MAGNETIC RESONANCE STUDIES OF STRONGLY-CORRELATED ELECTRON METALS

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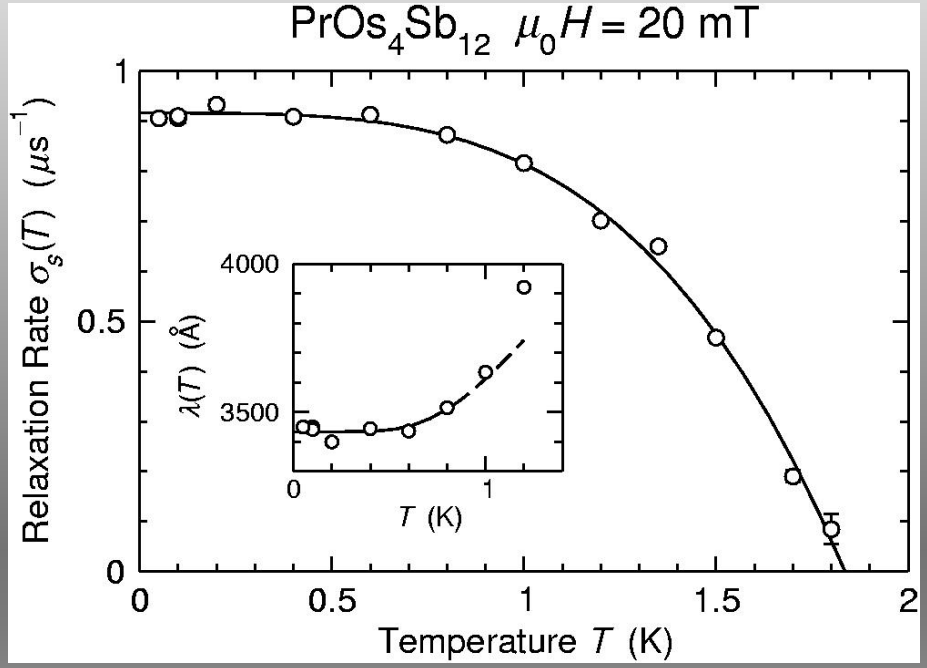
Magnetic Resonance in Strongly Correlated Electron Metals. Our group carries out nuclear magnetic resonance (NMR) and muon spin rotation (μSR) studies of electronic structure, superconductivity, and magnetism in materials in which strong correlations between electrons are important. μSR is conceptually similar to NMR, but the detection techniques are very different and the two methods are complementary in the study of local magnetism in solids. Many correlated-electron materials will be useful for future technologies, and fundamental knowledge of their properties is essential for technological progress.

Heavy-fermion materials, while not directly useful technologically, are test beds for studies of correlated-electron behavior. In these metals electron correlations increase the effective mass of the conduction electrons enormously, sometimes by as much as a thousand times. Heavy-fermion systems exhibit a wide variety of exotic forms of superconductivity and magnetism.



Nonmagnetic Heavy-Fermion Superconductivity. In "normal" heavy-fermion superconductors electron spin magnetism plays an important role. In the recently discovered "filled skutterudite" heavy-fermion superconductor $PrOs_4Sb_{12}$ this magnetism is quenched, leading to an entirely new form of heavy-fermion superconductivity. We are carrying out μSR studies of these materials to understand how the electrons remain "heavy" without magnetism, and how these electrons form a heavy-fermion superconducting state.

Our measurements show that the behavior of $PrOs_4Sb_{12}$ appears remarkably "conventional" for a heavy-fermion superconductor. The muon relaxation rate, a measure of the spread in magnetic fields inside the superconductor, is expected to vary more strongly at low temperatures than we observe (see figure). This behavior tells us that the superconducting state is *robust*, or not easily broken up. Understanding the origins of this robustness may help in future applications.

Electrical current is carried through a metallic conductor by electrons that are free to move between the atoms of the metal. Collisions between these *conduction electrons* and imperfections in the crystal structure of the metal lead to dissipation of the electrons' energy, which gives rise to electrical resistance. The lost energy reappears as light and heat in incandescent light bulbs and electrical heaters, for example.

Superconductors are metals that have completely lost their resistance. Superconductivity usually occurs only at very low temperatures, but the recently discovered *copper oxides* become superconducting at temperatures that, while still low, are hundreds of times higher than more conventional superconductors such as tin and lead. With high-temperature superconductors many technological applications become imaginable that would be too expensive if ultra-cold refrigerators were required.

But a basic understanding of the phenomenon of high-temperature superconductivity has proved to be very difficult, because the electrons in the copper oxides interact with each other much more strongly than in conventional superconductors. Similar strong electron correlations show up in other superconductors, in particular in heavy-fermion superconductors. These materials have lower superconducting temperatures (about 1.8 kelvin for $PrOs_4Sb_{12}$), but their superconductivity is still complicated and poorly understood. A broad-based attack on a wide range of correlated-electron superconductors is thought by many to be a good strategy for solving this important problem in the physics of metals. Our NMR and μSR studies of correlated-electron materials are part of this effort.

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Low-temperature solid-state NMR/μSR at UC Riverside. Left to right: Mark Rose, Doug MacLaughlin, Anika Bosse, Lei Shu, in the UCR Physics Department NMR lab. Mark recently obtained his Ph.D. with a dissertation on NMR in a non-Fermi liquid heavy-fermion alloy. Anika is a graduate student at Braunschweig Technical University, Germany. She visited our lab for six months last year, and participated in μSR experiments on $PrOs_4Sb_{12}$ at TRIUMF. Lei is a second-year graduate student at UC Riverside. Her Ph.D. dissertation will be on the results of her μSR experiments on $PrOs_4Sb_{12}$ and related materials.

Muon Spin Rotation at TRIUMF, Vancouver, Canada. Intense beams of spin-polarized muons are available at "meson factories" such as TRIUMF. The TRIUMF Meson Hall, where many of our experiments are carried out, is shown to the right.

Our students travel to TRIUMF to participate in μSR experiments. These two-week visits are intense experiences in experimental physics, since data must be taken under severe time constraints. Our students also benefit from contact with other research physicists visiting TRIUMF from around the world.