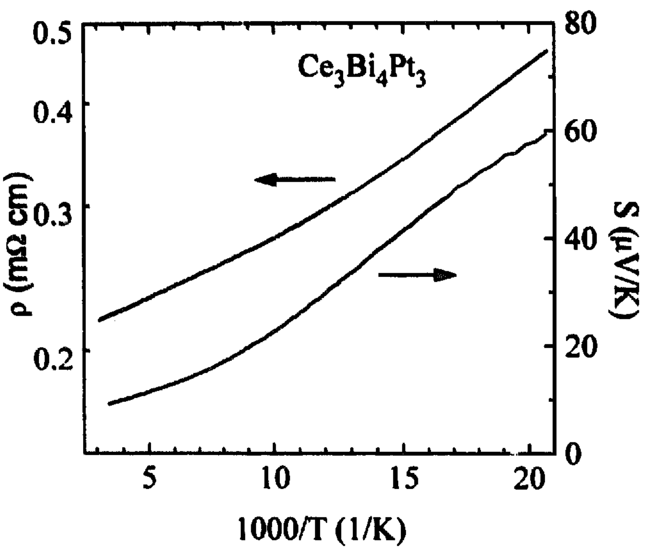

Fig. 1. Log$_{10}$ ρ and S plotted as a function of $1/T$. In both cases the slope drops with increasing temperature, indicating that E_g is a decreasing function of temperature.

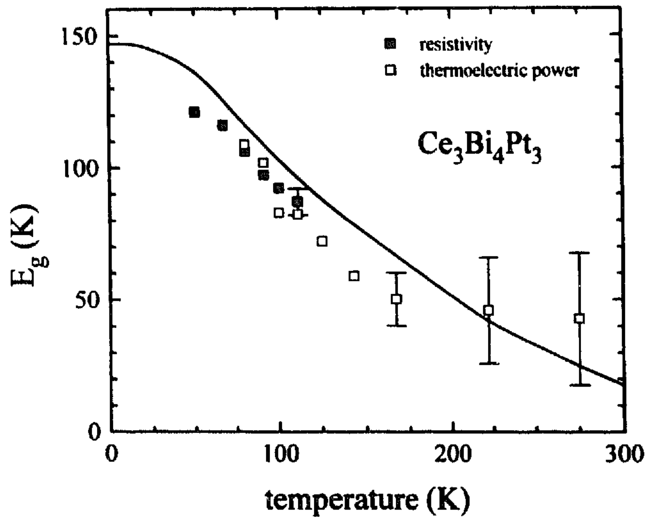

Fig. 2. $E_g(T)$ as determined from analyses of ρ (filled squares) and S data (open squares). The solid line is a mean-field prediction [3] based on the Anderson lattice Hamiltonian.

SIK scattering involves electrons in an Abrikosov–Suhl resonance of width T_K near E_F. With a wide gap centered at E_F no scattering occurs. As the temperature is raised and E_g falls well below T_K, a partially gapped resonance will develop; therefore, SIK scattering should become evident as the temperature is raised. Preliminary high-temperature ρ measurements suggest that the gap disappears above 350 K and Ce$_3$Bi$_4$Pt$_3$ acts as an SIK metal.

The volume thermal expansion β of Ce$_3$Bi$_4$Pt$_3$ also displays a temperature dependence dominated by many-body effects [5]. If the temperature dependence of β and E_g result from hybridization driven by correlations they must be quantitatively interconnected. We can ensure that the gap scales with the thermal expansion by comparing $E_g(T)$ with bulk modulus and pressure-dependent gap $E_g(P)$ measurements. With a bulk modulus $B \approx 900$ kbar, the thermal contraction at 4 K relative to 300 K is equivalent to 14.4 kbar pressure [5]. With $\partial E_g/\partial P \approx +11 \pm 6$ K/kbar [1], the expected increase upon cooling from 300 K to 4 K is $\Delta E_g = +160 \pm 90$ K; despite the crude nature of this calculation it is in good qualitative agreement with the data in Fig. 2. This quantitative consistence is a manifestation of the fact that all physical quantities controlled by many-body interactions in Ce$_3$Bi$_4$Pt$_3$ are fundamentally interrelated and their respective temperature dependencies are scaled by the Kondo energy scale T_K.

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