NHMFL REPORTS
NATIONAL HIGH MAGNETIC FIELD LABORATORY
FALL 1997
Florida State University • University of Florida • Los Alamos National Laboratory

OPEN HOUSE 1997

Enhancing Public Awareness of Science and Technology

The 4th Annual Open House of the National High Magnetic Field Laboratory on Saturday, October 11, attracted a huge crowd of 3,568 people to the laboratory's facilities in Tallahassee. Nearly seventy-five percent of these visitors were making their first trip to the laboratory; almost half of them were K-12 students; and a large number were elderly. The attendance was more than double the very successful 1996 event.

By all accounts, the laboratory basked in the warmth of beautiful Florida skies: Our guests gained a genuine appreciation for the world-class facilities of the NHMFL and the outstanding—and enthusiastic—faculty and staff who comprise the "Magnet Lab."

The open house is traditionally held in early October on the anniversary of the laboratory's dedication on October 1, 1994. During this once-a-year event, the laboratory opens its doors to the general public for a fun-filled day of science, discovery, and even a little magic. This year's extravaganza featured exciting new demonstrations, hand-on activities, a self-guided tour, and extensive new displays and videos. These efforts are all designed to explain magnetism and the importance of science and technology to our quality of life, to regional economic development, and to the competitive position of the United States.

The pictures on pages 8 and 9 tell the story of Open House 1997—a great day for science awareness that reached thousands of people and received extensive television, radio, and front-page newspaper coverage.

GAMMA: AN EDUCATIONAL TOOL FOR MAGNETIC RESONANCE

GAMMA—A **G**eneral **A**pproach to **M**agnetic Resonance **M**athematical **A**nalysis—was first featured in the Summer 1996 Issue of *NHMFL Reports*. As part of CIMAR, GAMMA provides computational support to visiting users at the NHMFL in need of MR-related simulations. It is also widely used in research institutions around the globe, both academic and corporate. Since its release to the general public about three years ago, there has been a growing list of scientific papers that reference use of GAMMA—well over thirty citations as of early 1997. We are proud that this list now contains two authors who are Nobel laureates: Dr. Richard Ernst who won the prize for work in NMR (and in whose laboratories GAMMA was conceived) and this year's winner in medicine, Dr. Stanley Prusiner.[1,2]

GAMMA's popularity in the magnetic resonance research community stems from its modularity and flexibility. GAMMA users assemble objects commonly found in MR descriptions to achieve their specific simulations. This flexibility, which makes GAMMA an invaluable research tool, also provides an excellent means for teaching magnetic resonance concepts on both beginning and advanced levels. Students and educators alike have an easy means of examining both the mathematical basis of MR (Hamiltonians, spin operators, spherical tensors, etc.) as well as MR experimental aspects (pulse sequences, phase cycles, data processing, etc.). This article highlights some of the ways the platform is currently being used for educational purposes.

The GAMMA WWW site, ***http://gamma.magnet.fsu.edu***, in part serves as an educational outreach. Users anywhere in the world may access these pages to run illustrative simulations, learn the background mathematics, and download associated GAMMA programs for local use. Two specific examples are given in the following sections.

GAMMA *cont. on page 4*

From the Director's Desk

1997 NSF Site Visit

In early October, the National Science Foundation External Review Committee conducted its annual site visit of the NHMFL. On several previous occasions the committee met in Tallahassee, and in 1996, the committee met at Los Alamos National Laboratory. This year the review was held at our partner institution, the University of Florida in Gainesville.

As the director of the laboratory, I am considering asking the NSF to suspend these site visits for a few years, as the convening of them has coincided with the unanticipated departure of people who have been vital to the laboratory's development and success. We cannot afford to lose any more of these distinguished leaders! You will recall that during the 1996 site visit, Sig Hecker's departure from LANL was announced. This year, to our great surprise, Dr. Charles B. Reed, the Chancellor of the State University System of Florida, announced his move to California to become Chancellor of the California State University System. While we certainly wish to congratulate him, his departure leaves us without our strongest and most steadfast ally. Without any doubt, the person who deserves the greatest recognition for this laboratory's establishment in Florida in 1990 is "Charlie" Reed, as it was his commitment to its vision that forged this extraordinary federal-state, multi-institutional partnership. Beginning in 1990, and continuing through to the present, his leadership and interactions have redefined the term "cooperation" and have played a pivotal role in the NHMFL's early and continuing success. We trust that his move to the West Coast will open new opportunities for inter-state and multi-university collaborations, and that he will continue to share his unique perspective and counsel with his old friends in the Sunshine State.

Another, perhaps even more personal, departure was also recognized at the NSF site visit—that of Larry Campbell, who has served as the director of the NHMFL Pulsed Field Facility (PFF) at Los Alamos since its inception. Drs. Parkin, Sullivan, and I presented Larry with the first NHMFL Distinguished Service Award for his many contributions to science and research in ultra high magnetic fields. Larry guided the establishment of the first U.S. PFF and nurtured its development during the last six critical years. In addition, he brought a truly international focus to high field research through the Dirac Series, which joins researchers from six countries to investigate phenomena never before measured. These experiments are already opening new frontiers in science, as discussed in the last issue of *NHMFL Reports*. Larry's leadership and contributions to many aspects of the laboratory will be missed, and we hope that he will always look upon the NHMFL as home and its faculty and staff as friends.

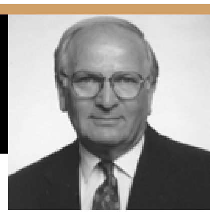
Readers of this column are probably wondering if any "work" was accomplished at this year's site visit. Indeed there was. Committee members received a series of presentations over two days covering the broad spectrum of NHMFL programs—from progress reports on the Hybrid and the 900 MHz magnet systems, to user activity updates, to a review of present and planned educational programs. We have not received the committee's report yet, but preliminary discussions suggest that the NHMFL continues on course to meeting its missions and goals.

One issue that did come up (and one already identified by NHMFL management) is that the laboratory must—at this critical juncture in its evolution—plan for the future. The Executive Committee of the laboratory has discussed the need for long-term planning frequently, and we recognize the need to set new targets and matrices. More of our time is being devoted to long-term strategies, and we look forward to new discussions with the Users' Committee, which will meet at LANL in November, and with the External Advisory Committee, which will meet in January.

Aside from the uncanny connection of NSF site visits to the departure of key associates, they serve as vitally important motivators. The leadership of the NHMFL very much appreciates the committee's recognition of the laboratory's progress and success to this point, and we rededicate ourselves to avoid the complacency that so frequently accompanies achievement.

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



Continuing the tradition of reporting on exciting recent discoveries at the NHMFL, this issue reports on studies by C.H. Mielke and associates at LANL. They studied the Fermi surface of an organic compound that has many properties in common with high temperature superconductors. Prior to these measurements, there was substantial belief that the lack of observation of a Fermi surface in this material placed it in the same category as the high T_c cuprates, which show anomalous transport and are unconventional metals. This work illustrates the crucial importance of high quality sample preparation and measurements in this challenging area of research.

R. Schrieffer

κ-(ET)$_2$Cu[N(CN)$_2$]Br Found to be a Fermi Liquid

C.H. Mielke, N. Harrison, R.M. Vestal, L.K. Montgomery, J.D. Thompson, D.G. Rickel, and A.H. Lacerda

Interest in the superconducting and normal metallic state properties of organically based superconductors has been fueled by similarities to the "high T_c" cuprate systems. Both systems are layered (quasi-2D), have negligible or inverse isotope effects on T_c,[1] exhibit spin fluctuations,[2,3] have a relatively low carrier concentration (~10^{22} carriers/cm^3) compared to normal metals, and are thought to possess unconventional pairing mechanisms.[4,5,6] Despite the similarities, the cuprate systems have T_c's that are nearly an order of magnitude greater than the radical cation-based organic systems. Organic systems, however, have the distinct advantage of being electronically cleaner, and thus more information regarding the electronic structure (Fermi surface) is accessible, especially at facilities like the NHMFL.

Measurements of the Fermi surface are made by observation of Shubnikov-de Haas (SdH) and de Haas-van Alphen (dHvA) quantum-oscillatory effects. These phenomena often are observed in pure metals and readily occur in organic conductors. Detailed experiments studying the Fermiology of organic superconductors have brought forth an understanding of how subtle changes of the band structure can result in superconducting, spin density wave, insulating, and metallic ground states as well as verifying the validity of the Fermi-liquid description. Ironically, the highest T_c radical cation-based organic superconductor κ-(ET)$_2$Cu[N(CN)$_2$]Br (Tc = 11.6K), first synthesized in 1990,[7] previously has shown no such indications of quantum-oscillatory effects at ambient pressure. The apparent lack of an observable Fermi surface as well as other magnetic measurements has aroused considerable interest in the possibility that κ-(ET)$_2$Cu[N(CN)$_2$]Br possesses a non-Fermi-liquid ground state.

Transport and magnetization have been attempted on κ-(ET)$_2$Cu[N(CN)$_2$]Br by numerous researchers in pulsed and static fields; however, the only indication of a Fermi surface stemmed from measurements performed under a hydrostatic pressure of ~7 kbar.[8] Recently, high quality single crystals were synthesized at Indiana University by Montgomery's group. Transport measurements[9] performed at NHMFL-Los Alamos in fields of 60 T, see Figure 1, showed for the first time quantum oscillations in κ-(ET)$_2$Cu[N(CN)$_2$]Br at ambient pressure. A careful analysis of the temperature dependence of the quantum oscillations indicates Fermi-liquid behavior. The observed frequency of 3798 ±5 T corresponds to 100% of the Brillouin zone area (to within 0.1%). Low temperature crystallographic measurements and band structure calculations predict a closed hole pocket nested between two 1-D sheets. Magnetic breakdown between the closed pockets and the 1-D sheets result in an SdH frequency equal to the Brillouin zone. It is interesting to note that

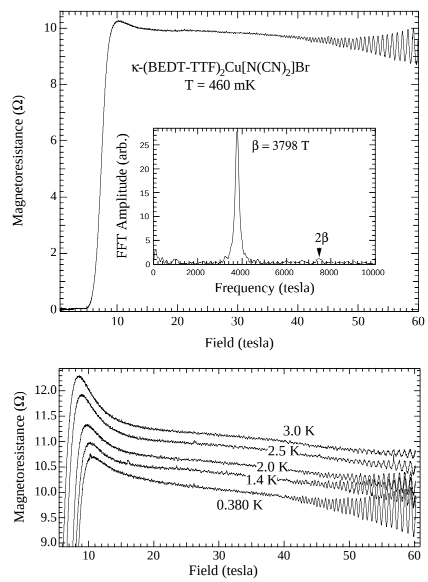


Figure 1. Magnetoresistance of k-(ET)$_2$Cu[N(CN)$_2$]Br, showing quantum oscillations beginning at ~38 T. Measurements were made at T=460 mK The inset shows the FFT amplitude with a peak at 3798 T. The lower figure shows the temperature dependence to fields of 60 T. Note the negative slope extending to the highest fields.

the measurements, shown in Figure 1, indicate a negative slope to the magnetoresistance. Further investigation in a DC magnet to 18 T showed a temperature dependence of the negative slope. In some model systems, a negative magnetoresistance is due to randomly oriented magnetic impurities. An applied magnetic field polarizes the impurities and reduces the scattering as the field intensity increases. Our observation is consistent with such behavior. It is well known that one of the starting

FERMI LIQUID *cont. on page 5*

GAMMA *cont. from page 1*

The Bloch Equations Online

One of the earliest of magnetic resonance concepts presented to students is that of a classical magnetization vector evolving under the influence of applied static and rf magnetic fields. The phenomenological Bloch equations are used to precisely describe this evolution. Still, it can be difficult for students to visualize magnetization evolution based on mathematical arguments (rotating frames, effective fields, relaxation rates, etc.).

As such, there is now an online GAMMA simulation that embodies this Bloch picture. Its URL is ***http:// gamma.magnet.fsu.edu/online/relax/bloch/.***

Students can input their own rf-field conditions and relaxation parameters to run Bloch calculations from their WWW browser, see Figure 1. The GAMMA program will return both two-dimensional (1D) and three-dimensional (3D) plots of magnetization evolution. Figure 2 is the three-dimensional (3D) plot returned from one such simulation. This shows initial magnetization evolving to a steady-state condition under the influence of an applied rf-field of phase 45 degrees and an offset of 20 Hz.

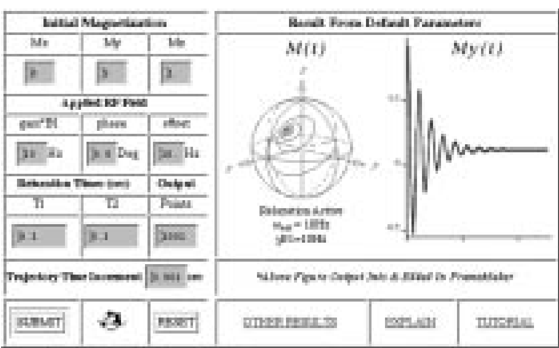


Figure 1. Sample Bloch calculation run by GAMMA program.

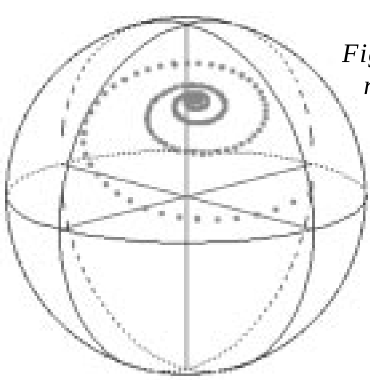


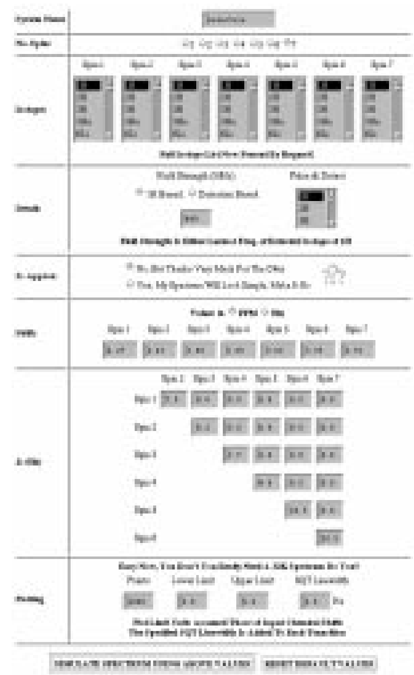
Figure 2. Sample 3D plot returned from a GAMMA simulation showing initial magnetization evolving to a steady-state condition under the conditions and parameters entered into the program.

1D NMR Online

The simplest pulse sequence, a hard pulse followed by data acquisition, will likely be the first NMR experiment run by a student. Those learning magnetic resonance, as well as students in organic chemistry, spend a good deal of time interpreting the resulting spectra, not always a trivial task when one considers strong coupling effects, magnetic equivalence, and the multitude of possible spin networks.

We have put a generic heteronuclear 1D NMR simulator on WWW, see Figure 3. By entering in spin isotope types, chemical shifts, and coupling constants, users can directly obtain both a spectrum and a listing of the transitions therein. The program URL is ***http:// gamma.magnet.fsu.edu/online/nmrliq/1D/ Spectrum/.***

Figure 3. Sample generic heteronuclear 1D NMR simulator available via GAMMA.



Although this type of 1D simulation is rather simple when treating isotropic liquid samples, a surprising number of students and researchers don't have local access to such a program. Access via internet to the GAMMA WWW site allows anyone in the world to perform 1D simulations. Dr. W. Bauer (Institute for Organic Chemistry, University of Erlangen, Germany) used this remotely for his research on lead-phosphorous compounds, and Dr. J. S. Moore (Department of Chemistry, University of Illinois) used this to teach organic chemistry students about strong coupling.

Other Online Simulations

We are continually expanding the GAMMA WWW site, slowly adding more online simulation programs that illustrate simple and complex MR concepts. Current programs feature:

- 1D NMR FIDs with WBR Relaxation
- Isotropic ESR Spectra
- Quadrupolar Powder Patterns
- Gaussian Shaped Pulses
- Rectangular Pulse Profiles
- Q3 Gaussian Cascade Pulses
- Dipolar Powder Patterns
- Spin Echoes in Gradients
- Mutual and Non-Mutual Exchange
- COSY, E-COSY, Soft-COSY

GAMMA *cont. on page 5*

FERMI LIQUID *cont. from page 3*

materials in the synthesis of κ-$(ET)_2Cu[N(CN)_2]Br$, namely CuBr, is susceptible to a decomposition process that results in conversion of Cu(I) to Cu(II). Cu(II), having a magnetic moment, is likely to be the source of the magnetic impurity. Further evidence supporting this hypothesis was obtained in magnetization and transport studies performed on crystals containing approximately 1% of Cu(II); these crystals showed no indication of the SdH effect. Magnetization measurements performed on crystals that showed the SdH effect indicated that Cu(II) concentrations were reduced to levels nearing the resolution of the SQUID magnetometer.

Determinations of the Dingle temperature and scattering length on crystals that exhibited quantum oscillations resulted in T_D=3.4 K and a scattering length of 250 Å. This Dingle temperature is rather high and the scattering length is nearly an order of magnitude shorter compared to most organic superconductors, which exhibit quantum oscillations. Magnetic impurities resulting in an increased Dingle temperature and a reduced scattering length easily could have masked the SdH effect in earlier measurements and also give rise to the observed spin fluctuations.

We would like to acknowledge M. Pacheco, W. Bowman, and S. Roybal for their efforts in this study. The state-of-the-art facilities at NHMFL-Los Alamos were made possible by the National Science Foundation, the State of Florida, the Department of Energy, and Los Alamos National Laboratory. Research at Indiana University was sponsored by the Division of Materials Research of the National Science Foundation (NSF DMR-9414268).

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GAMMA *cont. from page 4*

- Pulse Offset Effects
- Dipolar - Shift Anisotropy Powders
- Dynamic Frequency Shifts
- Cross Correlation, Relaxation Effects

Many of these are being collected into a single simulation engine that will eventually become part of a planned "virtual" spectrometer.

A Virtual NMR Spectrometer

Nuclear magnetic resonance (NMR) is used in many different areas of scientific research. Despite the fact that a modern NMR spectrometer can cost well in excess of a million dollars, they remain in high demand. Not surprisingly, these instruments operate 24 hours a day and research time on such machines is a valuable commodity. There are two areas in which computer simulation can help optimize spectrometer usage.

First, spin system response to an applied pulse sequence can be simulated *prior* to its implementation on a spectrometer. There are often several parameter settings (pulse lengths, delay times, phase cycle, etc.) that are critically important to an experiment's success. Keep in mind that some experiments take several days of instrument time—time that potentially could be wasted if parameters are inadvertently mis-set. A simulation that implements the proposed pulse sequence and uses the exact input parameters would point out whether conditions are favorable for experimental success.

Second, because simulations can mimic spectrometer operation quite well, students could learn the many facets of setting up and running an NMR spectrometer (shimming, pulse calibration, pulse sequence programming, data processing, etc.) without taking any time away from research efforts. They will also encounter the same experimental pitfalls without the possibility of damaging expensive equipment.

We have begun work on a WWW based virtual spectrometer, with GAMMA serving as its computational core. The spectrometer URL is ***http://magnet.fsu.edu/virtualnmr*** for readers wishing to watch its development. This is a joint project between Drs. S.A. Smith, Michael W. Davidson, and Sam Spiegel. Dr. Davidson is an expert in WWW server performance (http://micro.magnet.fsu.edu). Dr. Spiegel runs the highly successful educational programs based here at the NHMFL (http://k12.magnet.fsu.edu).

This article was contributed by Scott A. Smith. GAMMA was written by Dr. Smith and Tilo Levante while working for Dr. R.R. Ernst at the ETH, Zurich. Dr. Smith is now an assistant in research at the NHMFL and coordinates GAMMA development. He may be contacted at 850-644-6348, ssmith@magnet.fsu.edu.

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Unique Magnetism Curriculum Distributed to Florida Schools

L to R: NHMFL Director Jack Crow, Leon County Superintendent of Schools Bill Montford, K-12 Educational Programs Director Sam Spiegel, and Florida Commissioner of Education Frank Brogan.

In March, 1997, the NHMFL received a $100,000 grant from the Florida Department of Education for a new science curriculum package for middle school students and teachers. The K-12 Education Programs group of the laboratory had been developing and field testing a prototype product since mid-1996, but the grant, which came through the county school system, pushed the initiative into high gear. After months of intensive effort, an important new educational resource—named *MagLab: Alpha*—was released this fall. The release and distribution of *MagLab: Alpha* to 200 Florida classrooms was announced at a press conference held at the laboratory on October 2 by Florida Commissioner of Education Frank Brogan, the Leon County Superintendent of Schools Bill Montford, and NHMFL Director Jack Crow.

The need for magnetism curriculum materials was identified by the NHMFL in the early 1990's, when the laboratory was developing a traveling exhibit on electricity and magnetism with the Museum of Science and Industry in Tampa, Florida. Through various outreach activities in 1995 and 1996, teachers from across the state confirmed the lack of quality teaching and learning materials on magnetism and began to tackle the challenge of creating *MagLab: Alpha*.

Under the direction of the laboratory's two full-time educators, nine teachers joined with students, scientists, and researchers to develop a new standards-based interdisciplinary curriculum package to study magnets, magnetism, and related concepts. Its design was based on national and state standards for science and mathematics education, as well as other content area standards, and is intended to support a vision of reform in the science classroom. The materials allow students to explore a variety of concepts that lead to further student research and discovery. Furthermore, activity-based materials are included that allow both the teacher and the student to assess and evaluate student learning. The collaborative nature of the materials models how science is done in real-world research institutions.

MagLab: Alpha consists of three parts: the Alpha Guidebook, the Alpha Pack, and the Alpha Interface. The three parts are coordinated by the "Alpha Team," a group of characters who represent the idea of working through hands-on activities as a team of students.

Plans for *MagLab: Alpha* include an agreement with a national publisher of educational materials to facilitate nationwide distribution. For more information on *MagLab: Alpha*, contact Pat Dixon, K-12 Educational Programs, 850-644-4707, *pdixon@magnet.fsu.edu*.

- The Guidebook takes students on a journey to find out more about magnets and magnetism. As students complete each "Expedition," they are encouraged to take advantage of suggested "Excursions" that link magnets and magnetism to mathematics, literature, language arts, geography, history, world cultures, art, and music. The Guidebook provides background information, instructions for teachers on how to use the materials, and discussions of issues that enhance teaching and learning in the science classroom.
- The Alpha Pack contains all the equipment (gear) necessary to complete each of the Expeditions. Materials in the Pack are nonconsumable and include resources necessary to engage a class of up to thirty-six students.
- The Alpha Interface is a CD-ROM that is closely aligned with the Alpha Guidebook to provide support for both students and teachers. The Interface can be used to directly support learning in the Expeditions or to launch deeper probes into areas of interest. Features include graphics and animations of complex concepts, an interactive interpreter that helps students choose the correct path, and in-depth information that both informs and leads students to further study.

The creators of *MagLab: Alpha* provided a three-day training session at the NHMFL for representatives of Florida's Area Centers for Educational Enhancement (ACEE), including university educators, classroom teachers, county science coordinators, science supervisors, and ACEE coordinators. Participants worked through activities, explored the materials, and prepared plans to disseminate 200 *MagLab: Alpha* packages to Florida middle schools. Some of their comments reflect the positive reception of *MagLab: Alpha* by educators.

"MagLab: Alpha is a fantastic program which encourages student-centered learning. The program *involves* students in the learning process where they are developing and using problem-solving skills. The program also allows the teacher to be a learner as well as a facilitator."

ACEE Representative, Lake County

"This type of consortium with the NHMFL is the type of help that we teachers in the state need to promote science instruction in the schools. I am sure that there are other such possibilities available. Please continue to promote such activities."

ACEE Representative, Dade County

Attention Users

Larry Campbell
Director, Pulsed Field User Programs

There have been several recent user developments at the Pulsed Field Facility.

- Alex Lacerda assumed responsibility for managing the user program at the Pulsed Field Facility on September 3. In addition, Alex will undertake certain responsibilities for user support currently exercised by Dwight Rickel, who will soon begin a six-month sabbatical at the Australian National Pulsed Magnet Laboratory. All requests for magnet time should now be sent to Alex at *lacerda@lanl.gov*. His phone is 505-665-6504; fax is 505-665-4311.

For some time, Alex has successfully managed the user program for the 20 T superconducting magnet. The above change expands his role to include the capacitor driven magnets and the 60 T quasi-continuous magnet, and overall coordination of the Pulsed Field Facility user program. I am sure you will experience the highest levels of care, expertise, and response with Alex.

- In August, Paul Pernambuco-Wise and Benny Lesch brought some prototype (capacitor-driven) user magnets to Los Alamos for testing, with dramatic results: the 15 mm bore magnet reached 73 T and the 24 mm bore magnet reached 64 T. Neither magnet exploded at its maximum field but showed more subtle damage that halted the tests.

These tests mean that the old standards of 50 and 60 T for the workhorse 24 and 15 mm bore magnets can be upgraded to 60 and 70 T, respectively. Users may wish to stay a few tesla below the maximum fields to increase the magnet lifetime until we gain more experience with the new magnets.

At the present capacitor bank voltage of 10 kV the new magnets tend to overheat, so modifications are planned to raise the voltage to 12 kV, which will make the pulse length somewhat shorter. A favorable thermal property of the new magnets is their approximately 40 percent faster cool-down time.

- The 60 T, 32 mm bore quasi-continuous magnet is now undergoing commissioning tests and has already reached 60 T—a world's record for this type of magnet. (Quasi-continuous means the maximum field can be held constant for 100 ms.) When the first data are taken at 60 T an appropriately restrained announcement (fireworks and brass bands) will be made to the international user community.

Besides being the most powerful of its class in the world this magnet is also the first of its kind in the United States. It promises to be a significant new research tool—and requests for time have already been received from leading industrial and university research centers in the United States and abroad. User experiments are expected to begin in November. A variable temperature insert is nearing completion, a He-3 cryostat is being constructed, and a top-loading dilution refrigerator with a 17 mm sample space is on order.

- The NHMFL Executive Committee chose two Pulsed Field Facility user projects for further study to develop conceptual designs and assess costs:

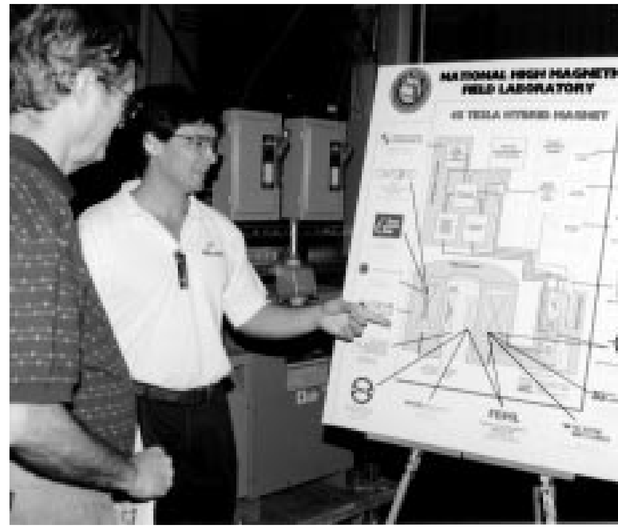
1. ***A modulation and compensation coil for the 60 T quasi-continuous magnet.*** This would provide deep modulation (i.e., having an amplitude of 1 to 2 T) at 60 T for de Haas-van Alphen, Shubnikov-de Haas, and cyclotron resonance experiments; and active field ripple compensation by an order of magnitude or more. Because the innermost coil of the 60 T magnet would be used there would be no reduction of bore size.

2. ***A single-turn pulsed magnet system.*** This magnet, familiar to users in Japan and Germany, would provide micro-second fields between 100 and 200 T in a 10 mm bore and would not destroy the sample, although the single turn coil must be replaced for every shot.

I will be leaving the NHMFL in December and wish to take this opportunity to say that my interactions with you, the members of the user community, have been a highlight of my present tenure. The coming years show every prospect of being a golden age of high magnetic field research, with the leadership of the NHMFL.

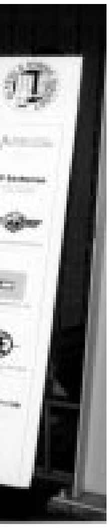
~Larry

Images of



1st Annual NHMFL Skate, Shuffle, and Roll!

Open House



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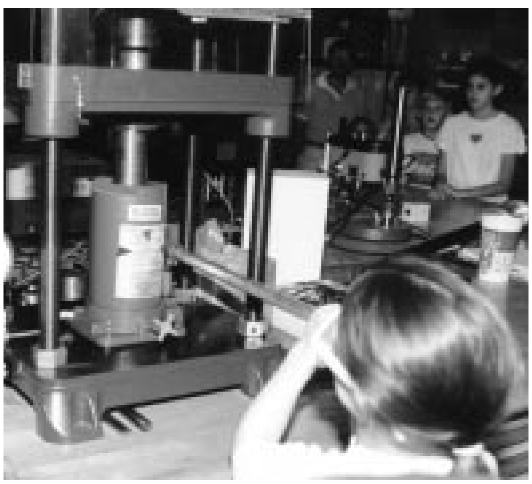


Electron Magnetic Resonance at the NHMFL

EMR spectroscopy is strongly represented at Florida State University (FSU) and the University of Florida (UF) with seven independent groups, headed by Alex Angerhofer, Louis-Claude Brunel, Naresh Dalal, Peter Fajer, Betty J. Gaffney, William (Bill) Moulton and William Weltner. The interests of these groups cover a very broad spectrum—from biology to chemistry and physics. This article centers around the recent achievements of Dr. Brunel's group in high field/high frequency EMR spectroscopy, which from October 1996 to September 1997 supported four user groups from FSU; four from UF; twelve from other U.S. universities; and six from outside the United States.

Although the frequency for which an EMR measurement should be labeled "high frequency" depends on the sample under investigation, most experiments performed at or above 95 GHz (3.4 T) are termed "high field/high frequency." A commercial spectrometer from BRUKER is now available at 95 GHz. In the United States, there are five home built instruments located at Cornell University (170 GHz and 250 GHz), Northeastern University (220 GHz), MIT (140 GHz), University of Illinois (95 GHz), and the NHMFL.

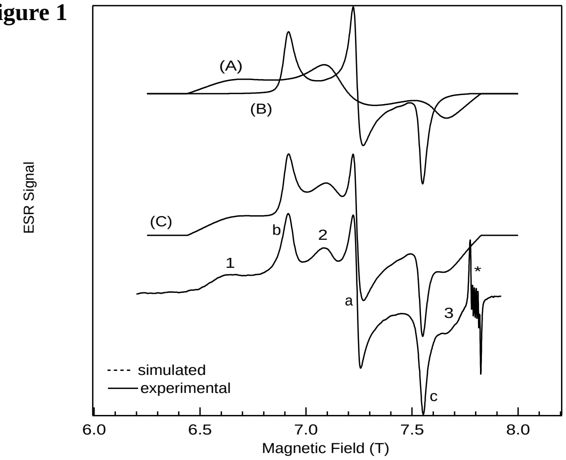
The NHMFL High Field EMR Spectrometer

Frequency range:	95 GHz up to 550 GHz with peak performance at 220 GHz and 330 GHz
Sensitivity (spin/gauss):	with a Fabry-Perot: room temperature: 10^{10}; 4 K: 10^8
Averaging:	up to 100 spectra
Field calibration:	g determination accuracy: +/- 3.10^5
Resolution:	1 to 10 ppm
Sample temperature:	1.4 - 300 K

In-House Research Program Activities

Study of Spin Gapped Low Dimensional Compounds. In collaboration with E. Dagotto (NHMFL Condensed Matter/Theory Group), A. Hassan, G. Martins, L.A. Pardi, and L.C. Brunel are studying Zn doped $CuGeO_3$, a spin-Peierls system. The focus is on the influence of nonmagnetic impurities upon phase transition. Dagotto and Martins conjectured that Zn will introduce states in the gap due to "loose" end of chain spins 1/2. In Figure 1, features a, b, c, are due to normal Cu in the chains; the temperature dependence of the intensity of the features noted 1, 2, 3, absent in pure $CuGeO_3$, undoubtedly demonstrates that these features originate from states in the gap. Figure 1 (A) shows a simulated spectrum for the in gap states; (B) for Cu in the chains; and (C) = (A)+(B).

Figure 1



Alia Hassan joined the EMR group at the very beginning, March 1994, and has been instrumental in the development of the group from both an experimental and a scientific point of view. She defended her thesis in November—the first one from Brunel's group—and Dr. Hassan will assume a postdoctoral position with the EMR group in January 1998.

High Field EMR of the Primary Donor P700+ in Plant Photosystem I. A. Angerhofer from UF is interested in photosynthesis and is conducting this project with P. Bratt, M. Rohrer, and J. Krzystek. One of the challenges is to determine the electronic structure of the primary donor $P700^+$ in photosystem I. One approach is to correlate the g-tensor with the electronic structure of the dimer chlorophyll of the primary donor. High field EMR is needed to resolve the g-tensor components, as can be seen on Figure 2, which displays the spectra of $P700^+$ at 9 GHz (A), 110 GHz (B), 220 GHz (C), 330 GHz (D) and 440 GHz (E). This is the first time that the g-tensor of a chlorophyll radical has been resolved without prior deuteration; this is only possible at or above 330 GHz. No other commercial or home built instrument can tackle this problem.

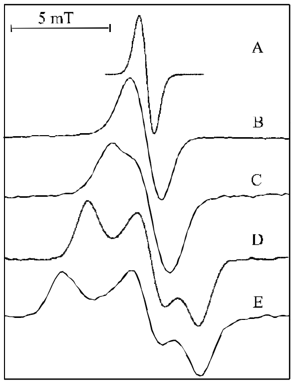


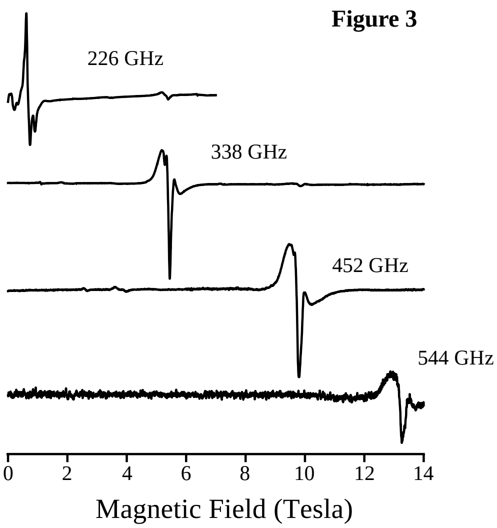
Figure 2

EMR spectroscopy covers a very broad spectrum— from biology to chemistry and physics.

External Users and Visitors Research Program

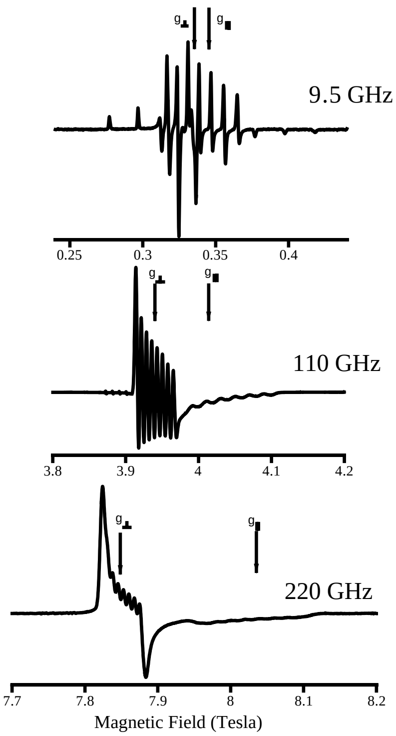
Large Zero Field Splitting Systems. These systems are EMR silent at low frequency. B. Hoffman from Northwestern University is interested in mono and polynuclear Mn(III), which is of central importance in biological systems such as superoxide dismutase, catalase, and photosystem II. The spectra reported on Figure 3 for frequencies from 226 GHz up to 544 GHz are evidence of the interest of a high and multifrequency instrument. No signal can be observed below say 200 GHz, and only a multifrequency study allows for the determination of the Zero Field splitting parameters of the spin Hamiltonian.

Figure 3



High Field EMR of Vanadyl Ion. M. Makinen from the University of Chicago is interested in vanadyl ion (VO^{2+}), which has been extensively used as a spin probe in structural ENDOR investigations of biologically relevant systems. The main motivation for employing high frequency EMR is to separate the two principal components of the axial g-tensor. Typical spectra are displayed in Figure 4: At 9 GHz (top) the hyperfine components are not resolved; the spectrum at 110 GHz shows an almost complete separation of the hyperfine patterns of the principal components of the g-tensor; and the spectrum at 220 GHz presents a much lower resolution due to g-strain effects. For such a system the "optimum frequency" is 110 GHz, and here again the potential of a multifrequency approach is apparent.

Figure 4



Bruce Robinson, professor of chemistry at the University of Washington, Seattle, is visiting the NHMFL for three months. Bruce's interests are in the study of the dynamic of biological materials, like DNA and proteins, in the liquid state. His visit is intended to work at high frequency and to develop spectra simulations with P. Fajer and S. Smith; he has been very pleased and excited by the experimental results recently obtained.

EMR Projects Under Development

The Keck Magnet. A 25 T, 52 mm bore, high homogeneity, resistive magnet, has been funded by the W. M. Keck Foundation. There is tremendous interest in the study of motional dynamics in complex fluids (spin labeled systems of biological interest). Jack Freed, from Cornell University, will be within the NHMFL Visitors Program in 1998 with a research project focused on experiments with the Keck magnet.

The 14 T Transient EMR Spectrometer. This project, funded by the NSF (grant CHE 9601731), involves ten collaborators from four different U.S. universities. This

***EMR** cont. on page 14*

Conference & Workshop Activity

Robert Schrieffer Tutorial Series

October 4–14, 1997
Los Alamos National Laboratory
Los Alamos, New Mexico

The NHMFL, the LANL Center for Materials Science, and the Condensed Matter and Statistical Physics Group (T-11) at Los Alamos are co-sponsoring an annual tutorial series called the *Robert Schrieffer Tutorial Series on High Magnetic Field Phenomena*.

The first series held in October was entitled Extreme Games: Type-II Superconductivity in a Magnetic Field and included four talks given by a former Los Alamos postdoctoral fellow, Zlatko Tesanovic of Johns Hopkins University. The lecture titles were Beyond Abrikosov; Landau Levels in Superconductors I: Quantum Oscillations in High Magnetic Fields; Landau Levels in Superconductors II: Fluctuations and Phenomenology; and Gauge Fields in Superconductors: From Theory to Experiment.

This yearly series is being overseen by NHMFL Chief Scientist Robert Schrieffer, who is a LANL External Fellow. It features prominent scientists presenting lectures on significant developments in high magnetic field research in a tutorial mode in order to be accessible to a wider audience than are technical seminars.

The syllabus and references for Dr. Tesanovic's talks are currently available and notes are being prepared. Contact Lou Miller, lmiller@*lanl.gov*, 505-667-7598 for more information.

High-Tech Florida Means Business

The Future of Science and Technology in Florida: Trends and Indicators
September 29–30, 1997
Orlando, Florida

The NHMFL participated in a major technology conference sponsored by the State of Florida and the American Association for the Advancement of Science and organized by the University of Florida. The laboratory's exhibit featured various industrial partnerships, NHMFL user facilities, and development opportunities stemming from research in high magnetic fields. The meeting attracted over 250 leaders from industry, government, and higher education and focused on issues critical to the state's economic growth in a high-tech environment.

Physics of Manganites, Ruthenates, and Related Materials

November 10–11, 1997
NHMFL
Tallahassee, Florida

The NHMFL hosted a workshop to share information about the physical properties of Mn- and Ru-based transition metal oxides and to discuss science and technology opportunities in this area. Informal meetings such as this one are consistent with the NHMFL's mission to develop an in-house science program and to promote collaboration among scientists and engineers working in areas related to magnetism and magnet development.

In addition to about a dozen NHMFL/FSU faculty members, the list of invited participants included *Robert Guertin*, Tufts University; *Elihu Abrahams*, Rutgers University; *Michael Coey*, Trinity University, Dublin Ireland; *John Goodenough*, University of Texas, Austin; *David Singh*, Naval Research Laboratory; *Stephen Nagler*, Oak Ridge National Laboratory; *Malcolm Beasley*, Stanford University; *Philip Allen*, SUNY; *Jeffrey Lynn*, NIST; *Andrew Millis*, Johns Hopkins University; *Daniel Agterberg*, ETH-Honggerberg; *Andy Mackenzie*, University of Cambridge; *Yoshiteru Maeno*, Kyoto University; *Igor Mazin*, Naval Research Laboratory; *David Johnston*, Iowa State University; *Anton Puchkov*, Stanford University; *Gabriel Kotliar*, Rutgers University; *D. I. Khomskii*, University of Groningen; *David Tanner*, University of Florida; *Arthur Ramirez*, Lucent Technologies; *Dr. Robert Heffner*, LANL; and *Ward Plummer*, University of Tennessee.

8th U.S.–Japan Workshop on High Temperature Superconductors

December 7–10, 1997
NHMFL
Tallahassee, Florida

The NHMFL will host the eighth workshop in this series between members of the Japanese and U.S. science communities that explores the latest innovations in high temperature superconductor research. The series is co-sponsored by the Japanese, and this year's co-chairs are Professor K. Tachikawa from Tokai University and Justin Schwartz of the NHMFL. Discussion topics include HTS coil for high field use; bulk synthesis, structures and applications;

thin films; vortex structure, critical current, and AC loss; new materials and characterization. A special lecture, entitled "Strong Coupling Effects in Short Coherence Length Superconductors," will be given by NHMFL Chief Scientist Robert Schrieffer. Attendance was principally by invitation; approximately seventy-five participants are anticipated.

High Field NMR: A New Millennium Resource

January 15–16, 1998
Washington, D.C.

The NHMFL is organizing a conference in Washington, D.C., on the frontiers of biology and chemistry in high magnetic fields. Representatives from the National Science Foundation, the Department of Energy, and the National Institutes of Health are expected to participate.

The conference will focus on science drivers for the next generation of high field nuclear magnetic resonance, which have the potential to address critical national science opportunities in the fields of chemistry and biology. Specifically, four frontier areas will be addressed: Beyond the Genome, Neuroscience, New Materials, and Gene Regulation. Another major focus of the conference will be to discuss how networking using the Internet II can support collaborative research through shared instrumentation that is regionally positioned throughout the United States. This concept of a "virtual laboratory" or "center without walls" on the Internet could provide important training opportunities for undergraduate and graduate students in magnetic resonance techniques and their applications to emerging science and technology frontiers.

For further information and registration, contact conference coordinator Jo Ann Palmer, 850-644-1933; *palmerj@magnet.fsu.edu*; (fax) 850-644-1366. A website is also being designed: look for it on the NHMFL homepage, *http://www.magnet.fsu.edu*, "What's New."

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

October 18–23, 1998
NHMFL
Tallahassee, Florida

Complete Information & Registration:
http://edmediaserver.magnet.fsu.edu/Megagauss/MegaSearch.html

Megagauss VIII is the next meeting in a series that began in 1965 in Frascati, Italy. The scope of the conference is to provide the latest results on the generation of high magnetic fields at the megagauss level and higher, and to present up-to-date highlights of state-of-the-art research in extremely high magnetic fields. Principal topics will be the generation of multi-megagauss fields, the production of non-destructive fields up to a megagauss, the handling of extremely high power in the terawatt range at high energy density, and the application of ultra-high fields in technology and science.

The meeting is intended to combine technological and scientific aspects of generation and use of megagauss fields. Researchers actively involved in ultra-high field studies, engineers building these advanced devices, and young engineers, scientists and students who want to get acquainted with this new and promising area of ultra-high magnetic fields should plan to attend.

For further information, see the NHMFL website above or contact conference coordinator Ysonde Jensen, 850-644-0566; *megagauss@magnet.fsu.edu*; (fax) 850-644-0867.

Physical Phenomena at High Magnetic Fields-III (PPHMF-III)

October 24–27, 1998
NHMFL
Tallahassee, Florida

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

Once every three years, the NHMFL hosts PPHMF—a major conference for which it is the sole sponsor. PPHMF-II in 1995 attracted 189 participants from universities and laboratories around the world. PPHMF-III expects to bring together experts to discuss recent advances in areas of science and applications in which high magnetic fields play an important role. The program will include invited and contributed papers as well as posters, covering a broad range of materials and phenomena, including semiconductors, magnetic materials, superconductivity, organic solids, the quantum Hall effect, chemical and biological systems, and the technological use of high magnetic fields.

For further information, see the NHMFL website above or contact the conference coordinator, Mary Layne, 850-644-3203; *layne@magnet.fsu.edu*; (fax) 850-644-5038.

EMR *cont. from page 11*

state-of-the-art machine will operate with a time resolution of a few hundred picoseconds.

The Quasi Optics Based Spectrometer. A proposal to the In-House Research Program by J. Krzystek, in collaboration with D. Budil from Northeastern University, has been funded to develop quasi optical techniques. The sensitivity of the spectrometer will be enhanced by more than one order of magnitude.

The Continuous Wave (CW) and Pulsed Gyrotron. An in-house research proposal has been funded to study the feasibility and the characteristics of a CW and pulsed gyrotron in the 150 to 600 GHz range.

EMR Looks to the Future

The NHMFL EMR group is preparing to launch into the development of Electron Nuclear DOuble Resonance (ENDOR) and Optically Detected Magnetic Resonance (ODMR) techniques and is actively seeking funds for such projects.

Acknowledgments

The initial momentum to this program was given by A. Hassan, A. McCarty, H. Whitaker, L.A. Pardi, G. Martins, J. Krzystek, M. Rohrer, W. Moulton , P. Fajer, A. Angerhofer. The program later benefited from an energy boost from B. Cage, G. Fanucci, S. Aubin, V. Williams, A.L. Maniero, A. Scienkiewicz, J. Furdyna, D. Goldberg, J. Telser, F. MacMillan, P. Bratt, B. Robinson, A. W. Rutherford, and all our collaborators. The EMR program is well established thanks to the NHMFL, which is supporting the only Center for Interdisciplinary Magnetic Resonance Facility worldwide.

Vaughan Williams, a mechanical engineer with the NHMFL, is a very valuable contributor to EMR activities, as his design and technical skills are decisive for the development of state-of-the-art instrumentation.

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4. J. Krzystek, D. Mustafi, M.W. Makinen, L.C. Brunel, High Field EPR Spectroscopy of Vanadyl Ion, 29 SEMRC, Gainesville, FL, October 1997.

EURUS Acquires HTS Tape Technology

EURUS Technologies, Inc.®, the NHMFL's first on-site industrial partner, announced the acquisition of Plastronic Inc., the U.S. Midwest developer and manufacturer of high temperature superconductor (HTS) electric conductor tape in early September. This acquisition reinforces the company's strategy of investing in HTS products whose price performance allows integration into near-term applications.

The acquisition aims to capitalize on a number of new and exciting discoveries related to second-generation HTS products, as announced by the Department of Energy's 1997 Annual Peer Review. These developments underscore the opportunities for the new EURUS-Plastronic family of HTS products. "Rapid incorporation of BSCCO improvements will enhance our tape's functionality and current carrying capacity. Plastronic was the obvious choice for EURUS expansion due to the manufacturability and therefore long term performance advantages of its Continuous Tube Filling and Forming (CCTF) process," said John Romans, EURUS general manager.

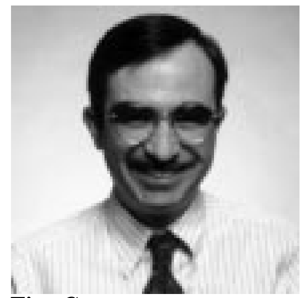
The HTS tape is designed for use in AC and DC power transmission cables, fault current limiters, magnetic separation devices, and various superconductive coil windings. Following the comprehensive design review, EURUS will launch manufacturing of the new HTS tape (to be called Power Plus™) at Innovation Park, the home of the National High Magnetic Field Laboratory in Tallahassee, Florida.

For further information, contact Sanford Cohen, EURUS Technologies, Inc., 2031 East Paul Dirac Drive, Innovation Park, Tallahassee, Florida 32310, Phone 850-574-1800, FAX 850-574-2998, www.TeamEURUS.com.

Kathleen Amm, a graduate student in Magnet Science and Technology, won the Student Meritorious Paper Award at the 1997 International Cryogenic Materials Conference for her work entitled "The Influence of Metallic Interfaces on the Properties of Bulk (Hg,A)$Ba_2Ca_2Cu_3O_x$ (A=Pb, Bi) Superconductors." She also is a finalist for the Materials Research Society Graduate Student Award and will participate in the Special Student Talks Session at the 1997 Fall MRS Meeting in December. At the end of the year, Kathleen and her husband Bruce Amm (an NHMFL postdoc featured in the last issue of *NHMFL Reports*) will be relocating to Schenectady, New York, where Bruce has accepted a position with General Electric. Before leaving, however, Kathleen is expected to receive her Ph.D. in physics from Florida State University, as she successfully defended her thesis in mid-November. She was supervised by Justin Schwartz, associate professor of mechanical engineering.


Kathleen Amm

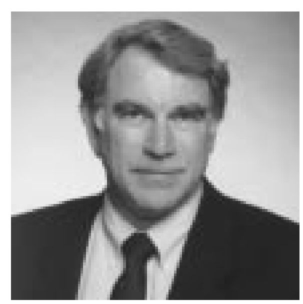
Tim Cross, professor of chemistry and key member of the NMR group at the NHMFL, was recently elected a Fellow of the American Association for the Advancement of Science. Cross was cited "for research in membrane protein structural biology, especially for the development of solid state NMR techniques for elucidating high resolution polypeptide structures." Dr. Cross was also recently named to the advisory board of *Magnetic Resonance in Chemistry*.


Tim Cross

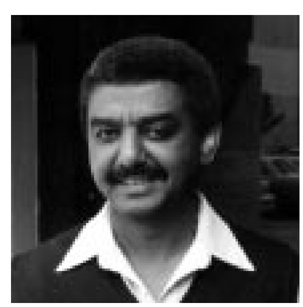
Arthur Edison, an NHMFL colleague at the University of Florida and an assistant professor in the Department of Biochemistry and the Center for Structural Biology, received the Robert J. Boucek, M.D. Research Award for highest merit rated researcher. This award is sponsored by the Florida Affiliate of the American Heart Association.


Arthur Edison

Alan G. Marshall, director of the NHMFL's Ion Cyclotron Resonance Program, recently received an NSF Creativity Award. This award provides a two-year extension of his existing NSF individual operating grant, with increased equipment and operating budget, in recognition of outstanding performance during the first two years of the project.


Alan G. Marshall

Guebre X. Tessema began a sabbatical year at the NHMFL Pulsed Field Facility in September. Originally from Ethiopia, Prof. Tessema received his Doctorate from the University of Grenoble, France, and is a physics professor at Clemson University. From 1994-1996, he served as NSF Program Director for Condensed Matter Physics, Division of Materials Research. He has held visiting positions at the University of Joseph Fourier of Grenoble, University of Southern California, and UCLA, and has been a consultant for the Naval Research Laboratories. Among his research interests are the effect of uniaxial stress on the Fermi surface and the threshold electric field for charge density wave depinning. He has already begun an active research program using the pulsed magnets at Los Alamos.


Guebre X. Tessema

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Inside this Issue Fall 97

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