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Nernst effect in CeCu_2Si_2

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Abstract.

We report on an ongoing multiprobe experiment on a very high purity CeCu_2Si_2 single crystal at ambient and high pressure. The Nernst signal, which has not been measured in this compound so far, exhibits quite uncommon features and seems to be coupled to the antiferromagnetic phase, rather than to the vortex motion within the superconducting mixed state.

Although the superconducting state of CeCu_2Si_2 has been discovered thirty years ago [1], its nature is not yet fully understood and a lot of activity is still going on in order to understand the complex low temperature $H - T - p$ phase diagram of this compound [2–4]. At $p = 0$ the ground state of CeCu_2Si_2 depends strongly on the exact stoichiometry of each sample [3; 5; 6]. Silicon rich samples show an antiferromagnetic ground state (A-type samples), copper rich samples have a superconducting ground state (S-type samples) and in high quality 1:2:2 samples antiferromagnetism and superconductivity compete (A/S-type samples). Under a pressure of about 0.2-0.3 GPa the antiferromagnetic phase disappears [7; 8] and an increase of the superconducting transition temperature T_c from about 0.7 K up to over 2 K is observed at $p > 2$ GPa [9]. Antiferromagnetic fluctuations at ambient pressure [10] and valence fluctuations around the maximum T_c (4.5 GPa) [11] are commonly thought to provide the superconducting pairing glue.

The main motivation of our work is to better understand the nature of the superconducting state of CeCu_2Si_2 by performing different magneto-transport measurements on the same sample at ambient and high pressure. Particular attention is put on the Nernst effect, a probe already proven to be useful for studying exotic states in correlated electron systems [12; 13]. Here we present brand-new results of the Nernst effect at ambient pressure.

A multiprobe set-up has been designed, which allows us to measure the electric resistivity ρ , the thermopower S , the transverse Hall resistivity ρ_{xy} , the Nernst coefficient ν and the ac specific heat C_p on a single sample. However, its geometry has been optimized for measuring ν and ρ_{xy} . The ambient pressure set-up can be transferred without modification into a Bridgman-type pressure cell. High pressure measurements are currently under way. The current is injected along the a-b plane of the sample and the magnetic field is applied perpendicular to that plane. Measurements are performed in a He^3/He^4 dilution fridge between about 100 mK and 4.5 K. A high purity single crystal of A/S-type CeCu_2Si_2 and with a size of $600(l) \times 576(b) \times 25(w)$ μm^3 is used for the present study. The sample comes from a batch already used earlier by our group [14]. At ambient pressure, it has a T_c of 780 mK and a large residual resistivity ratio of 18. Throughout this communication T_c is determined by the vanishing of ρ . The Néel temperature T_N , as determined by the ac specific heat measurements, roughly coincides with T_c . Under field,

superconductivity is completely suppressed at around 2.5 T and T_N decreases to about 0.6 K at 5 T, in accordance with previous reports [7; 15].

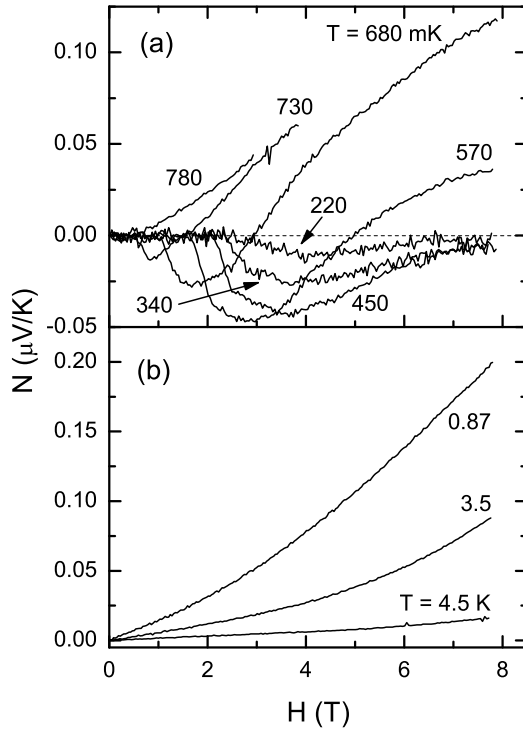


Figure 1. The Nernst signal N as a function of the applied magnetic field. **a** Measurements below the zero field T_c , **b** measurements above the zero field T_c .

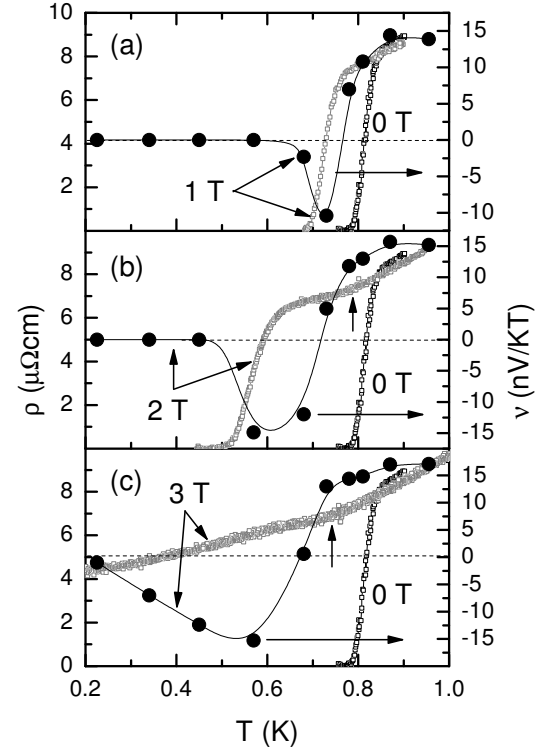


Figure 2. The Nernst coefficient $\nu = N/B$ and resistivity ρ as a function of temperature at different magnetic fields. In all plots, the zero field resistivity curve is shown as a reference. The thin black line is a guide to the eye and the horizontal dashed line indicates the zero of ν . The vertical arrows in **b** and **c** show T_N .

Fig. 1 shows the Nernst signal N as a function of an external magnetic field H for various temperatures. N is the transverse electric field generated by a longitudinal temperature gradient $\partial_x T$ ($N = E_y / |\partial_x T|$). The Nernst signal is antisymmetrised with respect to H and its sign is defined according to the so-called vortex convention, which is based on the Josephson equation $E \parallel (H \times (-\nabla T))$ for moving vortices [16]. In this convention the Nernst signal generated by moving vortices is positive. The Nernst signal of CeCu_2Si_2 exhibits rather uncommon features. A first look at Fig. 1 shows that the overall magnitude of N is quite small ($N \leq 200$ nV/K), at least compared with another heavy fermion compound, CeCoIn_5 [13; 17]. As expected, N is zero below the corresponding superconducting critical fields (Fig. 1a). Above the critical fields, N is negative, and with further increasing field, N goes through a minimum before changing sign. At the lowest temperatures, N stays negative up to the highest fields. Above T_c (Fig. 1b) N is positive throughout the whole explored field range and exhibits a positive curvature. It is worth noting that the curvature of N changes to negative for lower temperatures and fields higher than the minimum of N (Fig. 1a).

Fig. 2 shows the temperature dependence of the Nernst coefficient $\nu = N/H$ and of the resistivity ρ for 1, 2 and 3 T below 1 K. The Nernst coefficient has a prominent maximum around

900 mK before dropping at higher temperatures (not shown, as can be inferred from Fig. 1 b). On decreasing the temperature, it changes sign, goes through a field dependent minimum and becomes zero in the superconducting state. As seen in Fig. 2 c, above the resistive upper critical field $H_{c2}(0)$ of about 2.5 T, ν diminishes to small but non zero values at low temperatures. One also observes a large broadening of the negative peak of ν with increasing field.

In order to shed light on this complex Nernst signal, a closer look at the H-T phase diagram of CeCu_2Si_2 is necessary [6; 15]. Below T_c the superconducting phase exists up to a field of roughly 2.5 T. On further increasing field one enters the antiferromagnetic A-phase, which extends up to about 7 T. Now, a close look at Fig. 2 suggests that the Nernst signal has two main contributions: a positive one, which peaks around 900 mK, and a negative one which becomes dominant below that temperature. Interestingly, the signal below T_c may be best described by being related to the A-phase rather than to vortices or superconducting fluctuations [18]. It is well known that in the superconducting mixed phase moving vortices can generate a large Nernst signal [19]. The sign of the Nernst signal generated by such moving vortices is well defined and would be positive in the sign convention used in this experiment. However in CeCu_2Si_2 the sign of the Nernst signal below T_c is negative, a clear indication that the vortex contribution to N is either absent or small compared to the contribution arising from the A-phase. Fig. 2 c corroborates this conclusion. At 3 T, e.g. above the upper critical field and well inside the A-phase, the negative contribution to N is still present, of the same order of magnitude as at lower fields, and appears already at the lowest temperatures since it is not shunted by the superconducting condensate. Furthermore, the temperature dependence of ν at 2 T (Fig 2 b) clearly demonstrates that the sign change in $\nu(T)$ is much better linked to T_N (indicated by the small vertical arrow) than to the superconducting transition. This correspondence holds for all temperatures, where $N(H)$ has been measured. Finally, the A-phase is readily destroyed by pressure [7; 8] and therefore, if the assumption of a Nernst signal arising from the A-phase is correct, one would expect a drastic change in the behavior of $N(T, H)$ with pressure. Preliminary results at 2 GPa do indeed show a more “conventional” Nernst signal, which is positive throughout the whole investigated temperature and field range.

In conclusion, the first low temperature Nernst data at ambient pressure in CeCu_2Si_2 reveal unexpectedly a predominant negative contribution from the A-phase, rather than a signature of the vortex state. Not yet understood is the behavior of the positive Nernst signal in the paramagnetic phase, in particular its maximum and subsequent drop above 1 K leading to a rather small value at 4 K. Measurements at higher temperatures and in other Ce compounds are necessary in order to elucidate the uncommon features of the Nernst signal further, especially in the light of a generic Nernst behavior in heavy fermion systems.

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