Strongly Correlated Electron States in Praseodymium Alloys

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There is a great scientific and practical interest in materials where strong interactions among electrons lead to new states of matter (strongly correlated electron states) and novel behaviors. Such a novel and unexpected behavior was recently discovered among some metals containing Praseodymium, most notably $PrOs_4Sb_{12}$. Our goal was to determine the ionic configuration of Pr, which could provide important information about the origin of this behavior. We have performed investigations of $PrOs_4Sb_{12}$ at very high magnetic fields, available at the National High Magnetic Field Laboratory, and determined its magnetic phase diagram, i.e., phases that exist at a given temperature and field (Fig. 1). This phase diagram allowed us to unambiguously determine the ionic state of Pr. Our work has severely restricted the number of possible theoretical models of the correlated electron state and exotic superconductivity. It has also provided important information on how to search for other examples of this novel behavior.

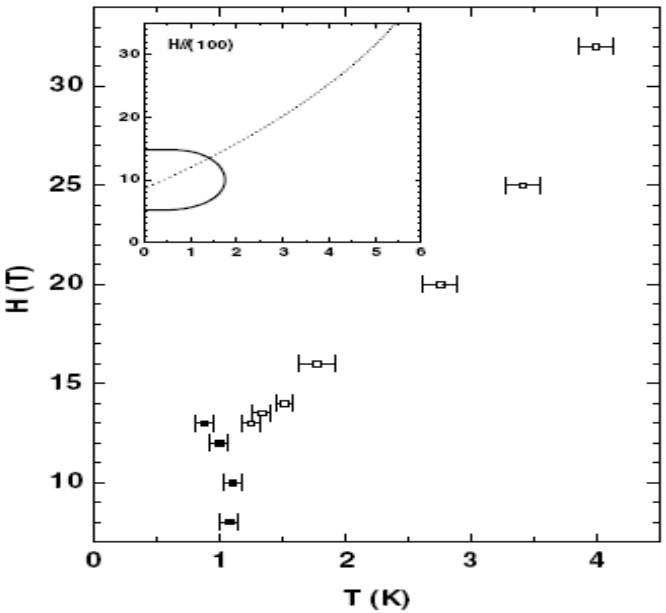

Fig. 1. Magnetic phase diagram of $PrOs_4Sb_{12}$

1. C. R. Rotundu et al., Phys. Rev. Lett. **92**, 037203 (2004).

Strong electron interactions in metallic systems lead to exotic behaviors and new states of matter, referred to as strongly correlated electron states. These strongly correlated electron states are critically important to theoretical condensed matter physics since they depict main deficiencies of current theories and models of condensed matter. From the practical point of view these strongly correlated electron systems are a source of many unpredictable discoveries that can find practical applications. A new class of behaviors has been recently found among some Praseodymium containing alloys. The model material, which most clearly shows this novel behavior, is $PrOs_4Sb_{12}$. We have provided an important insight into the nature of this phenomenon by investigating $PrOs_4Sb_{12}$ at very high magnetic fields. By measuring specific heat we have constructed a phase diagram (phases that exist at a given temperature and field) of this system. Our analysis of these phases lead us to conclude a specific ionic state of Pr that excludes a number of previously postulated models of this state and suggests a new theoretical scenario. This new theoretical model is currently tested on alloys chemically related to $PrOs_4Sb_{12}$.

These results were published in the Physical Review Letters; another article on this research has been submitted to the Physical Review Letters.

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Education

A high school student participating in the University of Florida Student Science Training Program, a graduate student (Costel Rotundu), and a postdoctoral associate (Hiroyuki Tsujii) were involved in this project. They have gained experience in the synthesis of single-crystalline samples and were exposed to a wide range of measurements involving very low temperatures and magnetic fields to 32 T. H. Tsujii has since accepted a position of an Assistant Professor at the Low Temperature Physics Laboratory, RIKEN, Wako, Saitama, Japan. Costel Rotundu will participate in the Summer School on Neutron Scattering organized by the Argonne National Laboratory.

Broader impact

Investigated materials have enormous significance to modern theoretical condensed matter physics and have great potential for practical applications. They have been identified among the most promising materials for future thermoelectric applications. Environmental concerns are behind strong efforts to replace compressor-based refrigeration technologies by the “clean” technologies based on the thermoelectric effect (cooling by electrical current).