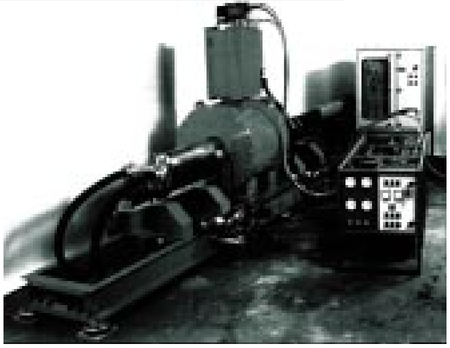
NATIONAL HIGH MAGNETIC FIELD LABORATORY
NHMFL REPORTS
SPRING 1998
Florida State University • University of Florida • Los Alamos National Laboratory
Volume 5 • No. 2

NHMFL Joins Carpco and DuPont in Developing New High Temperature Superconducting Ore Separator Magnet

A technical team comprising DuPont Superconductivity, Carpco, Inc. of Jacksonville, Florida, and the NHMFL has received funding from the U.S. Department of Energy to develop a prototype magnetic ore separator system. The three-year, $6 million project is one of six funded under the DOE Superconductivity Partnership Initiative (SPI) program.

The principal goal of the DuPont/Carpco/NHMFL project is to develop a one quarter commercial scale reciprocating magnetic separator based on high temperature superconductors (HTS). The reciprocating magnetic separator physically cycles magnetic material into and out of the magnet bore collecting the product in a fine mesh iron screen. Eventual replacement of conventional water-cooled, copper coils with HTS would save the ore separation industry more than 90 percent of its energy costs. This has been confirmed by Carpco, the largest commercial supplier of low temperature superconductor based separator magnets.



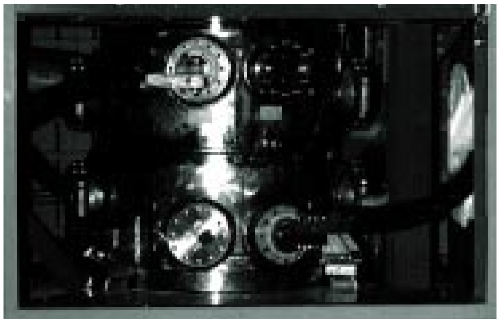
Separator magnet system, similar to the one to be developed by DuPont, Carpco, and the NHMFL.

The project includes the design, development, testing, and installation of the HTS magnetic ore separator at the DuPont Superconductivity laboratory in Wilmington, Delaware. The NHMFL work scope involves design and

ORE SEPARATOR continued on page 9

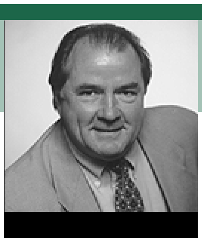
Keck Magnet Commissioned at the NHMFL

On February 17, 1998, a new DC magnet was successfully tested to full field at the NHMFL. This magnet, funded by the W.M. Keck Foundation of Los Angeles, California, and the NHMFL, sets a new mark for magnetic field uniformity and stability at high field. The goal for the magnet is to provide 25 teslas (T) in a 52 millimeter (mm) bore with field non-uniformity less than 1 part per million (ppm) over a 10 mm diameter spherical volume (DSV). A few successful experiments have been conducted to date, and the magnet appears to have a promising future for supporting the needs of the user community where high field and high homogeneity and stability are critical requirements for the research.



Magnets with field uniformity of 1 ppm over a 1 centimeter (cm) DSV are typically built using superconducting technology and are limited to about 18 T. To accomplish a 25 T machine, resistive magnet technology is required. The Keck magnet uses the Florida-Bitter magnet technology comprising three concentric coils of copper alloy Bitter disks with heavily elongated cooling holes in a staggered grid. This cooling hole arrangement

KECK continued on page 9



Filling Vacancies

Every organization experiences the difficult and time consuming task of "filling vacancies." This is especially true when looking for leaders of programs that are young and growing, undergoing significant change, or are ripe for expanded new opportunities. I am pleased to announce the selection of **Greg Boebinger** as the head of a newly formed NHMFL Center for high magnetic field research at Los Alamos National Laboratory, and **Tim Cross** as the new director of the NMR Program at the NHMFL.

Greg Boebinger is a world recognized scientist and national leader in the development of pulsed magnetic field research and eminently qualified to direct the new center. He comes to the NHMFL and LANL from Bell Laboratories, where he, together with Al Passner, established a world-class pulsed magnetic field laboratory using magnets of their own design and construction. He discusses his current research activities in the Chief Scientist's column, page 3.

Greg is well-recognized around the NHMFL, as a colleague, a user, and an advisor. He is presently serving on the laboratory's Users Committee (he also served in that capacity from 1993-1995), and he was on the NSF Site Visit Review Committee in 1993 and 1994. In addition, he is the current chairman of the External Advisory Committee for the LANSCE/NHMFL Project to build a 30 T Pulsed Magnet for Neutron Diffraction Studies.

The formation of the NHMFL Center at Los Alamos represents the Los Alamos commitment to the continued development and future of the NHMFL program. The success of the three-institution partnership and the scientific contributions of the Pulsed Field Facility led to Los Alamos recognizing NHMFL with the status of a programmatic center. The NHMFL Center will report to the Materials Science and Technology Division and will be staffed by the scientists, engineers, and technicians responsible for its operation and success. With this increased visibility and focus, NHMFL Los Alamos will continue to advance the pulsed magnetic field user program and facility.

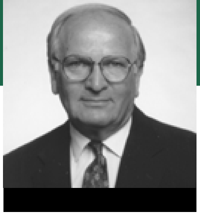
Tim Cross brings to his new appointment as director of the NMR Program years of insight into the vision for a multidisciplinary, high magnetic field research facility that underpins the NHMFL. Tim was a significant contributor to the original NHMFL proposal to the National Science Foundation in 1989, and pushed hard for incorporating the needs of chemistry and the life sciences into the planning for a new laboratory. He was then and continues to be an advocate for extending magnetic resonance to higher magnetic fields, for special field configurations, and for advancing electronics and magnetic resonance techniques to support promising new opportunities for a wide range of science and engineering disciplines. As an example, Tim's group was one of the first to explore the use of the laboratory's resistive magnets for NMR biological structure research (see NHMFL Reports, Fall 1996). Tim also was a significant force contributing to the successful development of the Keck magnet, featured on page 1, and he, along with an inter-institutional and interdisciplinary group of colleagues prepared and submitted the successful proposal to fund a new NMR console for the recently commissioned 830 MHz solid state NMR system (see Random Observations, page 11).

Always one to look ahead to new opportunities, Tim put together the very successful national magnetic resonance workshop held in Washington, D.C., in January of this year. Entitled "High Field NMR: A New Millennium Resource," the conference focused on scientific frontiers important to the national science agenda and addressable through the next generation of high field NMR spectrometers. It also evaluated the potential for knowledge networking to support collaborative research through shared instrumentation and a multi-institutional education and technology program across the United States. The conference report, which will be submitted to the Department of Energy, the National Institutes of Health, and the National Science Foundation, continues to drive an important national dialogue on the subject.

Filling these two critically important positions with the right people has been a challenge. We are confident that with Drs. Boebinger and Cross in place, the programs will continue to move forward aggressively and with the best interests of our science and engineering users in mind.

Jack Crow, Director and Co-Principal Investigator, FSU
Don Parkin, Co-Principal Investigator, LANL
Neil Sullivan, Co-Principal Investigator, UF

From the
Chief Scientist's Desk



High-Temperature Superconductors: Non-Fermi Liquids Requiring 100 Teslas

Greg Boebinger, Bell Laboratories, Lucent Technologies and NHMFL/LANL

> We are delighted to welcome Dr. Gregory Boebinger as the head of the new NHMFL Center at LANL. Dr. Boebinger is a leader in the field of pulsed high field magnets and their applications in condensed matter physics. In this issue he discusses the topic of strongly correlated electric systems in which strange electronic properties are being explored. These materials are of high current interest in regard to their fundamental appeal and application to high temperature superconductivity.
>
> R. Schrieffer

Among the many active research areas in condensed matter physics, intense magnetic fields are particularly well suited for studying those materials in which electron interactions lead to non-Fermi liquid behavior. In order to understand that opening statement, we must first define one key term. At a recent conference on non-Fermi liquids, Andy Millis of Johns-Hopkins offered his own working definition: "A non-Fermi liquid is any compound whose low-temperature behavior is not understood." While this tongue-in-cheek definition may initially seem overly negative and even depressing in tone, recognize that it virtually guarantees the robust growth of non-Fermi liquid research in the years to come!

So what is a Fermi liquid? (...so we can figure out what a non-Fermi liquid is not.) A Fermi liquid is any material for which a wide range of properties, such as its electrical resistance and its response to a magnetic field, can be explained within a simple approximation that treats electrons as individual, independent particles. Many ordinary materials, such as copper, qualify as Fermi liquids. At the outset, it is not obvious that such a simple approach could be successfully applied to the electrons in any solid: In every solid, there are so many electrons packed so closely together that they are necessarily experiencing strong, mutual repulsion. Additionally, in every solid, overlapping electron orbitals from neighboring atoms form electron energy bands, which can develop quite complex relationships between each electron's energy and momentum, very unlike that of an isolated electron (whose energy is always proportional to the square of its momentum).

How can a Fermi-liquid description apply accurately to any solid, much less many solids? First, one must understand that, in every solid, electrons seek to occupy the lowest energy states available. This means that, despite the complexities of any given solid, at absolute zero temperature, all electron states are occupied up to a single, well-defined energy, known as the Fermi energy. Above the Fermi energy, all electron states are unoccupied at absolute zero temperature. Because those electrons with energies near the Fermi energy are the most energetically accessible, they often govern the electronic properties of a material at low temperatures. At sufficiently low temperatures,[1] only a few low energy excitations can be created at any given time. These few excitations can be very widely separated and, thus, can be treated in many materials as weakly interacting particles, called "quasiparticles." In these "Fermi liquids," the vast majority of the electrons are "frozen out" and the few weakly-interacting quasiparticles give rise to a common set of physical properties, such as a low-temperature resistance which increases as the square of the temperature.

In a non-Fermi liquid, however, the effects of electron interactions are especially strong, due perhaps to vibrations or magnetism or some other mechanism at work in a given material. In non-Fermi liquids, a simple quasiparticle model breaks down and, at low temperatures, something other than Fermi liquid behavior is observed. (At this point, Millis' definition is probably looking fairly well motivated!) Physicists are now directing considerable attention toward phenomena that are difficult or impossible to understand in terms of Fermi liquid behavior.[2,3]

Intense magnetic fields are effective in probing non-Fermi liquids because they alter the orbital and spin energies of the electrons in a solid. For each tesla (T) of applied magnetic field, the electron energies are typically shifted by an amount corresponding to roughly one kelvin (K) of thermal energy. Since the electron correlations that lead to non-Fermi liquid behavior usually correspond to small energies, they occur only at low temperatures, typically below 10 or 100 K. To probe these correlated electron effects using intense magnetic fields, one must apply a comparable magnetic field, that is, 10 to 100 T.

NON-FERMI LIQUIDS continued on page 4

NON-FERMI LIQUIDS continued from page 3

High-temperature superconductors exhibit a particularly striking example of non-Fermi liquid behavior.[4] At temperatures above the superconducting transition temperature, all superconductors exhibit a so-called "normal state" in which the motion of charge carriers is accompanied by energy dissipation, the same type of dissipation that leads to the finite resistivity observed in ordinary metals. In high-temperature superconductors, the normal state is two-dimensional: charge carriers travel easily within those parallel planes of the crystal that consist of copper and oxygen atoms, while motion between different copper-oxygen planes is difficult. The two-dimensional normal state of the high-temperature superconductors is highly unusual, characterized by optical, magnetic, and transport properties unlike anything previously discovered. It is these normal-state properties that comprise a non-Fermi liquid behavior which is sufficiently strange that many physicists believe it holds the key to eventually understanding the physical mechanism for high-temperature superconductivity.

The most striking non-Fermi liquid behavior of the high-temperature superconductors is the normal-state resistivity: as the crystal is cooled, the "in-plane" resistivity (ρ_{ab}) decreases linearly with temperature, in sharp contrast to the quadratic behavior of Fermi liquids. At the same time, the "out-of-plane" resistivity (ρ_c), increases rapidly with decreasing temperature. This contrasting behavior between the "metallic" ρ_{ab} and "insulating" ρ_c persists down to the superconducting transition temperature, Tc. Below Tc, the behavior of the normal-state resistivities is hidden by the presence of superconductivity, as depicted in Figure 1. The goal of a recent series of experiments utilizing pulsed magnetic fields[5,6] was to destroy the superconductivity and reveal the low-temperature behavior of the unusual normal-state resistivities in the high-temperature superconductor $La_{2-x}Sr_xCuO_4$ (LSCO). Because Tc is so high (40 K), magnetic fields exceeding 60 T were required to successfully complete these experiments. Thus, while it was the large value of Tc that sparked the initial excitement over high-temperature superconductivity, currently the large

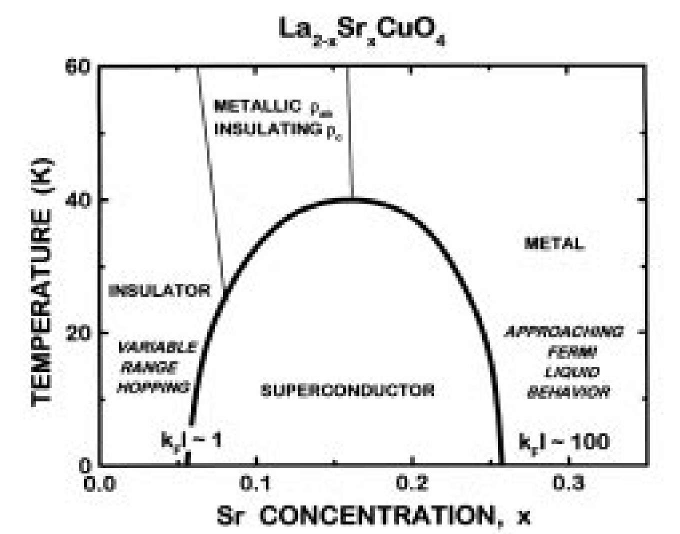


Figure 1. The phase diagram of LSCO, showing the superconducting phase that obscures the low-temperature behavior of the non-Fermi liquid normal state near optimum doping, as well as the crossover from insulator to metal with increasing carrier concentration.

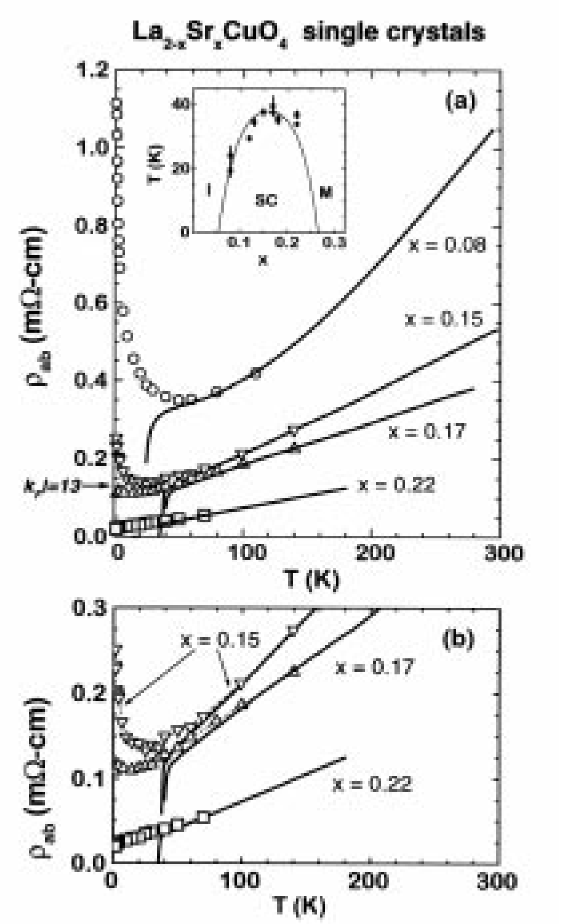


Figure 2. Resistivity of the normal state of LSCO for various carrier concentrations, x. The solid lines are zero magnetic field data, while the symbols are B=60 T data. The lower panel is an enlargement of the data for the samples near optimum doping (x~0.16). Note that all underdoped samples (x<0.16) show insulating behavior at low temperatures.

NON-FERMI LIQUIDS continued on page 5

value of Tc is primarily an annoyance...forcing the use of intense pulsed magnetic fields in order to adequately suppress the superconductivity and enable the study of the non-Fermi-liquid normal state at low temperatures.

As shown in Figure 1, the superconducting transition temperature can be optimized by tuning the concentration of charged carriers. Varying the carrier concentration is accomplished in the case of LSCO by varying the strontium concentration, x. Figure 1 shows that the maximum Tc (40 K) in LSCO is achieved for x~0.16, which is thus called "optimum doping." If the carrier concentration is reduced below the optimum doping, Tc is reduced and superconductivity is eventually destroyed for x<0.06. Compounds in this regime are insulators; that is, the resistivities increase with decreasing temperature and extrapolate to an infinite resistivity (no current flow) in the limit of zero-temperature. In this regime, the compounds exhibit "variable range hopping,"[7] a well-known type of conduction in which charge carriers are mostly localized near individual impurities and hop between impurities in response to an applied electric field.

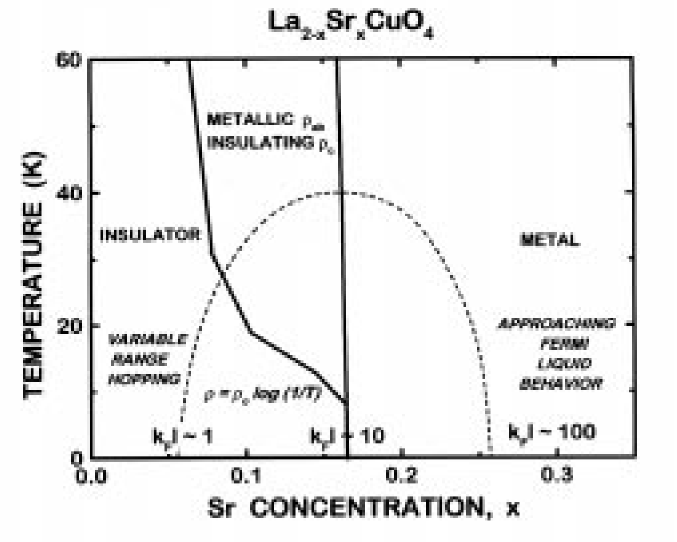


Figure 3. The phase diagram of LSCO once superconductivity is suppressed by an intense pulsed magnetic field. The insulator-to-metal crossover is seen to occur near optimum doping and a new insulating regime is revealed, in which the resistivity diverges as the logarithm of the temperature.

Increasing the carrier concentration above optimum doping also decreases Tc until the destruction of the superconducting state reveals a metallic phase, whose properties approach those of a Fermi liquid. One would like to study the insulator-to-metal crossover in the normal state; however, once again the superconducting phase obscures the desired observation—unless a pulsed magnetic field is applied!

It turns out that pulsed magnetic fields provide a relatively gentle way to destroy superconductivity. When a field of 60 T is applied to LSCO, superconductivity is completely destroyed and new features of the normal state are revealed. Figure 2 shows the most obvious new finding, that all "underdoped" samples (x<0.16) exhibit insulating behavior at low temperatures and that the crossover between insulator and metal occurs very near the same carrier concentration that gives rise to optimum superconductivity (x~0.16).[6] This coincidence, though not yet understood, seems difficult to ascribe to mere chance. Furthermore, while the insulating phase in non-superconducting underdoped samples (x<0.06) exhibits conventional variable range hopping, the insulating phase in superconducting underdoped samples is quite unusual, in that both the in-plane and c-axis resistivities diverge as the logarithm of the temperature.[5] The phase diagram of LSCO once superconductivity is suppressed is shown in Figure 3.

Future high magnetic field experiments seek to determine which of the strange new normal-state behaviors revealed in LSCO are common to other high temperature superconductors. Many of the high-temperature superconductors have such large Tc's (near or above 100 K) that still more intense magnetic fields are required to perform these experiments. Thus, the puzzle of high-temperature superconductivity provides strong incentive to build still stronger pulsed magnets.

References:

[1] Since the Fermi energy in many materials corresponds to many thousands of kelvins, "low temperatures" in this context can range up to room temperature (300 K) and even beyond.

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1997: A Banner Year for NHMFL Education Programs

The NHMFL continued to expand its many educational programs in 1997 and engaged more students in integrated research and learning experiences than ever before. All of these programs—whether designed for K-12, technical, undergraduate, graduate, and postdoctoral—are developed in close consultation with and guided by the research scientists, engineers, and technicians at the laboratory, including members of the visiting community.

In this tradition, we are offering for the sixth consecutive year the NHMFL Minority/Women Summer Internship Program. Over 120 applications have been received for our 20 slots this summer. The selected undergraduate students will be placed for two-month-long research experiences with mentors in Tallahassee, Gainesville, and Los Alamos.

The K-12 educational programs of the laboratory have matured dramatically since their start in 1995. These programs are designed to excite and educate students, teachers, and the general public about magnets and magnetism, science, technology, and the world around them. The K-12 educational program now comprises six areas: Teacher Education, Student Education, Curriculum Development, Partnerships, an Educational Resource Laboratory, and a research program focused on the teaching and learning of science.

Through these innovative programs, the NHMFL engaged over 11,000 students in outreach programs in 1997, toured approximately 4,000 K-12 students through the laboratory, and reached countless others through our website and curriculum products. Our educational programs serve not only the K-12 community, but also the general public. In 1997 approximately 6,000 members of the general public experienced guided tours of the lab, and our 4th Annual NHMFL Open House held in October, 1997, attracted over 3,500 visitors. Some highlights of our K-12 educational programs from 1997 follow.

Teacher Education

In conjunction with the FSU College of Education, science education centers and museums, and local school districts, the NHMFL established two new activities in 1997 that are enriching an already well-established teacher education program.

- A variety of statewide and regional workshops are now being offered for elementary, middle grades, high school, and community college teachers.
- NHMFL K-12 faculty are teaching graduate courses to prospective teachers through FSU's College of Education (e.g., Conceptual Learning in Elementary School Science, Instructional Technology in Teaching and Learning Mathematics).

Student Education

- Our outreach program sends NHMFL educators directly to the schools with presentations and workshops on science. These multifaceted and interdisciplinary programs reached over 11,000 Florida students in 1997.
- The NHMFL provides mentorship and internship experiences for students from the middle grades (grades 6 to 8) through the graduate level. Each year we host over 75 middle or high school students and more than 40 undergraduate students, including students in our Minority/Women Research Internship Program (see http://k12.magnet.fsu.edu/intern/index.html).
- The lab created and maintains an extensive website including educational programs and resources (http://k12.magnet.fsu.edu). It has an "Ask an Expert" component that allows students of all ages to pose questions to scientists and experts at the NHMFL; a virtual tour of the lab; and other student resources.

Curriculum Development

The K-12 Curriculum Development Program has led to new and unique resource materials such as MagLab: Alpha. This integrated science, standards-based curricular resource package is designed to enhance the teaching and learning of magnet-related science in middle grades. This product has already been distributed to 200 Florida classrooms, and we anticipate national marketing of it in the fall of 1998.

Teaching and Learning Research at the NHMFL

The NHMFL is developing a research agenda to examine the teaching and learning of science, mathematics, and technology and to evaluate the laboratory's educational programs. Current studies are investigating: teacher professional development models; the impact of NHMFL education programs on students, teachers, and members of the general public; and the affect of mentorship experiences on student perceptions of science and career choices.

For more information about the NHMFL's educational activities, contact Dr. Sam Spiegel, Director K-12 Educational Programs, (850) 644-5818, spiegel@magnet.fsu.edu.

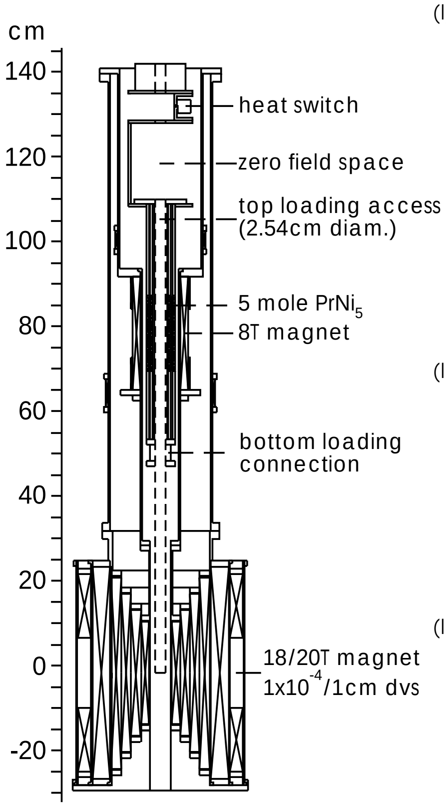
ATTENTION USERS

Neil Sullivan
NHMFL Co-PI, Chair of UF Physics Department

The Ultra-High B/T Facility at the University of Florida was commissioned in the fourth quarter of 1997 as a new NHMFL facility. The facility is located in the third bay of the Microkelvin Laboratory in Gainesville and is designed for experiments that require simultaneous use of high fields (up to 20 T with delivery of fourth coil) and very low temperatures (down to 0.5 mK).

This new facility is now open to users through NHMFL's regular application procedure (http://www.magnet.fsu.edu/users/specialfacilities/bt_lab/index.html) and by contacting Dr. J. S. Xia who operates the facility for the NHMFL. The capabilities are of special interest to researchers studying new phenomena such as transport in highly polarized systems and the magnetic phase diagrams of nuclear ordered states where the new phenomena are only accessible through the establishment of high initial spin polarization.

The facility consists of a complex two-stage magnet system shown in Figure 1:



(I) An 8 T nuclear demagnetization stage using a $PrNi_5$ nuclear refrigerator with a cooling capacity of close to 10 nW at 0.5 mK. This cooling capability corresponds to a warming rate of about 10 μK per day for a typical sample.

(II) A 20 T persistent superconducting magnet for the experimental region, allowing experiments to be conducted at the highest steady state B/T ratio of $4x10^4$ T/K.

(III) A carefully designed compensating coil system to minimize field at the sample during magnetization of coil I.

Jian-sheng Xia, Associate-In Physics, who manages the High B/T.

The system is located in an ultra-quiet environment with specially-designed vibration isolation and "tempest" quality shielding from electromagnetic interference and noise. This design allows for high sensitivity measurements of weak effects such as transport properties and low field NMR. Another special feature designed for users is a long flexible bellows arrangement that provides rapid turnarounds (typically 24 hours) at dilution refrigerator temperatures without the need to warm up the magnets and helium bath.

A number of new experiments have been launched at the facility. These include studies of the fractional quantum Hall effect at high quantum numbers and at very low temperatures where anomalous features have been noted. The high field induced order/disorder transitions for solid ^{3}He will also be explored for the first time in the sub-millikelvin regime. The critical field for these transitions is related to fundamental components of the anisotropic exchange interactions and is important to our elementary understanding of quantum exchange in solid ^{3}He. Another new experiment of interest is the study of transport in highly polarized fluids. A number of unusual magneto-kinetic effects are predicted for spin transport in highly polarized Fermi fluids and will be clearly observable for the first time for the high B/T ratios achievable at the new Gainesville facility. Other possible experiments include NMR studies of the microscopic dynamics of quantum Hall systems, and the achievement of high spin polarizations or solid D_2 and HD, which are of potential significance for inertially confined fusion.

The facility's specifications are as follows:

Experimental field:	currently 15.3 T (upgrade to 20 T in 1999/00)
Homogeneity:	2 X 10^{-5}/cm DSV
Persistence:	1.6 X 10^{-5}/day
Field calibration:	better than 10 ppm by ^{3}He NMR
Nuclear Cooling:	5 moles of $PrNi_5$, 8 T demagnetization magnet
Tmin:	~ 0.4 mK
Heat leaks:	< 5.0 nW
Warming rate:	~ 10 μK/day

For further information contact Dr. J. S. Xia, 352-392-8869, jsxia@phys.ufl.edu.

NHMFL Ion Cyclotron Resonance Group Counts the Sulfur Atoms in a 16 kDa Protein Based on Resolution of Species of Different Elemental Composition (i.e. Molecular Formula)

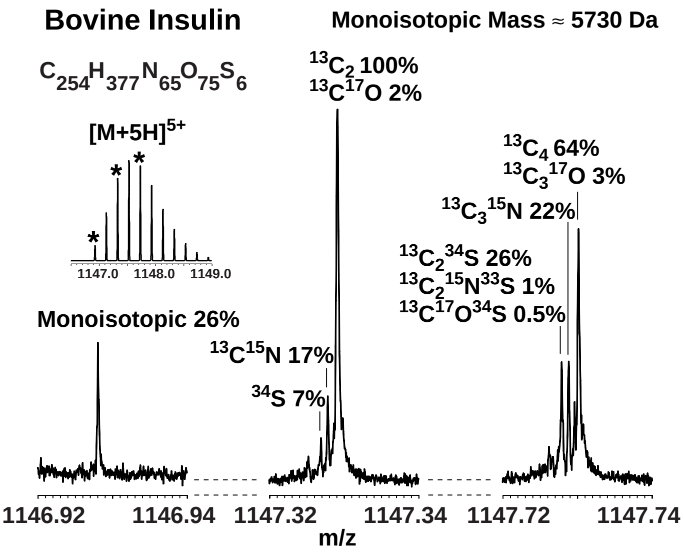


Figure 1. Ultrahigh-resolution spectrum of the sixth lowest-mass isobar of the isotopic multiplet of the 5^+ charge state of bovine insulin.

It is well known that elemental composition ($C_cH_hO_oN_n\cdots$) can be determined by sufficiently accurate measurement of the mass of a molecular ion (to ≤0.001 atomic mass units or Dalton). For molecules of less than ~1,000 atomic mass units (Daltons), the problem is relatively easy, because the most abundant ionic species is the "monoisotopic" species (i.e., the one for which all carbons are ^{12}C, all nitrogens are ^{14}N, all oxygens are ^{16}O, etc.), which is at least one Da lower in mass than all other isotopic combinations. Thus, ultrahigh mass resolution is not needed to determine the mass of that isolated singlet peak.

The problem is much more difficult for molecules of more than 10,000 Da (e.g., proteins and other biomacromolecules), because (a) the monoisotopic species is generally too low in relative abundance (≤0.1%) to be detected accurately, and (b) each of the remaining peaks separated by approximately 1 Da consists of a superposition of species of different chemical formulas (e.g., $^{13}C_2{}^{14}N^{32}S$ or $^{12}C_2{}^{14}N^{34}S$ or $^{13}C^{15}N^{32}S$, etc., at 2 Da above the monoisotopic mass). Such "fine structure" has been resolved (by FT-ICR MS) for small peptides,[1,2] but has proved unattainable for larger species due to the tendency of closely spaced peaks to coalesce into a single resonance.[3,4] The coalescence tendency scales inversely with magnetic field strength, however, so that one might hope to resolve such fine structure at sufficiently high magnetic field.

Late in 1997, graduate student Stone D.-H. Shi, working with NHMFL's Christopher L. Hendrickson and Alan G. Marshall, achieved the first resolution of the fine structure of species up to 16 kDa with the NHMFL 9.4 T electrospray FT-ICR mass spectrometer. A key feature of that instrument (in addition to the high magnetic field) is the use of quadrature detection, which provides a S/N enhancement of $\sqrt{2}$ and concomitant decrease in the number of ions necessary for detection (to be reported separately). Figure 1 shows an ultrahigh-resolution ($m/\Delta m \sim 5{,}000{,}000$) spectrum of the sixth lowest-mass isobar of the isotopic multiplet of the 5^+ charge state of bovine insulin (monoisotopic mass, 5,729.6 Da). At least five different elemental compositions can be identified. The data was collected by stored-waveform isolation of the 5^+ charge state followed by a slowly decreasing trap voltage ramp from 2 V to 0.2 V prior to frequency-sweep (chirp) excitation and digital heterodyne detection. By lowering the trapping potential, the NHMFL team was able to reduce significantly the number of trapped ions—crucial to avoiding coalescence. They have used similar techniques to resolve fine structure of proteins as large as cytochrome c.

As noted in a prior NHMFL Reports, another way to reduce the number of ions (and further increase the upper mass limit) is to "compress" the isotopic distribution into fewer species, by expression of a recombinant protein from a minimal medium containing ^{13}C-depleted glucose and ^{15}N-depleted ammonium sulfate.[5] Figure 2 shows resolution of the isotopic fine structure of doubly-depleted tumor suppressor protein p16 (15.8 kDa). Both simulated and experimental electrospray FT-ICR mass spectra

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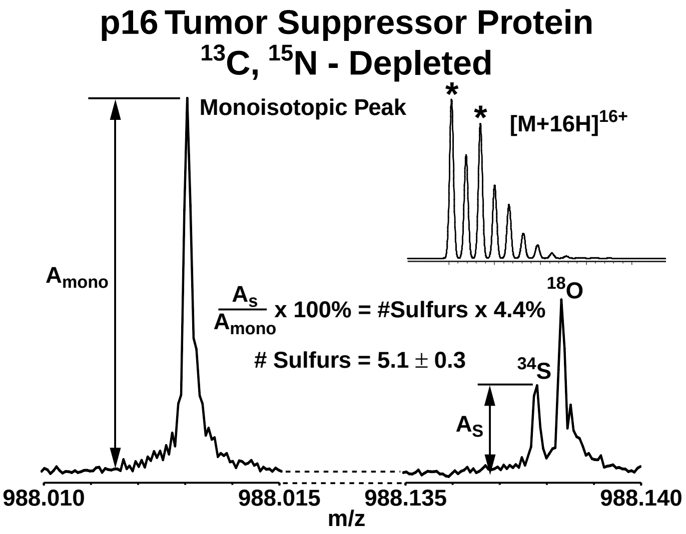

Figure 2. Isotopic fine structure of doubly-depleted tumor suppressor protein p16 (15.8 kDa).

show that ^{13}C,^{15}N double-depletion virtually eliminates carbon- and nitrogen-containing species from the fine structure. The depletion effectively increases the relative signal obtained from the ^{18}O and ^{34}S isotopes without increasing the total ion number. Note that the number of sulfur atoms in this 16 kDa protein (for which the actual number of sulfur atoms is 5) is determined directly (and correctly) as 5.1 ± 0.3 from the relative abundance of the ^{34}S peak vs. the monoisotopic peak! The results in Figure 2 represent a tenfold extension in the upper mass limit at which isotopic fine structure has been resolved.

For further information about the ICR Program, contact Alan Marshall (850-644-0529, marshall@magnet.fsu.edu), who contributed this article.

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ORE SEPARATOR continued from page 1

analysis of the HTS coil, which probably will be wound with Ag/BSCCO conductor purchased from industry. Nominal specifications for the HTS coil are listed below:

Coil inner diameter	200 mm
Coil outer diameter	300 mm
Coil length	500 mm
Pancake winding (Number)	100
Operating current	150 A
Engineering Jc	5000 A/cm^2
Magnetic field	1.25 T
Conductor length	9.3 km
Energy stored	15.8 kJ

The separator magnet will be horizontally configured, similar to one pictured in the photograph. The NHMFL also will be responsible for the design, analysis, acquisition, and assembly of the cryostat, vacuum system, and closed cycle Gifford-McMahon refrigerator needed to support the HTS coil. The coil will be conduction-cooled and the cryostat will provide HTS current leads for powering the magnet. The entire system will be assembled and demonstrated at the NHMFL in Tallahassee. Carpco will supply the ore separator process equipment and assist with its installation on the magnet. The completed system will then be shipped to DuPont Superconductivity for demonstrating the ore separation process.

For further information on this collaboration, contact Steven Van Sciver, director of NHMFL Magnet Science and Technology (850-644-0998, vnsciver@magnet.fsu.edu), who contributed this article.

KECK continued from page 1

reduces stress concentrations and radial force transmission compared with traditional Bitter magnet construction resulting in higher fields with the same materials.[1]

To attain a 1 ppm machine, we first need to understand exactly how we define field variations. In NMR measurements, the magnitude of the magnetic field vector is the important quantity. It should not vary by more than 1 ppm over a 1 cm DSV in this magnet. The magnitude of the field is given

$$|B| = (B_z^2 + B_x^2 + B_y^2)^{\frac{1}{2}}$$

$$|B| = B_z + \frac{1}{2}\frac{B_x^2 + B_y^2}{B_z^2} + \dots$$

so we see that for |B| to vary by less than 1 ppm over a given space, B_z must vary by less than 1 ppm but

KECK continued on page 10

KECK continued from page 9

B_x/B_z can vary up to 1000 ppm. Consequently, we only concern ourselves here with variations in B_z.

A typical high field resistive magnet has a spatial field inhomogeneity of about 1000 ppm over a 1 cm DSV. This inhomogeneity is given by the finite length of the solenoid. That is, the field generated by a perfect solenoid of finite length decays as one moves along the axis of symmetry from the midplane. This decay can be written $B = a + bz^2 + cz^4 + \ldots$ where the dominant term is the z^2 term. To eliminate the z^2 term of the magnet assembly, the middle of the three coils is stacked with a short at the midplane. That is, there is a zone of approximately 30 mm at the midplane of the middle coil where the current flows axially instead of circumferentially. This is accomplished by stacking 30 mm of Bitter conductors without insulators. This midplane short results in the field from the middle coil having a saddle shape, i.e. reverse curvature at the midplane. This reverse curvature is equal in magnitude to the curvature of the other two coils combined, so the sum of the three is governed by the z^4 term, which is small compared with the uncorrected z^2 term.

Furthermore, if the coils are not centered perfectly with respect to each other, odd terms in z come into the expansion. For example, if the outermost coil is 1 mm higher than the other two, there is a linear z gradient in the field at nominal field center of 5.3 ppm/mm. Since it is impossible to assemble the magnet perfectly, the magnet was designed with the intention of assembling it, running to full field, and performing an NMR map along the z axis. The inner two coils would then be shifted to correct any linear z variation seen.

In addition, if the magnet is not perfectly axisymmetric, there can be linear gradients in x and/or y. In a typical high field resistive magnet at the NHMFL, the three coils are connected electrically in series and operate at currents close to 40 kA. This means that there are bus bars inside the magnet housing connecting these coils that carry 40 kA approximately 300 mm from field center. The fringe fields from these bus bars can generate gradients at the center of the magnet in x or y with a magnitude up to 10 ppm/mm. To accomplish 1 ppm over 10 mm, these bus bars require careful design. The final solution involved several parallel bars spaced periodically around the magnet connecting any two coils in series.

The magnet was successfully tested to full field the first time on February 17, 1998. The first 25 T axial NMR field map was performed on March 11 by Victoria Soghomonian, a postdoctoral fellow with the NMR group at the laboratory. It showed a linear z gradient of 5 ppm/mm. The inner two coils were shifted up with respect to the outermost one and the magnet was remapped on April 4. The new gradient was seen to 1.3 ppm/mm. 3-D field maps have been made and the bus bars will then be modified as necessary to attain the proper uniformity in x and y. Final shimming will be performed with room temperature, wire-wound, shim coils.

Temporal field variations are also a significant issue in this magnet. The two most significant sources of temporal variation are ripple from the power supplies and inlet water temperature variations. Ripple from the power supplies is transformed almost directly into ripple in the field. Water temperature variations result in thermal expansion and contraction of the magnet coils resulting in lower or higher current densities and field variations of 17 ppm per degree C water temperature change. Various people have been working on the temporal stability issues for over a year. Peter Murphy, head of the electronics shop at the NHMFL, and others have been trying to reduce ripple in the power supplies. Jim Ferner, Director of Facilities and Instrumentation, and a team of specialists have been improving water temperature control. Victoria Soghomonian and her colleagues have been working on flux tubes and NMR locks. A combination of these approaches has demonstrated 1 ppm temporal stability in other magnets at the NHMFL. These improvements will be introduced into the Keck magnet in the near future.

For further information on the Keck magnet, see NHMFL Reports, Summer 1996, or contact Mark Bird, head of the Resistive Magnet Group (850-644-7789, bird@magnet.fsu.edu), who contributed this article.

References:

[1] Bird, M.D., et al., IEEE Transactions on Magnetics, **32**, no. 4 (July 1996).

NHMFL Commissions Second 33 T Magnet on April 9. The innermost coil of this system uses a high strength copper-silver alloy developed at the National Research Institute for Metals. This new material runs at a higher current density than the copper-beryllium alloy material used in the NHMFL's first 33 T magnet, allowing it—very impressively—to consume 10 percent less power than its predecessor. This demonstration was critical to the development of the resistive insert for the 45 T Hybrid, which will use some of the innovative design features tested in this magnet.

Update on the 60 T Quasi-Continuous Magnet at Los Alamos. Commissioning of the 60 T Q-C magnet is winding up this spring. All of the design goals have been met and the system has been working beautifully. The magnetic field waveform pattern used for commissioning is shown in the Figure 1. The waveform is one of an infinity of waveforms that the magnet can produce within the envelope of maximum field of 60 T and system I^2t limitations. Additional information on this magnet was published in the Winter, Spring, and Fall 1997 issues of NHMFL Reports.

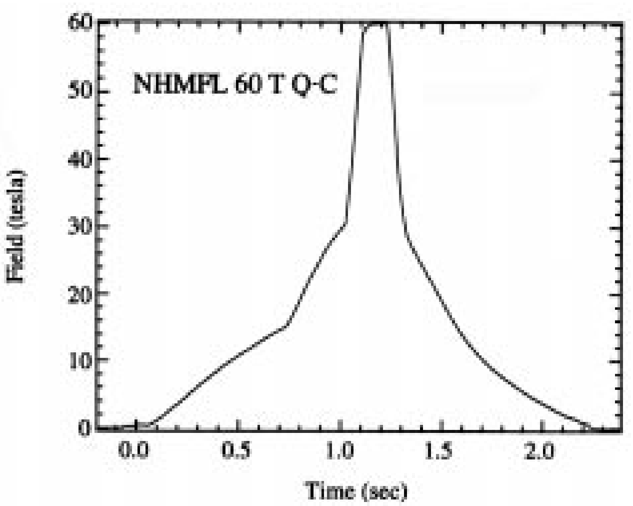


Figure 1. The magnetic field waveform used for the commissioning phase of the 60 T Q-C magnet. The magnetic field is held constant for a duration of 100 milliseconds at the peak. The rounding of the leading edge at field peak will be reduced when the power supply control parameters are optimized.

NHMFL Receives Significant NSF Grant. The NHMFL recently received support from NSF for an NMR spectrometer for the 19.6 T Magnex Scientific magnet. This narrow bore (31.6 mm) superconducting magnet with 1 ppm homogeneity over a 1 cm diameter spherical volume is the highest field persistent superconducting magnet for NMR spectroscopy in the world. The $557,750 award was for the spectrometer console, NMR probes, and for a Resonance Research field mapping device that will be used to map both this magnet and other magnets at the NHMFL accurately. Art Edison, Steve Gibbs, and Denis Markiewicz were co-principal investigators, and while Tim Cross was the principal investigator, the writing of this proposal represented a major team effort by more than 20 faculty in the NHMFL NMR program. At the present time, negotiations are ongoing with Bruker Instruments and Varian for a contract on the spectrometer, and the order is being placed with Resonance Research for the field mapping device.

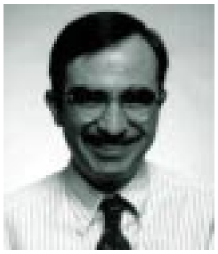
What New on the NHMFL Website.

- 1997 NHMFL Annual Report, Volume 1–Research http://www.magnet.fsu.edu/publications/index.html
- Megagauss VIII and PPHMF-III conference information and registration (see also, conferences, page 13) http://www.magnet.fsu.edu/whatsnew/index.html
- Virtual microscope for exploring optical and electron microscopy http://micro.magnet.fsu.edu/virtual/index.html

NHMFL
1997 Annual Report
Volume I

VIII th INTERNATIONAL CONFERENCE on MEGAGAUSS MAGNETIC FIELD GENERATION & RELATED TOPICS

People in the News



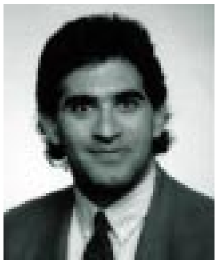
Timothy A. Cross, professor of chemistry and director of the NMR Program at the NHMFL, was recently named to the editorial boards of the Journal of Magnetic Resonance and the Biophysical Journal. JMR is the premier technique development journal in the field of NMR. He joins Alan Marshall, Raymond Andrew, Betty Gaffney, and Naresh Dalal on this board, illustrating the impact that the NHMFL is beginning to have in the field of magnetic resonance. BJ is the flagship journal of the Biophysical Society and Cross has been invited to the board representing the growing field of biological solid-state NMR.

Jack Crow, director of the NHMFL, is serving on FSU's Commission on the Future, a group of faculty leaders charged by FSU President Talbot D'Alemberte with developing a consensus vision for the future of the university. Crow was one of three distinguished speakers at the commission's February meeting, where he addressed, among other issues, the critical need to integrate research into the undergraduate experience. Crow remarked that "it is through the involvement of scholarship that the learning process occurs."

Betty Gaffney, a professor with the Institute of Molecular Biophysics, was recently appointed to the editorial board of Journal of Magnetic Resonance for a three-year period. She also continues on the editorial board of Annual Review of Biophysics and Biomolecular Structure. In both cases, her aim is to support and promote magnetic resonance applications to structural biology. On a related note, Dr. Derek Marsh, of Max-Planck-Institut fur Biophysikalische Chemie, Gottingen, Germany, visited Gaffney's lab in February for high frequency EPR studies of model membranes; he also gave lectures at FSU and UF.

Adriana Moreo, associate professor of physics and a theorist with the NHMFL Condensed Matter/Theory Group, received one of only twenty summer research grants awarded university-wide by FSU. The financial support will supplement her research program, the "Computational Studies of Models for Manganites." Moreo serves as a Member-at-Large to the Executive Committee of the Division of Computational Physics of the American Physical Society.

Robert J. Schrieffer, NHMFL chief scientist, was selected to serve on an external task force charged by FSU President Talbot D'Alemberte with reviewing numerous issues and opportunities facing Florida and FSU and identifying future directions for the university. Over 30 business, education, and civic leaders from across the state were chosen for this committee; Schrieffer is one of only three university representatives (engineering professor and former astronaut Norm Thagard being another).



Justin Schwartz, associate professor of mechanical engineering and group leader for HTS Magnets and Materials at the NHMFL, is the new editor for the Magnets and Magnet Applications section of IEEE Transactions on Applied Superconductivity. Schwartz succeeds John Miller, the head of the laboratory's Large Superconducting Magnet Systems group.

PEOPLE IN THE NEWS continued on page 15

Conference and Workshop Activity

VIIIth International Conference on Megagauss Magnetic Field Generation and Related Topics (Megagauss VIII)

October 18-23, 1998
NHMFL
Tallahassee, Florida
Complete Information & Registration:
http://www.magnet.fsu.edu/whatsnew

The VIIIth International Conference on Megagauss Magnetic Field Generation and Related Topics is expecting over 200 scientists from around the world. Discussions will focus on the latest results on the generation of very high magnetic fields at the megagauss level and higher.

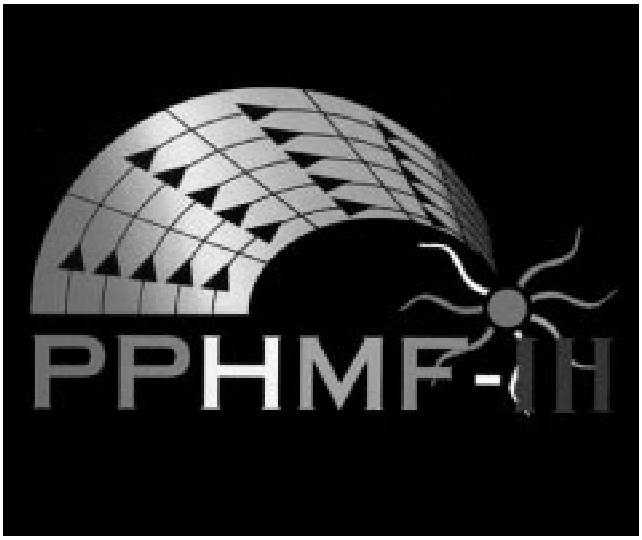
Pre-registration ($450) is due by August 1; late registration will be accepted at a higher rate. For further information, see the website or contact Ysonde Jensen (850-644-0807, Megagauss@magnet.fsu.edu, (fax) 850-644-0867).

Physical Phenomena at High Magnetic Fields (PPHMF-III)

October 24-27, 1998
NHMFL
Tallahassee, Florida

Complete Information & Registration:
http://www.magnet.fsu.edu/whatsnew

Deadline for Abstracts & Pre-registration:
Extended to May 31



Megagauss VIII and PPHMF-III are planned back-to-back intentionally, because many of the interesting science and research developments in these areas overlap. PPHMF-III is anticipating over 175 participants and forty speakers. The program will cover a broad range of materials and phenomena, including semiconductors, magnetic materials, superconductivity, organic solids, quantum Hall effect, chemical and biological systems, and the technological use of high magnetic fields.

For further information, check out the website or contact Mary Layne (850-644-3203, layne@magnet.fsu.edu, (fax) 850-644-5038).

New Physics Building Dedicated at UF

An impressive array of scientists, educators, and politicians gathered for the dedication of the New Physics Building at the University of Florida in Gainesville on April 9, 1998. The building represents far more than "bricks and mortar," as it brings together a department that had been operating out of four different locations on campus.

The new building spans 215,000 square feet (about two-thirds the size of the NHMFL in Tallahassee) making it one of the largest and most modern physics research and teaching facilities in the country. Neil Sullivan, UF Physics chair and NHMFL co-principal investigator, said of the complex:

> "The New Physics Building at UF has been a crucial factor in developing our new frontier research and educational programs. Without the additional space, we could not have developed the new experimental research efforts or modernized our instructional programs. Bringing all the department activities together will forge new synergisms that will lead to exciting new endeavors and allow us to build our undergraduate and graduate programs to the levels needed for the future."

The only facet of the Physics Department that did not relocate is the Microkelvin Laboratory, which houses the NHMFL's High B/T facility (see Attention Users, page 7).

Other facts about the building include the following:

- The oak tree gracing the front of the building is one of the oldest in North Central Florida; it was saved at the request of students and faculty.
- Total building cost: $31.5 million.
- It is the costliest non-medical building ever constructed at UF.
- The ground floor contains experimental research labs, modern machine and electronic shops, a 20-ton interior mobile crane, and an advanced cryogenic facility. Many of these activities are situated on separate foundation slabs to create vibration-free and ultra-quiet environments.
- The first floor comprises computer-equipped classrooms, a 350-seat auditorium and a 100-seat lecture theater (both equipped with specialized multimedia facilities), teaching labs, and tutoring rooms.
- The second floor houses faculty offices, conference rooms, and major computer facilities.
- The UF Physics Department taught approximately 9,500 students in 1996-97.
- Approximately 60 percent of all students who graduate from UF take a course in physics.

"When you see a building like this, it represents to me an enormous responsibility...because what we have here is a response—a very vigorous response—to the pundits of limited grasp who predict the end of science, the end of physics."

—Leon M. Lederman, Nobel Laureate, Director Emeritus of Fermi National Accelerator Laboratory, and dedication speaker

Jim Ferner
NHMFL Director of Facilities and Administration

One of the original charges to the NHMFL was to establish a magnet science and technology program in partnership with the private sector that enhances magnet and magnet materials technology and furthers U.S. competitiveness. A host of industrial, inter-agency, and international collaborations fostered since the laboratory's inception in 1990 attest to the laboratory's commitment to fulfilling this charge.

"U.S. competitiveness," however, also begins at home, and Jim Ferner, who oversaw the on-time and under-budget completion of the NHMFL facilities in Tallahassee in 1994 has become increasingly involved in regional economic development issues. First, he is the NHMFL Director's designated representative on and treasurer of the Leon County Research and Development Authority Board of Directors. The Authority is the owner and developer of Innovation Park, a 208-acre, university-related research and development park created to attract industry in support of the research and educational objectives and goals of historically black Florida Agricultural and Mechanical University (FAMU) and FSU. The NHMFL is the major facility in the park. The park presently comprises 27 other tenant organizations (including NHMFL-partner EURUS Technologies) occupying 289,000 sq. ft. and employing 1,100 people in addition to the NHMFL.

The Authority has recently undertaken a major new thrust in promoting regional economic development by forming an alliance with the regional Economic Development Commission to act as its marketing arm. This initiative has resulted in a major increase in community involvement in the development of the park, as well as in the promotion of the research capabilities of FSU, FAMU, the joint College of Engineering, and the NHMFL.

Ferner also was recently appointed to the Strategic Planning Committee of the Economic Development Commission (EDC). The Commission is supported by the city, county, universities, and private interests for the purpose of promoting economic development in Leon County and the surrounding region. This committee is reviewing the current strategic plan of the EDC and suggesting new thrusts and activities aimed at enhancing the effectiveness of the commission.

In addition, Ferner is active with the Gulf Coast Alliance for Technology Transfer (GCATT), a consortium of seven military labs, five universities, one community college, and the NHMFL, spanning the area from Mobile, Alabama, to Gainesville, Florida, home of NHMFL operating partner, the University of Florida. The purpose of GCATT is to assist the member institutions in commercializing new technologies, and regional economic development is a natural spin off of this activity.

Ferner's involvement with these organizations—much like Dr. Crow's participation on FSU's Commission on the Future and Dr. Schrieffer's role on the university task force (see page 12) —suggests that the NHMFL and its senior faculty and staff are now widely regarded as key players in the future of the university, the region, and the State of Florida.

NATIONAL HIGH MAGNETIC FIELD LABORATORY

NHMFL REPORTS

Florida State University • University of Florida • Los Alamos National Laboratory

Published by :

National High Magnetic Field Laboratory
1800 East Paul Dirac Drive
Tallahassee, Florida 32310
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