The heavy fermion system CeCoIn$_5$ displays several interesting properties in its superconducting state. These include the FFLO state in an in-plane magnetic field $H$, a large Nernst signal observed at temperatures $T < 30$ K, an in-plane resistivity that is $T$-linear below 20 K, and a Hall coefficient that is strongly temperature-dependent. Recently, Kasahara et al. measured the thermal conductivity $\kappa_{xx}$ and Hall conductivity $\kappa_{xy}$ and inferred a long quasiparticle mean-free-path $\ell$ below $T_c = 2.2$ K.

In CeCoIn$_5$, the thermal conductivity $\kappa_{xx}$ and Hall conductivity $\kappa_{xy}$ below $T_c$ display large anomalies below $T_c$. The strong suppression of the anomalies in weak fields implies the existence of low-lying quasiparticles. We also discuss briefly the Wiedemann-Franz ratio and the existence of a strongly field-dependent spin-fluctuation heat current.

![Figure 1](image.png)

**FIG. 1:** (Panel a) The $T$ dependence of the in-plane thermal conductivity $\kappa$ in $H = 0$ in CeCoIn$_5$. The anomaly below $T_c$ is 4–5 times larger than in earlier reports. (Panel b) The field dependence of $\kappa$ at selected $T$ below $T_c$. With decreasing $T$, the zero-field anomaly rises to a sharp, narrow peak. At $H_{c2}$, $\kappa$ displays a kink or step.

We report measurements of $\kappa_{ij}$ in crystals of CeCoIn$_5$ with exceptionally long $\ell$. Figure 1 shows $\kappa(T,0)$ at $H = 0$. Below $T_c$, $\kappa(T,0)$ rises steeply to a prominent peak at 1 K, reminiscent of the peak in high-purity YBCO. As shown in Fig. 1, the peak anomaly $-4-5$ times larger than in Ref. is extremely sensitive to $H||c$. Above $T_c$, the curve of $\kappa$ displays moderately strong field dependence. Below $T_c$, however, a sharp quasiparticle peak develops at $H = 0$ and rises rapidly. The narrow spike in $\kappa$ which reflects the strong suppression of the qp heat current in weak fields. The narrow spike is absent in earlier experiments. In the normal state above the upper critical field $H_{c2}$ (indicated by the step increase), $\kappa$ remains strongly $H$ dependent.

The thermal Hall conductivity $\kappa_{xy}$ detects the qp heat current of alone. Above 20 K, $\kappa_{xy}$ is nearly $H$-linear to 12 T, as expected of weak-field Hall response. As $T$ falls towards $T_c$, strong curvature becomes evident below 1 T, while the initial Hall slope increases sharply. Between $T_c$ and 0.5 K, a new anomaly appears in weak $H$ which is the Hall analog of the narrow spike in $\kappa$. In weak $H$, $\kappa_{xy}$ rises very steeply to a peak centered at 0.1–0.2 T before falling to a “plateau” value. Above $H_{c2}$, $\kappa_{xy}$ increases steeply once more to large values.

The unusual behavior of $\kappa$ and $\kappa_{xy}$ reveal several interesting low-$T$ features in both the vortex state and the state above $H_{c2}$ at low $T$. Below $T_c$, the strong sensitivity of $\kappa$ and $\kappa_{xy}$ to weak $H$ shows that the large thermal anomaly shown in Fig. 1 is entirely electronic in origin. It reflects the steep increase in $\ell$ below $T_c$. Moreover, the persistence of a large $\kappa_{xy}$ far below $T_c$ requires a sizeable qp population, which implies the existence of line nodes on the Fermi Surface. This was previously inferred from the 4-fold variation of $\kappa$ and the heat capacity $c_p$ with field angle in crystals with higher degree of disorder.

The curves of $\kappa_{xy}/T$ below $T_c$ (Fig. 2) show that the qp behavior is qualitatively distinct in the vortex-solid state below $H_{c2} \approx 5$ T, and in the normal state above. In the former, $\kappa_{xy}/T$ assumes a profile that is $T$ independent below 1 K. Interestingly, at the lowest temperatures (0.5–1 K) the value of $\kappa_{xy}/T$ is independent of $T$ to within...
FIG. 2: Curves of the thermal Hall conductivity divided by $T$, $\kappa_{xy}/T$ vs. $H$. Below 1 K, $\kappa_{xy}/T$ saturates to a $T$-independent profile with a prominent anomaly in weak $H$ (inset). At low $T$, $\kappa_{xy}/T$ sharply increases above $H_{c2}$ (step feature).

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