Discovery of the FFLO State: Magnetically Enhanced Superconductivity

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Development of rotatable heat capacity, high-pressure self-resonant, & plastic cantilever techniques; incorporated into the User Program utilizing the top-loading dilution refrigerator and new He-3 system for the 20 T SCMs at the NHMFL.

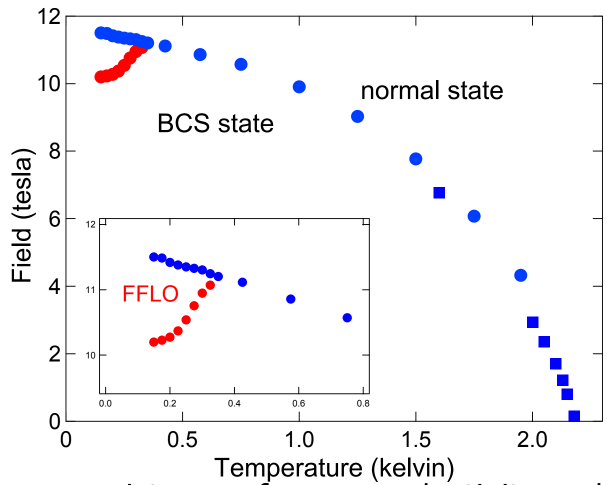
A novel superconducting state consisting of a periodic array of spin polarized electron domains alternating with superconducting regions was predicted in *1964: the Fulde-Ferrel-Larkin-Ovchinnikov (FFLO) phase*.

First thermodynamic evidence of the FFLO state.

Fundamentally new example of the *coexistence of magnetism with superconductivity*.

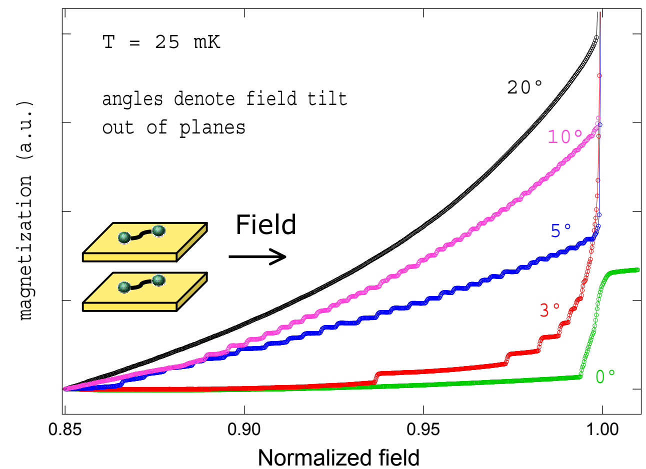
04Sept2003

$CeCoIn_5$ phase diagram (C_p)

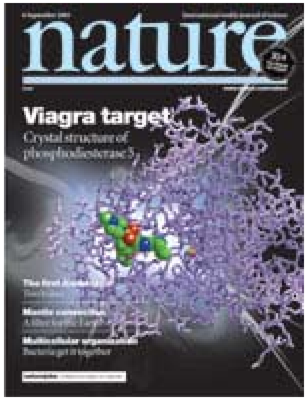


- coexistence of superconductivity and ferromagnetism
- connection to high-T_c superconductivity

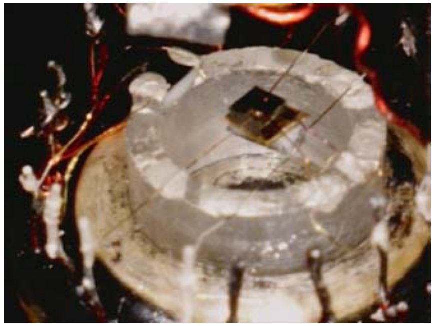
Landau level quantization



- order parameter with orbital momentum
- novel vortex structures



Heat capacity apparatus



Cantilever on He-3 rotator

Hidden Phases Revealed in Intense Magnetic Fields

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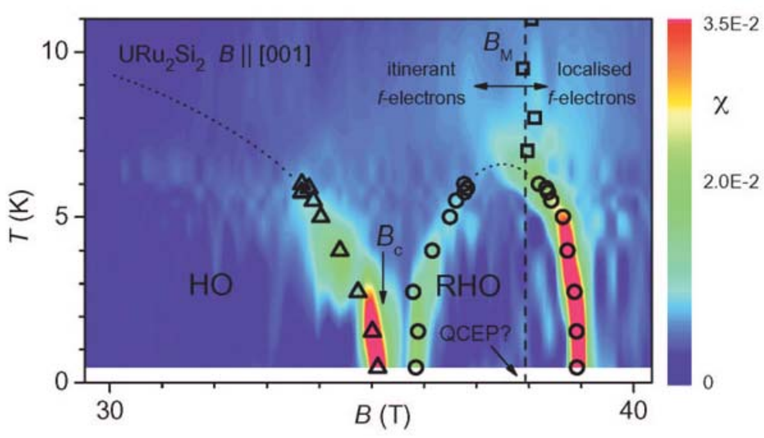
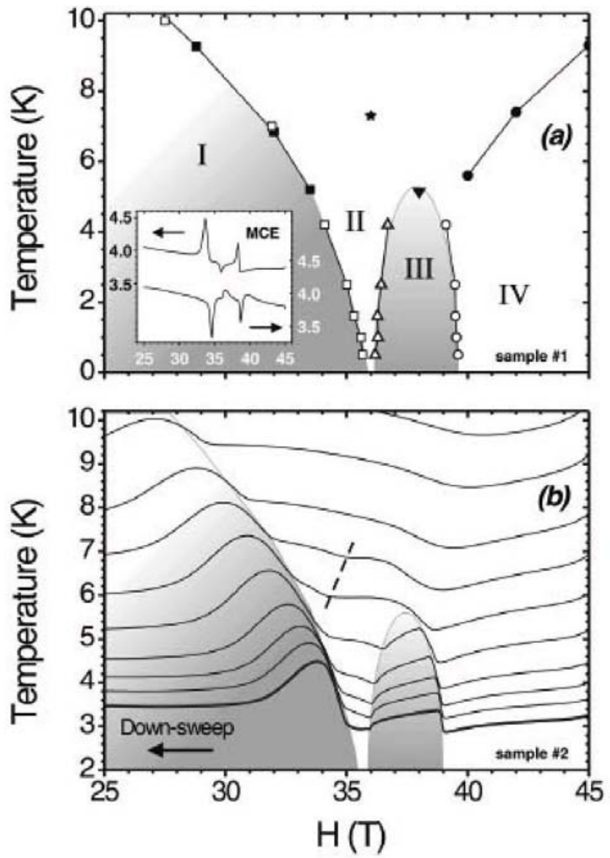
J. Mydosh, Leiden University and Max Plank Dresden
DMR-0084173

The phase diagram of URu_2Si_2 measured in the 45 tesla hybrid magnet in Tallahassee measured using specific heat (upper panel) and magnetocaloric (lower panel) measurements. This revised (H,T) phase diagram reveals for the first time a new high field/low temperature phase.

Color intensity plot of the magnetic susceptibility of URu_2Si_2 on traversing the hidden order (HO) and reentrant (RHO) phases measured in pulsed magnetic fields. The term "hidden order" refers to the low temperature phase in which the order parameter is yet to be identified. The RHO phase is believed to be created in the vicinity of a metamagnetic quantum critical end point. (Recently featured on front cover of Physical Review Letters: see below).





High Field Linear Magnetoresistance in Ag2+δSe

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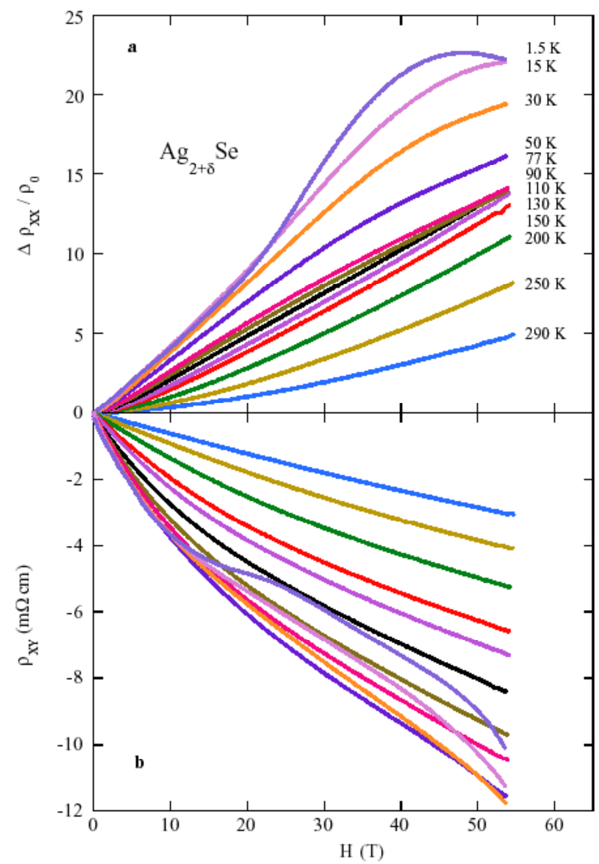
M.L. Saboungi, Argonne National Laboratory
DMR-0084173

The silver chalcogenide, AgSe, is a non-magnetic material, but reasons still unknown, its electrical resistance can be made very sensitive to magnetic field by adding small amounts - just 1 part in 10,000 - of excess silver. New high-precision resistivity measurements reveal a large (thousands of percent), nearly-linear increase with applied magnetic field with no evidence of saturation to the highest fields available. Semiclassically, the orbital magnetoresiatance of a normal metal is controlled by the product of the cyclotron frequency (ω_c) and the scattering time (τ), with a positive, quadratic magnetoresistance expected for $\omega_c t \sim 1$. In Ag2+δSe, the quadratic magnetoresistance required by symmetry considerations in the zero field limit is found to exist only below 0.01 teslas and the positive, approximately linear magnetoresitance continues to climb even for $\omega_c\tau > 50$, with no cut-off length scale in sight.



Magic-Angle Effect in Solid State NMR of Quadrupolar Nuclei

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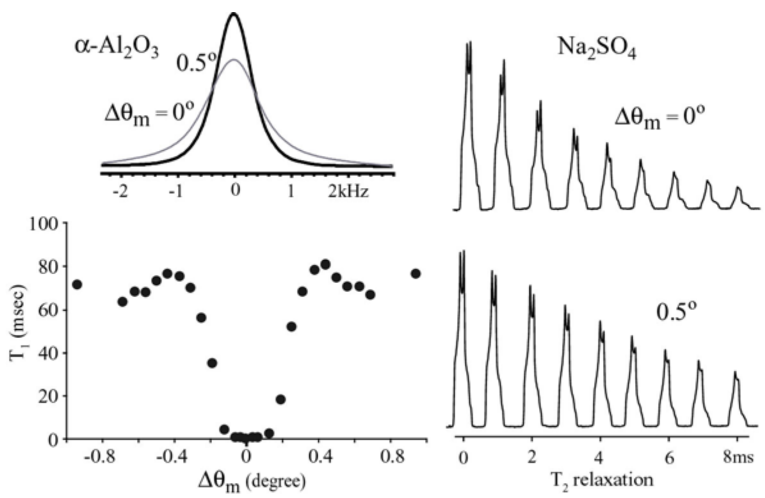
D. Massiot, CRMHT-CNRS, Orleans, France
DMR-0084173

Magic-angle spinning (54.76°) has become the standard method for high-resolution solid-state NMR spectroscopy of both spin-1/2 and quadrupolar nuclei for applications ranging from biological solids to material science. Recently, magic-angle effects have been discovered in compounds with quadrupolar nuclei that have challenged both current understanding and known NMR theory. Small magic-angle offsets, as little as a few tenths of a degree, significantly decrease line width and affect both T_1 and T_2 relaxation times (see figure). These magic-angle effects originate from rotational resonance that recouples homonuclear dipolar interactions under magic-angle spinning. The magic-angle effect and recovery of dipolar coupling under high-resolution conditions opens up new possibilities for improving spectral resolution and sensitivity, establishing connections among quadrupolar nuclei and measuring inter-nuclear distances for structural determination in solids.



Torque magnetometer measurements of a single-component molecular metal to 33 tesla

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S. Yasuzuka and S. Uji, National Institute for Materials Science, Tsukuba, Japan
E. Choi, D. Graf, and J. Brooks, National High Magnetic Field Laboratory
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NSF-DMR-0203532 and DMR-0084173

Traditionally, molecular metals require both a cation donor and an anion acceptor to maintain charge neutrality and exhibit metallic characteristics. A molecular metal[1] was recently synthesized containing only $Ni(tmdt)_2$ (see figure 1), where Tanaka, *et al.* had previously shown metallic character (ρRT = 3 x 10-3 Ωcm) with dR/dT > 0 to 0.6K. Using magnetic fields at the NHMFL DC facility and a microcantilever2, the de Haas van Alphen effect of this material was measured in temperatures as low as 0.5K. The sample stage consists of a piezoresistive-microcantilever (seen in figure 2) and a reference lever of nearly equal resistance. An AC bridge configuration is used to measure the small changes in resistance (~ mΩ) caused by displacement of the sample. The dimensions of the cantilever (platform width ~ 50μm) and its high sensitivity make it ideally suited for small samples. Figure 3 clearly shows de Haas van Alphen quantum oscillations of Ni(tmdt)2 up to 32 tesla, proving that this neutral molecular metal is indeed a metal with a Fermi surface. This is the first single component molecular material to unambiguously exhibit metallic character. The work is interesting in that it brings together the technology of nano-science (the AFM tip cantilever) with cutting edge molecular materials.

[1]H. Tanaka *et al.*, Science 291, 285 (2001)
2E. Ohmichi *et al.*, Rev. Sci. Instr. 73, 3022 (2002)

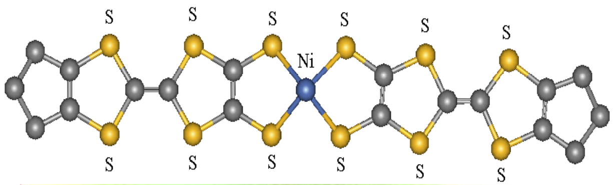


Figure 1. – $Ni(tmdt)_2$

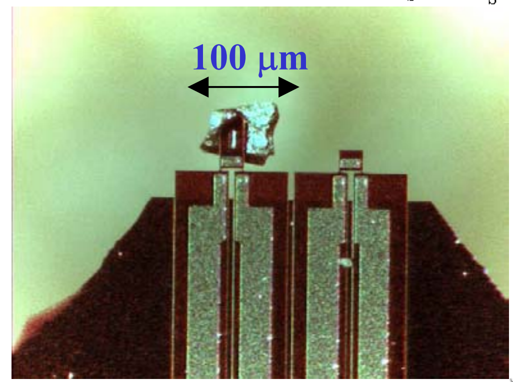


Figure 2. – Cantilever with sample mounted.

$\delta R/\delta F = 0.5\ \Omega/\mu N$

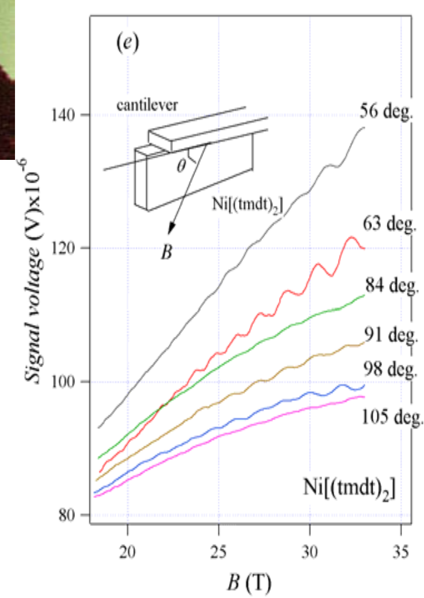


Figure 3. The dHvA effect in $Ni(tmdt)_2$

Dynamic Monte Carlo Simulations of Electrochemical Adsorption of Bromine on Silver

Per Arne Rikvold, Florida State University, DMR-9981815

Education:

Four undergraduates (Christina J. White Oberlin, Daniel E. Roberts, Shawn Havery, and Philip L. Coltharp), two graduate students (Steven J. Mitchell and Ibrahim Abou-Hamad), and two postdocs (Gregory Brown and Sanwu Wang) contributed to this work. Undergraduates White Oberlin and Roberts received Goldwater Scholarships, and White Oberlin is an NSF Graduate Fellow for 2002-05. Coltharp, Roberts, and White Oberlin are entering graduate school from 2002. Mitchell received his Ph.D. in 2001 and is presently a postdoc at Eindhoven University of Technology in The Netherlands.

Outreach:

With graduate student Mitchell, the PI experimented with LEGO construction toys in elementary and middle-school education. This included mentoring two middle-school students in building and programming LEGO robots.

The PI demonstrating LEGO compressed-air engines at the 2001 FSU Physics Open House.

EDUCATIONAL PROGRAMS AT THE NHMFL
Dr. Pat Dixon, National High Magnetic Field Laboratory
DMR-0084173

The Center for Integrating Research and Learning at the NHMFL works to create partnerships among teachers, scientists, researchers and educators to translate real-world science into classroom experiences and career opportunities for talented undergraduates.

RESEARCH EXPERIENCES FOR UNDERGRADUATES AND RESEARCH EXPERIENCES FOR TEACHERS

These two signature programs provide mentorships through which students participate in authentic laboratory experiences. 60 teachers have been challenged to extend their understanding of how science is done in the real world and to create classroom materials for over 4,000 K-12 students each year.

Undergraduate research placements reflect student areas of study and range from particle physics to geochemistry. Over its 10-year history, the program has provided 150 talented undergraduates with experiences that encourage them to pursue graduate courses of study and careers in the sciences.

Student presentations and papers (several of which have been published) since 1999 can be viewed at http://reu.magnet.fsu.edu.

In Summer 2003, the three sites of the NHMFL will host 19 undergraduates and 16 K12 teachers.

Partnerships

NHMFL Educational Programs continues to cultivate *new* partnerships as illustrated by a partial list that follows:

- Women in Math, Science, & Engineering
- FAMU Center for Equity
- High School/High Tech
- Transportation Research & Development Authority
- Boys' & Girls' Clubs
- FAMU Regional Institute for Math & Science

EDUCATIONAL PROGRAMS AT THE NHMFL
Dr. Pat Dixon, National High Magnetic Field Laboratory
DMR-0084173

Curriculum Development

Science, Tobacco & You continues to provide quality science curriculum materials to teachers nationwide. The 2002-2003 contract with Florida Department of Health provided another 500 teachers with materials. A total of 135 workshops for 6,750 teachers have been conducted. *MagLab: Alpha* and *Science, Optics & You* continue to provide structure to teacher workshops and summer institutes. 100 educators participated in NHMFL-led workshops.

Website Development

The education section of the NHMFL Website focuses on providing user-friendly resources for teachers, students and the general public. REU and RET application and workshop registration is completed online:scienceu.magnet.fsu.edu, education.magnet.fsu.edu,reu.magnet.fsu.edu, ret.magnet.fsu.edu

Future Directions

Girls in Science Program (proposal pending); RET; develop new outreach opportunities; continue Science, Tobacco & You funding/training; superconductivity project; Teacher-in-Residence program, expansion of professional development component.

TOURS & OUTREACH 2002

Numbers have increased significantly; outreach tripled in 2002, contact hours have almost doubled.

- ❖People touring the NHMFL = 2380
- ❖K12 Educational Outreach = 3958*
- ❖2003 9th Annual Open House = 2708

Total direct contact hours (not including Open House) with adults and K12 students = 17,473

*Outreach activities are conducted at the NHMFL and in schools and classrooms.

Students Design Capacitors to Improve NMR Analysis of Membrane Proteins

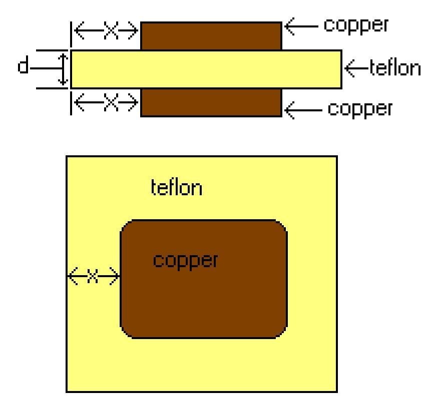
As participants in NSF's Research Experiences for Undergraduates (REU) summer program at the National High Magnetic Field Laboratory (NHMFL), two engineering students designed, built, and tested components that will be used to improve the analysis of membrane protein structure as determined by nuclear magnetic resonance (NMR) spectroscopy.

Membrane proteins play key roles in many important diseases, including influenza and tuberculosis. Solid state NMR is a new and important tool in understanding how viruses get through the cell membrane and gain access to the cell itself.

NMR spectrometers use a >500 W amplifier to blast the sample with short burst of an RF magnetic field, and then detect the microvolt-level resonances that have been induced in the sample. One of the obstacles to overcome is that in the high magnetic field required for NMR resonances can be induced in the electrical components such as the multilayer capacitors (MLC's) that are needed to efficiently couple the magnetic energy into and out of the sample. MLC's contain ceramics, and sometimes impurities in the ceramics exhibit a phenomenon known as piezoelectric resonance that can mask the tiny NMR signal.

Students Christine Amwake (Florida State University) and Nathaniel Falconer (Florida A&M University) developed capacitors that replace the troublesome ceramic with teflon, another material with low RF loss. Not only is teflon free from the ringing effects of the ceramic, but it is able to withstand the >5 kV potential associated with the short burst of RF magnetic field.

The students fabricated a range of capacitors from 1 to 10 pF. All capacitors passed a dielectric breakdown test to 5 kV. The capacitors will be made available to users in the next generation of solid state NMR probes at the NHMFL.



The copper-teflon-copper capacitors are based on commercial microwave substrate.

17,000+ Compositionally Distinct Components Resolved by 9.4 Tesla Electrospray FT-ICR MS

Alan G. Marshall, National High Magnetic Field Laboratory
Award CHE-99-09502 and DMR-0084173

Ultrahigh-resolution mass spectrometry has opened up a new field of "Petroleomics", namely, the relation between chemical composition and properties/reactivity of some of nature's most complex chemical mixtures: petroleum, coal, and humic/fulvic acids. Alan G. Marshall and co-workers at the NSF High-Field Fourier Transform Ion Cyclotron Resonance Mass Spectrometry Facility at NHMFL Florida State University have recently resolved and identified more than 17,000 chemically distinct components of a South Americn petroleum hevery crude oil (see Figure).