

Transport properties in the unconventional superconductor CeRh₂As₂ under extreme condition

Level : M1

General Scope: CeRh₂As₂ is a compound that has attracted significant attention since the discovery of two distinct superconducting phases within it in 2021. Until then, this feature had only been observed in a few uranium-based compounds such as UBe₁₃, UPt₃, and UTe₂. The H–T phase diagrams of CeRh₂As₂ for a magnetic field H applied along two different crystallographic directions are shown in Fig. 1a.

For **H ∥ c**, magnetic susceptibility and

dilatometry measurements clearly revealed a transition line at **H* = 4 T** between two superconducting phases: a low-field phase SC1 (**T_c = 0.35 K**) and a high-field phase SC2. The SC2 phase strongly exceeds the Pauli limit (**H_{c2} = 16 T**) and is therefore non-conventional in nature, possibly spin-triplet, whereas the SC1 phase is possibly spin-singlet. In contrast, for **H ⊥ c**, only the SC1 phase is observed, with a much lower upper critical field of only 2 T. The shape of the CeRh₂As₂ phase diagram can be quantitatively explained by its crystallographic structure (Fig. 1b), which locally breaks inversion symmetry at the cerium sites. This locally non-centrosymmetric structure allows for the presence of a spin-orbit interaction known as the Rashba interaction, which could explain both the anisotropy of the phase diagram and the presence of two distinct phases for **H ∥ c**. However, studies of the parent compound LaRh₂As₂, which has the same crystallographic structure but lacks 4f electrons, show only a single conventional superconducting phase. Thus, the magnetism arising from the localized 4f electrons of the cerium atoms likely plays an important role in the superconducting mechanism of CeRh₂As₂. Moreover, dilatometry, specific heat, magnetic susceptibility, and magnetization measurements have also revealed two normal (non-superconducting) phases within the compound. The first phase (I) is present in both directions below a critical temperature **T₀ = 0.5 K** and coexists with the two superconducting phases for magnetic fields below **H₀ = 7 T** when **H ∥ c**. For **H ⊥ c**, above a critical field **H_{cr} = 9 T**, another ordered state (phase II) appears and is strengthened by the magnetic field, without disappearing in any of the studies published to date. The nature of these two normal phases and their interaction with the superconductivity of CeRh₂As₂ remain under debate. An antiferromagnetic order has been detected for **T < T₀** by muon spin resonance (μSR) and by nuclear magnetic resonance (NMR), and various theoretical proposals involving multipolar charge orders that qualitatively reproduce the phase diagram have been put forward. Thus, studying these normal phases — whose nature is partly magnetic — could help to understand the exotic superconductivity of CeRh₂As₂.

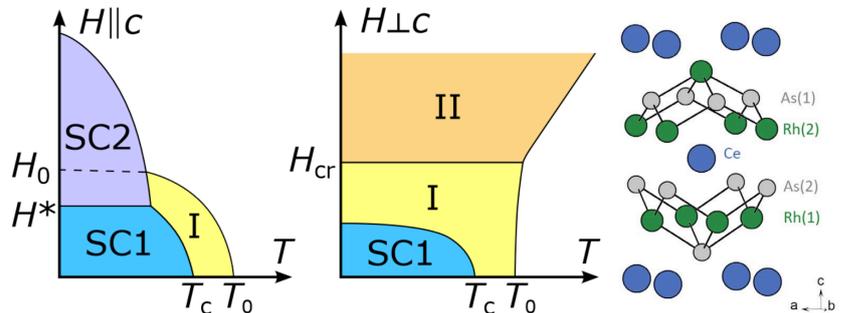


Fig1: a) Schematic phase diagram of CeRh₂As₂ for two different magnetic field directions. The numerical values of the various quantities are given in the text (b) Locally non-centrosymmetric crystal structure of CeRh₂As₂.

Research topic and facilities available : We propose an experimental and fundamental research project which will explore the phase diagram of CeRh₂As using different transport (resistivity, thermoelectricity) and thermodynamic measurements (specific heat) under extreme conditions (low temperature, high magnetic field and high pressure), to characterize this material, understand the different competing orders present.

Required skills : A strong interest for quantum materials and for challenging experiments and questions in condensed matter physics is required. Of course, no prior experiment in low temperature physics or strongly correlated systems is expected at the M1 level, this will be discovered during the interns

Starting date and duration : Week 21 (May 18 2026), 8 weeks minimum

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