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Title: Challenges In High Magnetic Fields

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NHMFL PFF
Chuck Mielke

Chuck Mielke
Director NHMFL-PFF

Los Alamos
National Lab

National High Magnetic Field Laboratory

Challenges in High Magnetic Fields

- *Extremes of high magnetic fields
- *Our Facilities
- *Pulsed field capabilities
- *Research in extremes of high magnetic field

Why High Magnetic Fields?

- *Magnetic fields couple to electrons in materials
- *Modify energy spectrum
- *Externally adjustable
- *Fully reversible

Why Extreme?

*In order to have a relevant energy scale when compared to interesting interactions in materials

*100 tesla $\sim$ 134 K (-218 F)

100 tesla $\sim$ 2 million times the Earth's field

Classic Example (superconductor)

Classic Example (superconductor)

Classic Example (superconductor)

The NHMFL

- *Three Sites of the NHMFL
 - *Tallahassee, FL (DC Field)
 - *Gainesville, FL (High B/T)
 - *Los Alamos, NM (Pulsed Field)

- * \$33M/yr
- * 350 employees
- * 1100 users/yr
- * 7 User Programs

DC Field Facility (Tallahassee)

Bitter Magnets

FIG. 18

- * Primarily used as DC magnets
- * Stack of plates that form a spiral
- * Holes line up for cooling water

45 Tesla Hybrid

- * Highest continuous (DC) magnetic field
- * 32 MW and 2000 gallons/min cooling required
- * Superconducting + Resistive

Micro-Kelvin

20 tesla fields

High B/T Facility (Gainesville)

Los Alamos, NM

1,430,000,000 Watt Generator

About 1100 Users come to one of the 3 sites of the NHMFL each year

Users preparing for a shot on a 65 T magnet

Winding a pulsed magnet

Pulsed Field Facility (Los Alamos)

Forces are enormous

- 4 GPa at 100 T (simple solenoid magnet)

16,000 x pressure in a car tire
10 x pressure of the chamber of a High Power Rifle

Failed Magnets are part of the business

Reduction of stress through distribution

10 MM Bore Insert @ 100 T

High Strength CuNb wire

High Strength Wire

Magnet System

NHMFL breaks the megagauss

barrier, reaches 100.75 tesla pulse*

100.75 tesla confirmed via magneto quantum oscillations in poly-crystalline copper. First nondestructive generation of magnetic fields in excess of 100T as a research tool.

This effort represents the culmination of a 15-year project funded by:

*World Record magnetic field intensity for a Non-Destructive Pulsed Magnet (22 March 2012)

Photo credit: Kim Schneider (LANL)

Science in High Magnetic Field

LETTERS

Quantum oscillations and the Fermi surface in an underdoped high- T_c superconductor

Nicolas Doiron-Leyraud¹, Cyril Proust², David LeBoeuf¹, Julien Levallois², Jean-Baptiste Bonnemaïson³, Ruixing Liang^{3,4}, D. A. Bonn^{3,4}, W. N. Hardy^{3,4} & Louis Taillefer^{1,4}

Higher fields result in higher resolution Fermi Surface cross sections allow better theoretical description of the physics

Quantum Oscillations from Nodal Bilayer Magnetic Breakdown in the Underdoped High Temperature Superconductor $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$

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Pnictide (intermetallic) Superconductor with H_{c2} near 100 T

Anisotropic H_{c2} up to 92 T and the signature of multiband superconductivity in $\text{Ca}_{10}(\text{Pt}_4\text{As}_8)((\text{Fe}_{1-x}\text{Pt}_x)_2\text{As}_2)_5$

Eunsook Mun,¹ Ni Ni,² Jared M. Allred,² Robert J. Cava,² Oscar Ayala,¹ Ross D. McDonald,¹
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The upper critical fields $H_{c2}(T)$ of single crystals of the superconductor $\text{Ca}_{10}(\text{Pt}_{4-x}\text{As}_4)((\text{Fe}_{0.97}\text{Pt}_{0.03})_2\text{As}_2)_5$ ($\delta \approx 0.246$) are determined over a wide range of temperatures down to $T = 1.42$ K and magnetic fields of up to $\mu_0 H \approx 92$ T. The measurements of anisotropic $H_{c2}(T)$ curves are performed in pulsed magnetic fields using radio-frequency contactless penetration depth measurements for magnetic field applied both parallel and perpendicular to the ab plane. Whereas a clear upward curvature in $H_{c2}^{\parallel c}(T)$ along $H \parallel c$ is observed with decreasing temperature, the $H_{c2}^{\parallel ab}(T)$ along $H \parallel ab$ shows a flattening at low temperatures. The rapid increase of the $H_{c2}^{\parallel c}(T)$ at low temperatures suggests that the superconductivity can be described by two dominating bands. The anisotropy parameter $\gamma_H = H_{c2}^{\parallel ab}/H_{c2}^{\parallel c}$ is ~ 7 close to T_c and decreases considerably to ~ 1 with decreasing temperature, showing rather weak anisotropy at low temperatures.

DOI: 10.1103/PhysRevB.85.100502

PACS number(s): 74.70.Xa, 74.25.Op, 74.25.Dw

Material is a physical manifestation of a long standing theoretical challenge

Magnetostriction and magnetic texture to 100.75 Tesla in frustrated $\text{SrCu}_2(\text{BO}_3)_2$

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Edited by T. Maurice Rice, ETH Zurich, Zurich, Switzerland, and approved May 26, 2012 (received for review January 18, 2012)

Strong geometrical frustration in magnets leads to exotic states such as spin liquids, spin supersolids, and complex magnetic textures. $\text{SrCu}_2(\text{BO}_3)_2$, a spin-1/2 Heisenberg antiferromagnet in the archetypal

is satisfied by the 1/2 plateau that becomes stable at extremely high fields.

Given the difficulties associated with conventional magnetiza-

- Field-tuned spin state crystallization in perovskite LaCoO_3

PRL 109, 037201 (2012)

PHYSICAL REVIEW LETTERS

week ending
20 JULY 2012

Cascade of Magnetic Field Induced Spin Transitions in LaCoO_3

M. M. Altarawneh,^{1,2} G.-W. Chern,³ N. Harrison,¹ C. D. Batista,⁴ A. Uchida,¹ M. Jaime,¹ D. G. Rickel,¹ S. A. Crooker,¹ C. H. Mielke,¹ J. B. Betts,¹ J. F. Mitchell,⁵ and M. J. R. Hoch⁶

Multiple Magnetic States are driven by magnetic field

Single Turn Technique

In Pulsed magnetic fields we routinely measure:

- IR/VIS transmission
- RF conductivity
- Magnetic susceptibility

Real time shot to 240 tesla at NHMFL - LANL

• Graphene

nt: Layla Booshehri (Rice U.)

Artist: Scott Crooker

L. G. Booshehri, et al. PRB 85, 205407 (2012).

- Wavelength Dependence

Graphene

Control of Fermi Energy

Formation and fragmentation of superclusters in semiconductors

Dilute GaAs_{1-x}N_x Measured in the 60 T Controlled Waveform Magnet

Photoluminescence spectra of a GaAs:N sample (0.04% nitrogen) as a function of magnetic field.

The schematic shows how the conduction band and nitrogen (N) cluster states evolve as the magnetic field is increased.

MFL User: Kirsten Alberi (NREL)

Enabling a magneticfield-induced delocalized to localized transition

WELCOME

to the NATIONAL
HIGH MAGNETIC
FIELD LABORATORY

pulsed
field facility

NHMFL PFF
Chuck Mielke