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

NHMFL REPORTS

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National High Magnetic Field Laboratory

New Science Curriculum Deemed a *Big* Success!

The NHMFL Center for Integrating Research & Learning unveiled its newest curriculum product at workshops around Florida during March. *Science, Tobacco & You* is aimed at 4th and 5th graders and includes an interactive compact disc that allows students to create a "virtual you," hands-on activities for the classroom, access to a specially-designed web site, and other materials. The program encourages students to use science to ask and answer questions; in this case, the medium used to promote scientific literacy is the issue of tobacco use and prevention.

Members of the Center traveled throughout Florida, holding workshops for teachers in 11 different cities: Tallahassee, Orlando, St. Petersburg, Tampa, Chipley, St. Augustine, Daytona Beach, Pensacola, Miami, Ft. Lauderdale, and Boynton Beach. Over 300 teachers, representing 60 of Florida's 67 school districts, attended and voiced unanimous approval of the program.

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Mysteries of Magnetoelectrochemistry

Michael Coey, Physics Department, Trinity College, Dublin
Gareth Hinds, Physics Department, Trinity College, Dublin
Fred Spada, Center for Magnetic Recording Research, University of California, San Diego.

Electrochemistry is a well established branch of physical chemistry with a 200-year pedigree stretching back to Volta and his voltaic pile. It is the foundation of technologies for producing pure metals, for energy storage and conversion (batteries, fuel cells), and for metal plating or etching, including electroplating interconnects in the semiconductor industry.

What is rather new is the idea that the chemical processes of nucleation from solution, ion diffusion, and electron transfer can be significantly influenced by a steady magnetic field. Many of these effects lack any convincing physical explanation; even the existence of some of them such as magnetic water treatment to control hard limescale formation is controversial. Our recent research at the NHMFL has focused on a "fruitfly" electrochemical reaction, the reduction of copper from solutions of copper sulphate.

The results provide incontrovertible evidence for dramatic effects of magnetic fields. Both the rate of electrodeposition and the morphology of the electrodeposit were greatly influenced by fields in the 1 tesla (T) range.[1] The deposition current at low pH (<1) increased by up to a factor of two in fields of 0.6 T and by up to a factor of six in 6 T (Figure 1). High field studies show that the effect saturates in fields of 5 T to 6 T. It appears that the rate of diffusion of the copper ions in solution is accelerated by the field. No mechanism by which this might arise has been quantitatively established, although it is thought that there is a magneto-hydrodynamic effect in the diffusion layer close to the cathode. Scanning electron microscopy revealed that the morphology of copper deposits was significantly altered when the electrodeposition was carried out in a magnetic field. In zero field streaky copper deposits form, while in a field of 0.6 T the deposits formed in smoother, rounded clumps (Figure 2).

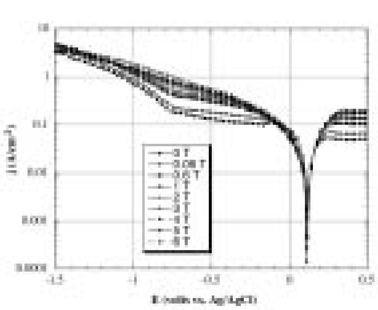

Figure 1. Potentiodynamic polarization plots of the ionic current in an electrochemical cell with a copper working electrode and 0.75 M $CuSO_4$ at pH 0.5. The effect of the magnetic field on electrodeposition (negative voltages) and electrodissolution (positive voltages) is evident.

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Change—on various fronts

Jack Crow

Change—it's inevitable. The leadership of the laboratory has been stable since the beginning in 1990: Neil Sullivan at the University of Florida, Don Parkin at Los Alamos National Laboratory, and myself at Florida State University. It is with sincere regret that I now report that Dr. Parkin has, for personal reasons, requested that he be relieved of his responsibilities as co-principal investigator at LANL, effective May 28, 1999. Don's leadership was pivotal during the initial stages of the NHMFL program design and proposal drafting, and continued throughout the decade as the NHMFL Pulsed Field Facility at LANL established and developed an important new user community. Don also was essential in developing the NSF and U.S. Department of Energy partnership that is funding a program to build a non-destructive 100 T pulsed magnet system at Los Alamos. This system will be the first *non-destructive* 100 T system and will provide 100 times more research volume and a pulse duration 1,000 times longer than other 100 T magnet systems in the world.

Don Parkin

Let me be clear—Don is not leaving LANL. In fact, Don is taking on a new responsibility with the Institute for Complex Adaptive Matter (ICAM), and his leadership role there may help to establish new ties between the NHMFL and LANL. In Don's words, "The Institute is taking on the challenge of implementing a research focus on complexity in hard, soft, and biological matter. The NHMFL is positioned to be one of the critical experimental resources in the pursuit of this creative risk-taking ICAM scientific agenda. I look forward to the possibilities of exciting collaborations between NHMFL and ICAM. Such a partnership could provide critical leadership in defining materials research for the new millennium."

Don, Neil, and I, with the support of the NHMFL Executive Committee and the operating institutions, recently recommended to NSF that Dr. Greg Boebinger be named as Dr. Parkin's successor. As most readers know, Greg is the current director of the NHMFL Pulsed Field Facility and a leading scientist in high magnetic field research who has contributed in many significant ways to the advancement of magnet and magnet materials technology. Everyone involved envisions a smooth transition and continued excellent support for the user community at LANL.

Change is coming on another front as well. The NHMFL is preparing its five-year renewal proposal that will be submitted to NSF in January 2000. Developing the vision for the laboratory is no easy task: We must be prepared to (1) efficiently and cost-effectively support the needs of our many science and engineering communities, (2) promote magnet and magnet materials technologies in partnership with the private sector, and (3) use the extensive facilities and faculty of the laboratory in support of the nation's educational goals.

Developing the proposal involves faculty meetings, workshops like the High B/T Workshop (see pages 7 and 9), Users' Committee and External Advisory Committee meetings, and the all-important dialogue with users. I want to thank Chuck Agosta, the Chair of the NHMFL Users' Committee, for his broadly-distributed e-mail that solicited comments from users on two questions:

1. What are the new scientific directions that should be pursued by the NHMFL, and/or what types of experiments do you see having high priority for the next five years.
2. What new technologies or infrastructure do you suggest the NHMFL acquire to aid in the pursuit of the priorities you set in question one?

Time is short, and your comments are needed *now*. Please send them according to the e-mail instructions or to Chuck Agosta, *cagosta@clarku.edu*.

As we move toward the next decade, and a new millennium, your suggestions and support of the NHMFL and its science, research, and educational missions are important. Of even greater importance, however, is the need for *all* of us-regardless of our discipline-to become a loud chorus of voices in support of U.S. investment in science and research. I urge you to write your congressional delegates, as I recently did, and ask for their support for increased federal funding for the National Science Foundation budget and the science and technology programs in all agencies. It is entirely possible that Congressional budget resolutions might significantly shortchange scientific research and development, so it is vitally important that we remind our elected officials of the very high payback that Americans enjoy from investments in research and development.

Change is inevitable. In ten short years, the NHMFL has been established, built from the ground up, and dedicated. It has built world-record magnets that are the envy of the world and has driven a new interdisciplinary dialogue. It has forged a multitude of interagency and private sector partnerships and developed outstanding educational programs. With all of these successes as a firm foundation, we must now prepare for a new decade in which the laboratory—as one facet of the nation's science and engineering resources—continues to address and achieve the nation's critical research and educational goals.

From the Chief Scientist's Desk

Robert Schrieffer

In this issue studies are reported on the fascinating question of whether low gravity environmental effects may be simulated by magnetic levitation. These experiments suggest that the arabidopsis plants used in the experiment were differentially stressed in the high magnetic field of the NHMFL Keck magnet and the low g-environment on NASA's KC-135 aircraft during parabolic flight. These results are of importance in the understanding of plant growth, which will be significant for humans to

Plant Growth and Development under Magnetic Levitation Conditions

Mark W. Meisel, Department of Physics and NHMFL, University of Florida

Robert J. Ferl, Department of Horticultural Sciences and the Biotechnology Program, UF

Anna-Lisa Paul, Department of Horticultural Sciences and the Biotechnology Program, UF

James S. Brooks, Department of Physics and NHMFL, Florida State University

This research effort is a collaborative effort involving the principle investigators; Thomas Stalcup, FSU physics graduate student; Brian Watson, UF physics graduate student; Lori Ann Justo, UF biomolecular engineering student; and Jennifer Reavis, a high school intern student at the NHMFL. This research was sponsored, in part, by the National Science Foundation, through support of the National High Magnetic Field Laboratory, and the W. M. Keck Foundation. The Space Biology research program of R.J. Ferl is supported by a grant from NASA (NAG 10-0145).

A number of significant problems must be solved before humans will be able to spend long periods of time in space. One major issue is the establishment of a sustainable food supply since, to date, plants cultivated in low gravity possess reduced growth characteristics, particularly with regard to seed set.[1] Consequently, a large number of plant growth experiments have been sponsored, and new programs are in queue.[2,3] For example, a group at the University of Florida is experimenting with arabidopsis (*Arabidopsis thaliana*)[4] as a model system for studying the effects of low gravity conditions on plant growth and gene regulation. Transgenic arabidopsis plants containing the *alcohol dehydrogenase* (*Adh*) driven GUS (β-glucuronidase) gene are being used to monitor the effects of reduced gravity on gene regulation of plant metabolism.

In general terms, the reporter gene that has been engineered into the plant responds to stress (*e.g.* hypoxia, cold, reduced gravity) that initiates a chemical reaction that results in a color change (colorless to blue) when incubated with a specific exogenous substrate (x-glucuronide). By monitoring the color changes, specific stresses can be identified, and preliminary experiments have been performed on NASA's KC-135 turbojet, which provides a milligravity (milli-g, where $g = 9.8$ m/s^2) environment. Plants experiencing parabolas exhibited marked increase in expression of the reporter gene, indicating the onset of stress inductions similar to those reported from shuttle missions.[5] Due to the parabolic nature of the KC-135 flights, the experiments experience an equal amount of milli-g and 2 g forces, so control investigations have been performed at the high-g centrifuge at the Ames Research Center. The results of the experiments on the KC-135, which have provided nominally 25 minutes of total time in a milli-g environment, confirm the ability to test the activation of various genes via this transgenic reporter gene technique. Longer term Earth-based testing, however, would contribute to our understanding of plant growth in low-g conditions and would help optimize the design of experiments that will eventually fly on the space shuttle which experiences between 0.1 to 10 milli-g while in orbit.[1] Magnetic levitation is an established technique[6-10] that can supply the longest term Earth-based low-g environment[1] but, to our knowledge, has not been used previously to study plant growth as a part of a space biology program.

Naturally, the crucial difference between the magnetic levitation and space shuttle environments is the presence of a strong magnetic field $B \leq 21$ T and gradients $B\nabla B \approx 1800$ T^2 m^{-1}.[6-10] Other researchers have studied the growth and development of wild-type and TC7 starchless mutant arabidopsis in gradients $B\nabla B \approx 60 - 530$ T^2 m^{-1} using medium strength magnetic fields ($B \approx 0.5$ - 0.8 T).[11] Some abnormal changes in root curvature were measured in wild-type arabidopsis, although no growth variations were detected in TC7 arabidopsis. These gradient strengths are similar to those needed for magnetic levitation, and this earlier work suggests that magnetic fields and gradients associated with levitation may not adversely effect some types of arabidopsis. With this

PLANT GROWTH continued on page 5

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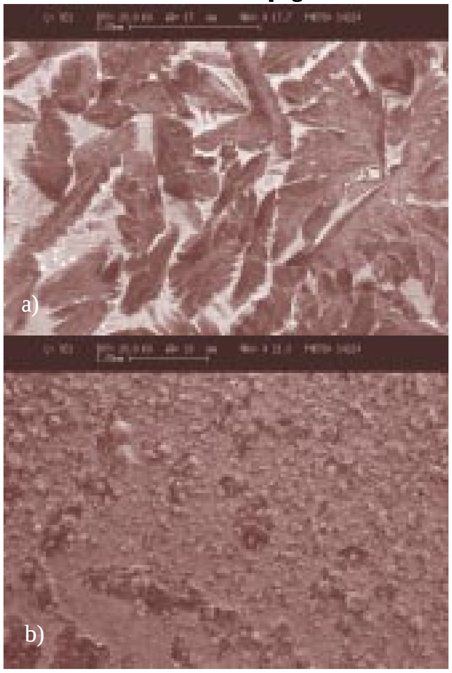

Figure 2. Scanning electron micrographs of copper electrodeposits a) without and b) with an applied field of 0.6 T.

A sensitive test of the field effect involves fractal electrodeposits in a two-dimensional geometry. The growth pattern of these deposits, which is sensitive to diffusion rate and ion concentration, is dramatically altered by the presence of magnetic fields as low as 5 mT. In the absence of any applied field, a dense radial growth is observed (Figure 3a). When a field is applied perpendicular to the plane of the cell, a dendritic spiral growth occurs (Figure 3b). The chirality of the spiral depends on the direction of the magnetic field, as might be expected for the Lorentz force (Figure 3c). A remarkable effect is observed when the field is applied parallel to the plane of the cell. A stringy deposit is then formed with growth predominating in one specific direction (Figure 3d), normal to the applied field. Repeated experiments showed that this direction was the one in which the Lorentz force and the gravitational force were acting in unison.

It must be emphasized that these results are entirely unexpected and are not predicted by theory. Elementary calculations show that the effect of the Lorentz force on a typical ion in solution is negligible—yet the observed effects are undeniably large. Similar effects have been observed in electroless deposition, electropolymerisation, and colloidal aggregation, again without any agreed physical explanation. It is this mystery, together with the new and dramatic effects that are being observed, that makes magnetoelectrochemistry the fascinating subject it is at present.

Reference:

1 G. Hinds *et al.* J. Appl. Phys. 83, 6447-9 (1998).

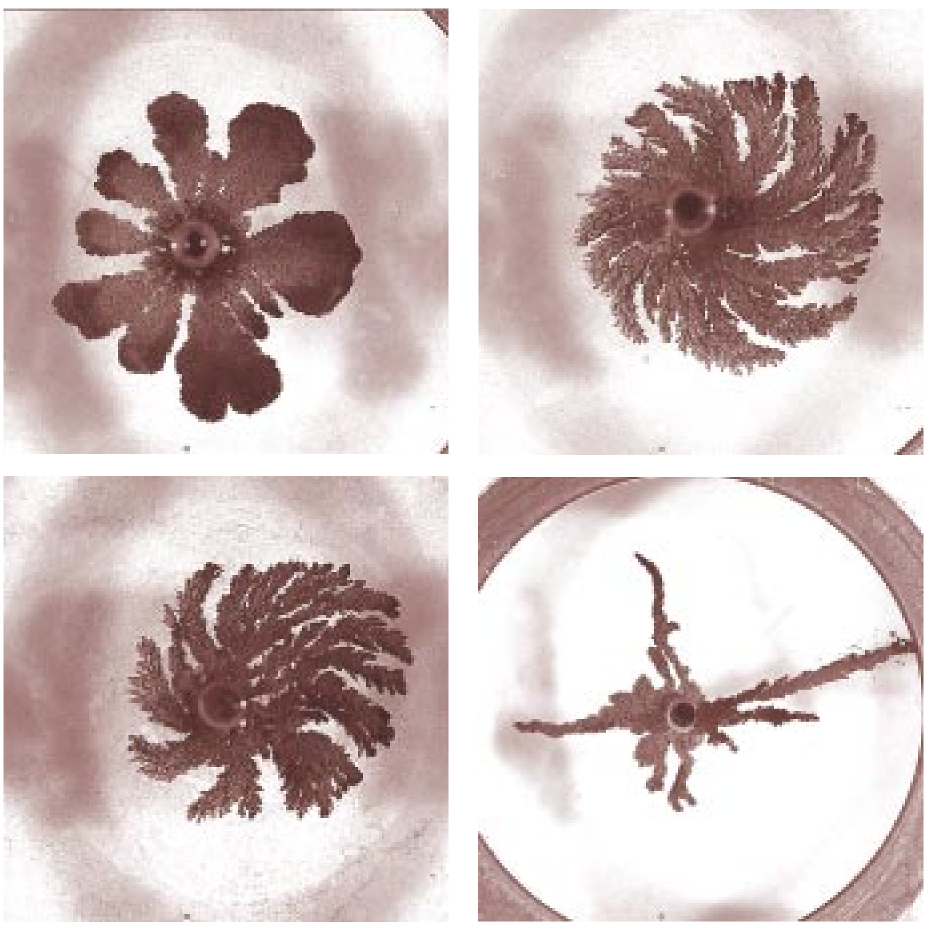

Figure 3. Two dimensional fractal copper electrodeposits obtained in zero field and in magnetic fields applied perpendicular (θ = 0, 180) or parallel (θ = 90) to the plane of the cell. a) B = 0 T b) B = 0.4 T, θ = 0 c) B = 0.8 T, θ = 180 d) B = 1 T, θ = 90.

SCIENCE CURRICULUM continued from page 1

"I can't wait, I am so excited and eager to implement this…it will enhance my students' awareness toward science and encourage them to acquire untapped knowledge through visual aids and hands-on experiments," commented a teacher from the Miami workshop.

Many teachers discovered the potential for this product within their classes and for use among fellow teachers. The program is aimed at all students, from gifted to at-risk: "…this will be an excellent way to collaborate with the science teachers and extend the learning from the classroom to activities that we do in our gifted program," wrote one teacher. Another stated, "I know that my at-risk students would enjoy these activities and I could easily integrate this into my weekly schedule."

Science, Tobacco & You is also inexpensive for teachers to replenish—an asset noted by a teacher from the Ft. Lauderdale

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background, we were motivated to conduct a magnetic levitation experiment using arabidopsis.

In preparation for the high magnetic field experiment, we measured the magnetic magnetization of wild-type arabidopsis (14 days old) in fields up to 5 T at 295 K. The studies were performed on whole plants, leaf/shoot tissue, roots, and distilled water. Using standard mathematical models,[7-9] the susceptibility values allow us to estimate the gravitational forces that the different parts of the plant might experience while being magnetically levitated. The results indicate that the leaf/shoots may experience about - 50 milli-g (the negative sign represents levitation) while the roots may experience about 10 milli-g. These somewhat coarse estimates compare favorably with the low-g environment (≤ 100 milli-g) that was established on the parabolic flights.

On September 19, 1998, three arabidopsis plants (4 weeks old) were magnetically levitated for a period of 2.3 hours using the Keck magnet of the NHMFL in Tallahassee. This growth window represents a significant fraction of the development time of arabidopsis that goes from a seed to mature plant in approximately 6 weeks. Moreover, 2.3 hours is a meaningful time frame in which to study gene activation phenomena, as stimulus-dependent regulatory events can be detected within tens of minutes. Equilibrium levitation conditions required B = 14.4 T and $B\nabla B$ = 1708 T^2 m^{-1} at the point where the plants were free floating, see Figure 1. At the

Figure 1. A magnetically levitated arabidopsis plant levitation in B = 14.4 T and $B\nabla B$ = 1708 T^2 m^{-1}. The view is looking down the bore of the Keck magnet, and the scale is set by the diameter of the bore which is 52 mm.

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area, “More than I expected…the materials supplied were not only plentiful but are cheap and easily obtainable.”

Teachers from around the state were very excited about the program. As one teacher stated, “Definitely an A+ project.”

For more information about Science, Tobacco & You, *see NHMFL Reports, Winter 1999 issue, or contact the Center director, Sam Spiegel, 850-644-5818.*

- *“[The Science, Tobacco & You] hands-on program is a wonderful learning opportunity for children—including the materials, internet, CD-ROM—everything is extremely interesting and diverse. It adapts to different learning styles of children.” — Tallahassee*
- *“The students will love the Virtual You on the CD-ROM and I will be able to integrate the entire program into the curriculum and be teaching science and technology while I teach the other curriculum areas.” — Orlando*
- *“It [Science, Tobacco & You] is a strong curriculum with technology built in to it.” — St. Petersburg*
- *“There are so many wonderful lessons and help that I would be foolish not to use Science, Tobacco & You with my students.” — Chipley*
- *“I had heard this was great, and I was not disappointed…I learned a lot and am excited to teach science, a subject I'm sometimes not comfortable teaching.” — Daytona Beach*
- *“These materials will help enhance the technology part of my curriculum for science as we study the human body.” — Miami*
- *“…a great model for integrating technology (comfortably) in the classroom.” — Boynton Beach*

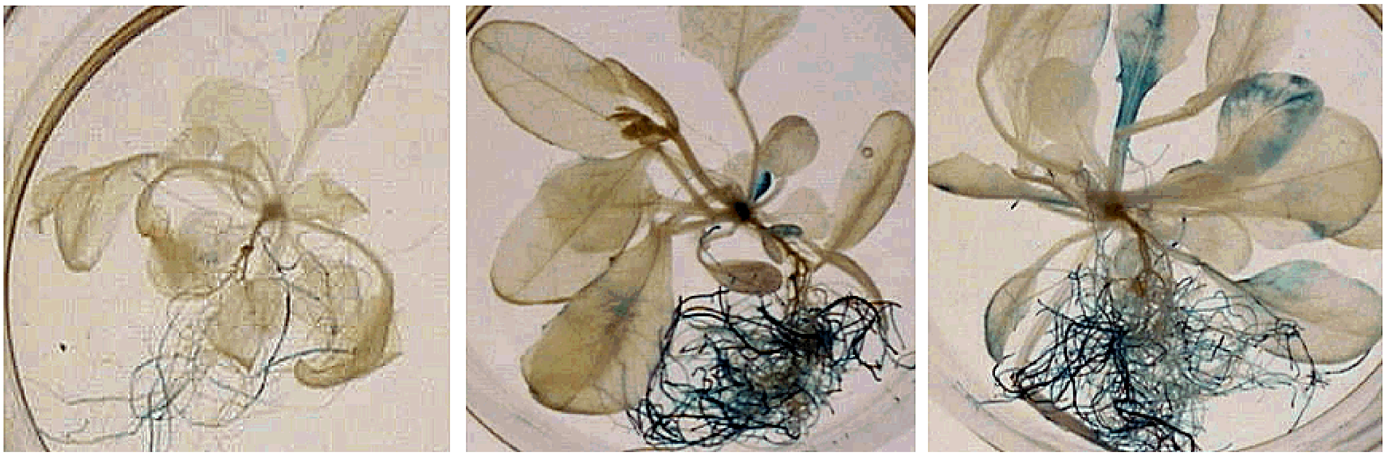

Figure 2. Typical results after staining of intact plants experiencing 2.3 hours of: (left) low field conditions of $B \leq 0.1$ mT, (center) constant magnetic field of $B = 18.9$ T and $B\nabla B \approx 0$, and (right) magnetic levitation in $B = 14.4$ T and $B\nabla B = 1708\ T^2\ m^{-1}$. The plants experiencing the large magnetic field environments (center and right) show stress response as indicated by the blue (*i.e.* dark) stain, while the low field control (left) shows significantly weaker stress response. Furthermore, the magnetically levitated plants (right) possess a higher level of expression of the reporter gene than the specimens in the constant magnetic field (center). This last result is not obvious in these pictures, but it is discernible in the full color versions, see *http://phys.ufl.edu/~meisel/arabexp.htm*.

same time, three plants were located at the center of the magnet $B = 18.9$ T, and an additional three plants were kept in a low magnetic field region $B \leq 0.1$ mT. All three experimental regions experienced similar conditions with respect to lighting, temperature (nominally 295 K), and atmosphere. After the 2.3 hours, the samples were stained and transported to Gainesville. After staining, the plants were placed in 70% ethanol to remove chlorophyll and other endogenous pigments, so the blue color of the reporter gene would be clearly visible. The results are shown in Figure 2.

Our experiments qualitatively suggest that the arabidopsis plants were differentially stressed by the high magnetic field and low-g environments. For plants, such a significant response to the presence of a strong magnetic field has not been reported in the literature. Our results are reminiscent, however, of the ones reported by Valles *et al*.[8], who have reported that cell division planes in *Xenopus laevis* (frog) embryos align with a strong magnetic field ($B \geq 10$ T). Similar effects may be occurring in arabidopsis, but further studies are necessary to confirm this hypothesis. Preliminary studies in homogeneous magnetic fields up to 9 T do not indicate the presence of a stress response. These qualitative experiments are presently being quantitatively verified by biochemical analysis of the GUS activity, and this work will be extended above 9 T once the data analysis has been completed.

In conclusion, it appears that low gravity environmental effects may be induced by magnetic levitation, albeit on a significant "*background*" response generated by the strong magnetic field. The magnetic effects need to be studied and understood if high magnetic field ($B \geq 20$ T) MRI is going to be used to image *in vivo* gene regulation, an application proposed for the new generation of GHz NMR facilities.[12] Clearly, more extensive experiments are needed to determine the molecular consequences of levitation and high magnetic fields on plant growth and development.

References:

1 D. Moore and A. Cogoli, in *Biological and Medical Research in Space*, ed. D. Moore, P. Bie, and H. Oser (Springer-Verlag, Berlin, 1996) pp. 1-106.

2 Program and Abstracts of the 13th Annual Meeting of the American Society for Gravitational and Space Biology, *Grav. Space Bio. Bull.* 11, 1-82 (1997). The ASGSB may be accessed at http://baby.indstate.edu/asgsb/.

3 *Plant Biology in Space: Proceedings of the International Workshop*, ed. A. Sievers, B. Buchen, and T. K. Scott, *Planta* 203, S1-S216 (1997), and references therein.

4 *Arabidopsis thaliana* is the *Latin* name for a mustard plant which is fast-growing and easily transformed genetically. Consequently, this system is ideal for transgenic analyses and has been well-characterized at genetic and physiological levels. For a review, see D. W. Meinke, J. M. Cherry, C. Dean, S. D. Rounsley, and M. Koornneef, *Science* 282, 662 (1998).

5 In fact, the degree of induction of the reporter gene activity was higher than that reported for *Adh* induction during

Second North American FT-ICR Mass Spectrometry Conference

March 18-20, 1999
San Diego, California

Two years ago, the NHMFL hosted the First North American Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR MS) conference in Tallahassee. In response to community demand for a repeat performance, the NHMFL staged an even more successful North American FT-ICR MS Conference in March in San Diego. The 1999 conference drew 128 attendees—a significant increase from 1997 (107 attendees, of which approximately 20 were local). Conferees were welcomed by Dr. Charles Reed, chancellor of the California State University System and member of the NHMFL External Advisory Committee.

The oral program (24 plenary talks) was organized entirely by the session chairs: Stephen A. Hofstadler (Ibis) on Instrumentation; Carlito Lebrilla (University of California, Davis) on Ion Chemistry and H/D Exchange; Richard D. Smith (Pacific Northwest National Laboratory) on Front-End Techniques (Ionization Methods, High-Performance Liquid Chromatography, Capillary Electrophoresis); and Evan R. Williams (University of California, Berkeley) on Tandem Mass Spectrometry (MS/MS). An additional 46 posters were shown. The conference arrangements were greatly facilitated by the generous support of several sponsors: Bruker, Cambridge Isotopes, Finnigan, Intermagnetics General Corporation, IonSpec, Isis, and Synrad. A third conference is scheduled for 2001, probably on the East Coast.

The conference concluded with an after-dinner lecture by John D. Baldeschwieler (Caltech), who recounted the period from about 1964 to 1974 when he and his collaborators introduced ion cyclotron resonance to the chemical community, and demonstrated its power for determining gas-phase ion-molecule reaction pathways, kinetics, energetics, and equilibria.

shuttle flights, see D. M. Porterfield, S. W. Matthews, C. J. Daugherty, and M. E. Musgrave, *Plant Physiol*. 113, 685 (1997).

6 E. Beaugnon and R. Tournier, *Nature* 349, 470 (1991).

7 E. Beaugnon and R. Tournier, *J. Phys. III France* 1, 1423 (1991).

8 J. M. Valles Jr., K. Lin, J. M. Denegre, and K. L. Mowry, *Biophys. Jour*. 73, 1130 (1997). J. M. Denegre, J. M. Valles Jr., K. Lin, W. B. Jordan, and K. L. Mowry, *Proc. Nat. Acad. Sci*. 95, 14729 (1998).

9 M. V. Berry and A. K. Geim, *Euro. Jour. Phys*. 18, 307 (1997).

10 A general lay review has recently appeared, see A. Geim, *Physics Today* 51, No. 9 (Sept.), 36 (1998). This review was followed by a discussion, see the "Letters to the Editor", *Physics Today* 51, No. 12 (Dec.), 11 (1998).

11 O. A. Kuznetsov and K. H. Hasenstein, *Planta* 198, 87 (1996).

12 *High Field NMR: A New Millennium Resource*, Conference sponsored by the NHMFL, Washington, D.C., 15-16 January 1998; see *http://www.magnet.fsu.edu/whatsnew/nmrcoll*.

High B/T Workshop

April 19-20, 1999
NHMFL, University of Florida

The High B/T Workshop provided an important forum for the discussion of experiments—recent, planned, and potential ones—that require the simultaneous use of high magnetic fields (B>15 T) and very low temperatures (T<10 mK). The group also considered special techniques required and new system configurations that the NHMFL might incorporate into its vision for the future. For more details, see Dr. Neil Sullivan's remarks in the Attention Users column, page 9.

Workshop on Power Distribution and Management for Electric Ship Applications

May 4-5, 1999
NHMFL, Tallahassee

This workshop was supported by the NHMFL, Florida State University, and the Office of Naval Research. The objective was to assess the state of the art in power distribution and management, as it may be applied to the U.S. Navy all-electric-ship concept. Attendees identified critical areas of research and development that must be addressed before the benefits in performance, reliability,

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survivability, weight, volume, and cost can be achieved through implementation of advanced and emerging power system technologies. Hosting this workshop is another example of the NHMFL helping to forge new partnerships between government, the private sector, and academia. In this instance, the focus was on issues important to the power distribution and management concerns of the Navy, with a need to explore complementary requirements for commercial marine and utility applications. Thirty people participated in the invitation-only conference.

16th International Conference on Magnet Technology (MT-16)

September 26-October 2, 1999
Sawgrass Marriott Resort
Ponte Vedra Beach, Florida
35 miles southeast of Jacksonville International Airport

Abstract Deadline: June 15, 1999
Early Registration Deadline: August 15, 1999

MT-16 will bring together scientists, engineers, and experts from around the world to focus the latest developments in technology, operation, applications of research and industrial magnets, and magnet materials. The program will focus on topics such as magnets for accelerators and fusion, as well as generation of high fields. A major emphasis will be on industrial applications, such as magnets for NMR and MRI, energy storage, levitation, and separation. Several sessions will be dedicated to new developments in high and low temperature superconductors and other magnet materials for reinforcement, impregnation, and insulation.

The meeting will combine technological and scientific aspects of magnet technology. Basic investigations involving magnet materials, electrodynamics, stability of superconductors, heat transfer, He II cooling, cryogenics, etc., will be an integral part of the conference program. System optimization, magnet analysis, design strategies, new instrumentation, and related issues also will be included.

Industrial & Scientific Exhibition. A special exhibition will be held at the conference that will display a wide range of products in the field of magnet technology, achievements in magnet technology, and services offered by industry, academia, and research laboratories. Organizations interested in participating in the exhibition should contact conference organizers.

Complete information and registration is available online at *www.magnet.fsu.edu/mt16*. Interested individuals or organizations may also contact Jo Ann Palmer (850-644-1933, *mt16@magnet.fsu.edu*, fax 850-644-8350).

30th Southeastern Magnetic Resonance Conference (SEMRC)

New Dates!! November 4-6, 1999
DoubleTree Hotel, Tallahassee

The NHMFL is pleased to host this conference—for the third time in five years! Following its traditional format, SEMRC will feature invited and contributed papers and posters in NMR, MRI, EPR, and ICR. Topics will include time-resolved and multidimensional spectroscopies, high magnetic fields, and applications of magnetic resonance technologies in materials science, physics, chemistry, biology, and medicine. Registration will be available on line (off the NHMFL web site *www.magnet.fsu.edu*) in the near future. For information, call Jo Ann Palmer 850-644-1933 or fax 850-644-8350.

Applied Superconductivity Conference (ASC04)

October 4-8, 2004
Tentative site: Jacksonville, Florida

The NHMFL is very pleased to report that it has been selected to host the Applied Superconductivity Conference in 2004. This is the premier conference in applied superconductivity and occurs in even numbered years only. The past two conferences have had over 1,500 attendees; less than half of the attendees have been from the United States. It is interesting to note that the dates happen to coincide with the 10th anniversary of the dedication of the NHMFL in Tallahassee on October 4, 1994.

Justin Schwartz (Associate Professor of Mechanical Engineering and leader of the HTS Magnets and Materials Group in NHMFL Magnet Science & Technology) is the conference chair; John Miller (head of the NHMFL Hybrid Project) is the program chair. Further details will be reported as they become available. In the interim, Dr. Schwartz may be contacted at 850-644-0874, *schwartz@magnet.fsu.edu* for further information.

ATTENTION USERS

Neil Sullivan
NHMFL Co-PI
Chair of UF Physics Department

Jian-sheng Xia
Associate-In Physics

High B/T Facility Developments

A series of experiments lead by Horst Stormer, Dan Tsui and collaborators on studies of GaAs/$Ga_{(1-x)}Al_xAs$ quantum Hall structures at high fractional quantum numbers at n=5/2 have been completed with measurement of the R_{xx} and R_{yy} components of the resistivity and the activation energies for electron temperatures of down to 4.2 mK. (*NHMFL Reports*, Vol. 6, no. 1, p. 12). The system has been warmed to room temperature following nine months of continuous operation for the quantum Hall studies and a new set of experiments on the high field magnetization of solid helium three is being installed. We are taking advantage of this interruption to attempt to have corrective action taken on the magnet system that at delivery had a break in the inner superconducting coil (coil 4). The manufacturer has rewound this section and reassembled the magnet and the magnet system now attains 17 T at 4 K. Preliminary tests have indicated a “short-sample limit” for the current in coil number 2 and this indicates that the wire will not carry additional current at this field and temperature. We are conducting further tests at lower temperatures to assess the problem.

A new experiment to determine the magnetic phase diagram of solid helium three has been set up and the facility will be cooled down in the next few days.

We are also considering the design of a small solenoid that will sit in the vacuum space above the nuclear demagnetization stage of the High B/T facility. This magnet would produce fields of 4 T to 5 T and provide users with additional capabilities at very low temperatures and moderate fields and enable us to meet the needs of a number of users who need access to sub-mK temperatures and moderate fields. Future experiments planned for the near future include “Studies of the transport in very dilute helium three in liquid helium four” by D. Candela and colleagues.

For information about the High B/T facility contact Dr. Xia, 352-392-8869, jsxia@phys.ufl.edu.

The Florida group organized a small **Workshop on Physics at High B/T** at the University of Florida on April 20 that was sponsored by the University of Florida Office of Research, Technology and Graduate Education. The purpose of the workshop was to review new and prospective experiments that require the simultaneous use of high magnetic fields (B>15 T) and very low temperatures (T<10 mK), the special techniques required, and new system configurations that the NHMFL might consider in its vision for the future. The invited speakers included:

- Giogio Frosatti, University of Leiden
- Wei Pan, Princeton University
- Bob Ragan, University of Wisconsin
- Louis Jansen, Laboratoire des Champs Intenses, Grenoble
- Don Candela, University of Massachusetts
- Bill Mullin, University of Massachusetts
- Chuck Agosta, Clark University
- Jim Brooks, NHMFL/FSU
- Hans Bozler, University of Southern California
- Janice Musfeldt, Binghamton University

User Update from Los Alamos

Dear NHMFL Users,

You have probably all heard of concerns in the U.S. Congress over national security issues at Los Alamos National Laboratory.

Since we are in charge of running an international Users' Program for pulsed magnetic field research, we want to state clearly that ALL scientifically-qualified users remain welcome to perform research here at the NHMFL Pulsed Magnetic Field Laboratory in Los Alamos.

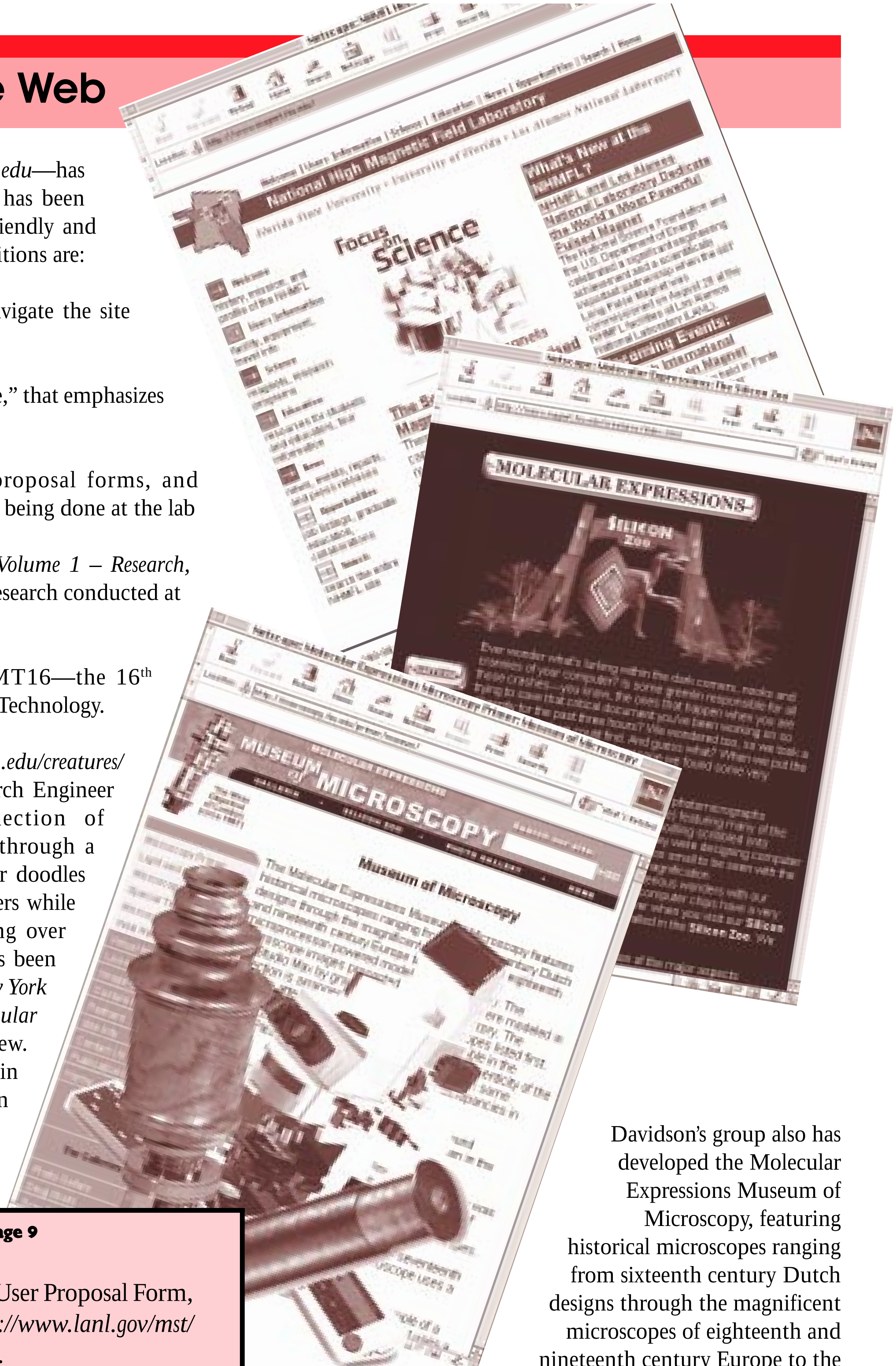
This is an appropriate place to remind potential pulsed magnetic field users that Los Alamos National Laboratory does continue to require visitors to obtain a visitor's badge before they are allowed on campus. Because of the present situation, the time required to process visitor badge requests has increased.

USER UPDATE FROM LANL continued on page 10

What's New on the Web

The NHMFL web site—*www.magnet.fsu.edu*—has undergone a facelift and an overhaul. It has been completely redesigned to be more user-friendly and informative. Some of the changes and additions are:

- A new interface allowing users to navigate the site quickly and easily
- A new section titled "Focus on Science," that emphasizes science being done at the laboratory
- An updated Users section with proposal forms, and calibrations and drawings for research being done at the lab
- The *1998 NHMFL Annual Report, Volume 1 – Research*, featuring nearly 300 brief reports of research conducted at the laboratory in 1998
- Information and registration for MT16—the 16th International Conference on Magnet Technology.



A related web site—*http://micro.magnet.fsu.edu/creatures/index.html*—designed by NHMFL Research Engineer Michael Davidson, features a collection of photomicrographs (photographs taken through a microscope) depicting creatures and other doodles etched onto silicon microchips by engineers while designing the computer chips. Receiving over 100,000 hits per day, the Silicon Zoo has been featured in the *San Jose Mercury News*, *New York Times*, *Washington Post*, *USA Today*, *Popular Science*, and *Newsweek* just to name a few. Davidson and the Smithsonian Institution in Washington, D.C., are collaborating on an exhibit to feature the silicon doodles later this year.

Davidson's group also has developed the Molecular Expressions Museum of Microscopy, featuring historical microscopes ranging from sixteenth century Dutch designs through the magnificent microscopes of eighteenth and nineteenth century Europe to the latest microprocessor-powered models available today. Over 50 microscope images were modeled in 3D Studio Max by graphic artists in Davidson's laboratory. When you visit this gallery, located at *http://microscopy.fsu.edu/primer/museum*, keep in mind that these are not photographs and that each model was created from scratch.

USER UPDATE FRON LANL continued from page 9

For up-to-date information and the User Proposal Form, please consult our web page at *http://www.lanl.gov/mst/nhmfl*. Click on User Request Form.

The success of the NHMFL depends on a users' program of international importance. Please feel free to pass our message on to your colleagues.

Sincerely,

Gregory S. Boebinger

Director, Pulsed Magnetic Field Laboratory of the NHMFL

Alex H. Lacerda

Head of NHMFL - Los Alamos Users' Program

PEOPLE in the NEWS

The NHMFL is very pleased to recognize faculty members, staff, and students who have received an interesting assortment of awards recently, from local and community to national and international.

NHMFL Director *Jack Crow* accepted, on behalf of the laboratory's education programs, the *Service to Science Education Award*, presented by the Leon Association for Science Teaching and the Tallahassee Scientific Society. This award recognizes exemplary efforts to enhance science and mathematics education by working through the Leon County School System. Dr. Sam Spiegel, director of the NHMFL Center for Integrating Research and Learning, was the featured speaker at the event on April 22. Following the day's Earth Day theme, Dr. Spiegel's talk was entitled, "Keeping the Breath in Science Education."

Elbio Dagotto (FSU Associate Professor of Physics) has accepted an invitation to be the Divisional Associate Editor (representing Division of Condensed Matter) of *Physical Review Letters*. Dr. Dagotto was also selected recently to be a fellow of the American Physical Society.

Alan Marshall (Director, Ion Cyclotron Resonance Program at the NHMFL) and Melvin Comisarow (University of British Columbia) have been selected as this year's winners of the American Society for Mass Spectrometry Award for a Distinguished Contribution in Mass Spectrometry. Drs. Marshall and Comisarow will each receive $2,000 and an engraved plaque in recognition of their co-invention of Fourier transform ion cyclotron resonance mass spectrometry in 1973. More than 260 FT-ICR instruments, representing a capital investment of approximately $100 million in 1999 dollars, have been installed worldwide. The award will be presented at the ASMS annual conference in Dallas in June, 1999. This award is Dr. Marshall's fourth national recognition since joining the NHMFL and FSU Chemistry faculty in 1993, having previously received the American Chemical Society Field-Franklin Award in Mass Spectrometry (1995, also joint with Comisarow), the biennial Spectroscopy Society of Pittsburgh Maurice F. Hasler Award (1997); and the New York Society for Applied Spectroscopy Gold Medal (1998).

Sawako Nakamae, a former graduate student with Justin Schwartz (FSU Associate Professor of Mechanical Engineering), won an NSF International Research Fellow Award that provides 13 months support. Saco, as she is better known to colleagues at the NHMFL, started a one-year postdoctoral position at Commissariant A L Energie Atomique (CEA) in France in January, 1999; this fellowship will allow her to continue her research there until January, 2001.

Ryan P. Rodgers (FSU Chemistry Ph.D. student) has been selected to receive an American Chemical Society–Division of Analytical Chemistry *Summer Graduate Fellowship*, one of six nationally. His summer fellowship is sponsored by the Society of Analytical Chemists of Pittsburgh, a co-sponsor of the Pittsburgh Conference. Ryan is being recognized for his construction of a complete FT-ICR mass spectrometer designed to analyze volatile mixtures, and for his use of that instrument to separate and identify sulfur-containing organics in crude hydrocarbon fuels, thereby quantitating and monitoring dozens of sulfur-containing species in diesel fuel before and after catalytic hydrodesulfurization. During the fellowship period, Ryan will go on to analyze jet fuel spills, identify arson accelerants, and explore the mechanism(s) by which bacteria degrade petroleum contaminants.

Florida State University Faculty Awards, April 12. Congratulations to *Alan Marshall* who received one of FSU's three Distinguished Research Professor Awards. The award includes a $3,000 one-time honorarium and recognizes "outstanding scholarly productivity, and national and international visibility in endeavors that emphasize research." Congratulations also to *Tim Moerland*, Associate Professor of Biology, who won a University Teaching Award. His students heaped praise on Dr. Moerland: "I couldn't wait to go to his class." "Each day that I went to class, I knew that he would tell me something amazing." "His enthusiasm and love for teaching are truly inspirational." "He forced me to think in terms of why, and not just what." "Even though I got a C in his class, I still believe that he is the best professor I ever had."

PEOPLE IN THE NEWS continued on page 12

PEOPLE IN THE NEWS continued from page 11

More news from Florida State:

Kathy Hedick, the NHMFL's coordinator of information and publications, received a 1999 FSU Exemplary Service Award on May 4. It was one of only eight awards given university-wide. Kathy facilitates and edits the laboratory's annual reports and newsletters, and manages a myriad of other publications and projects including the successful open house. The 6th Annual Open House will be held this year on October 23rd.

The FSU Chemistry Department selected *"Stone" Dong-Hui Shi* (FSU Chemistry Ph.D. student) as the winner of the first "Dorothy and Russell Johnsen Dissertation Award." Mr. Shi earned a 4.0/4.0 cumulative grade-point average in his graduate work at FSU, and set new records for high-resolution mass spectrometry of synthetic polymers (resolution of copolymer units separated by a mass difference of only 0.036 atomic mass units in copolymers of 7,000 Dalton) and proteins (making it possible to count the number of sulfur atoms in a 16 kDa protein simply by weighing it). His publications have been featured in *Chemical & Engineering News* and *Analytical Chemistry*. Stone's award was presented at his Chemistry Departmental Seminar on April 23, 1999.

NHMFL Chief Scientist *Robert Schrieffer* was one of a select group of faculty members profiled in the FSU College of Arts and Sciences *Across The Spectrum* newsletter on the topic of teaching and research. Dr. Schrieffer enjoys teaching his "Physics for Poets" classes for non-majors and remarked that "One of the most gratifying experiences I have is the involvement with students who have a relatively minimal background in science. I want to expose them to the wonders of science, the phenomena themselves." He went on to remind all readers that "the best teachers are very often the best researchers."

Faculty awards at the University of Florida are being announced and presented as this issue of *NHMFL Reports* is being published. Complete details will be reported in the next issue.

Former NHMFL Intern Wins Goldwater Scholarship

The integrated education programs of the NHMFL have reached thousands of young people over the last five years, and hundreds of students have had significant one-on-one mentorship experiences in the laboratory. The NHMFL is extremely pleased to report that one such student—Asa Hopkins, a student at Haverford College in Pennsylvania—has gone on to win a prestigious Goldwater Scholarship for 1999.

Hopkins teamed with Dr. Stan Tozer at the NHMFL for two summers, 1997 and 1998, and worked on various high pressure and low temperature experiments.

Upon learning of Hopkins' success, Tozer remarked, "I felt privileged to work with Asa. His interests are very broad, but he showed a love of physics that I have never seen in someone his age. I handed him the lab keys on the first day and never had a single regret. The first summer he spent preparing numerous experiments for others, but we agreed that he should spend more time the second summer setting up his own experiment and reading as much scientific literature as possible. His appetite for reading proved insatiable. I, and others here at the lab who worked with Asa, look forward to the substantial impact he will make in whatever area of the sciences he eventually pursues."

Hopkins recently reflected on his NHMFL experiences: "Last summer [1998] I worked on sample preparation mostly, for a visitor (Eric Jones, from Sandia) studying a semiconductor with solar cell applications, and for Stan putting leads on (or trying to) samples of TMTTF-2 PF-6, a possible quasi-one-dimensional organic superconductor." He discussed his semiconductor research activities in his Goldwater Scholarship essay and indicated that "this helped a lot with the scholarship...also with getting a good summer research job at the University of Connecticut this summer."

The Goldwater Scholarship is the nation's premier undergraduate award for study in the fields of mathematics, the natural sciences, and engineering. The scholarship, established in 1986 and named after former Sen. Barry M. Goldwater, is awarded annually to undergraduate sophomores and juniors. It is designed to encourage outstanding students to develop careers in the sciences. 1,181 students were

The Road to 1 ppm at 25 T

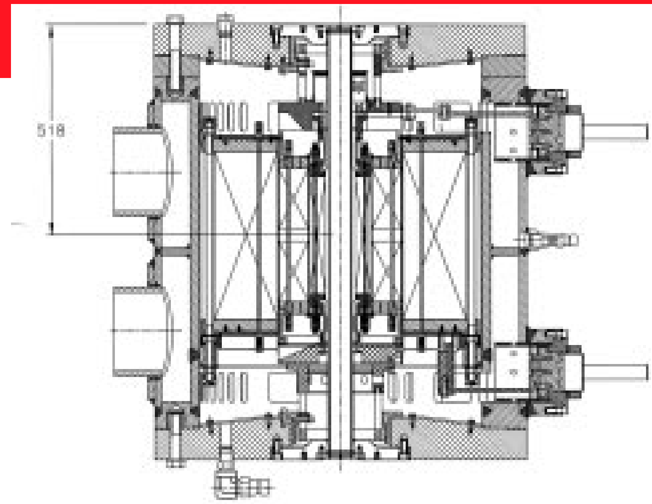


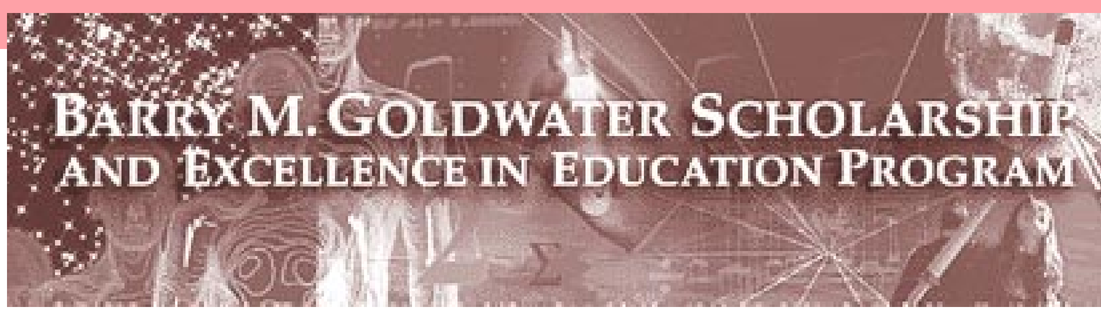
Figure 1. Section of Keck Magnet.

A few years ago the NHMFL undertook the challenge of building a 25 T, 52 mm bore resistive magnet with field uniformity and stability of 1 part per million (ppm) over a 1 cm diameter spherical volume (DSV). This is a very ambitious project as a typical high field resistive magnet has a uniformity between 500 and 750 ppm over 1 cm DSV and the highest field 1 ppm magnets previously attained are superconducting magnets around 18 T. Construction of this magnet was undertaken with funding from the W. M. Keck Foundation, the NSF grant for the NHMFL, and the State of Florida.

Magnet Design Concepts

To obtain 25 T DC, a Florida-Bitter magnet similar in construction to our 30 T magnets was designed. The magnet consists of three concentric Florida-Bitter coils labeled A, B, and C from the inside out as shown in Figure 1. The 30 T magnets at the NHMFL have field uniformity of about 630 ppm over 1 cm DSV. This inhomogeneity is dominated by the term z^2-1/2R^2. In the Keck magnet this term is compensated by putting a split of 31.8 mm in the B coil. This method was previously used successfully in cell 5 and cell 7 of the NHMFL by putting a short in the B coil of the 27 T, 32 mm bore magnets. Comparison of the corrected and uncorrected field plots of the 27 T magnets is presented in Figure 2. This simple second order correction will not provide the required uniformity of 1 ppm due to imperfections

1 ppm at 25 T continued on page 14



nominated for the 1999 Goldwater Scholarship; 304 awards were made.

Hopkins is the second NHMFL intern to receive this prestigious award. Robert Cox, who worked with Dr. Tim Cross on molecular modeling, won a 1998 Goldwater Scholarship.

Hopkins and Cox took Advanced Placement Physics at Leon High School in Tallahassee. Their teacher, Jim Baker, was delighted to hear that two of his past students had received this award: “They were particularly impressive since [my AP Physics class] was their first exposure to physics…I’m happy and proud that these two young men have pursued physics, and doubly so that they have won such a prestigious award.”

The NHMFL education program has grown steadily since it began shortly after the laboratory’s establishment in 1990. Now called the Center for Integrating Research and Learning, the program’s faculty develop and manage a broad spectrum of educational opportunities for students. In addition, the Center offers continuing education programs for teachers, conducts educational and general public tours and outreach activities, and develops novel curriculum materials like *Science, Tobacco, and You* (see page 1).

When former NHMFL interns and students pursue degrees in math, science, or engineering; earn graduate degrees (19 Ph.Ds. in 1997 and a similar number in 1998); and win awards like the Goldwater Scholarship; it is, for NHMFL faculty, proof that mentorship *works*. As the laboratory and its educational offerings continue to mature and expand, we are confident that the success of Hopkins and Cox will be repeated many times over.

1 ppm at 25 T continued from page 13

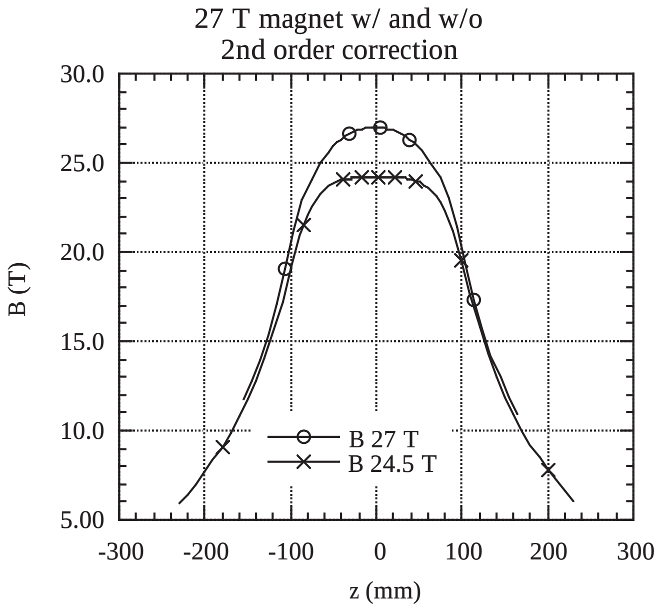


Figure 2. $B_z(z)$ for a standard magnet and a second order compensated magnet.

inherent in real magnet construction. Consequently, the bore tube of the Keck magnet has an extra 5 mm of glass-epoxy on its outer radius to provide space for water cooled shims.

Spatial Uniformity

For NMR applications, the relevant uniformity measurement is the variation of the magnitude of the magnetic field vector over the sample space i.e.

$$\left|\vec{B}\right| = \sqrt{B_z^2 + B_y^2 + B_x^2} = B_z\left(1 + \frac{B_y^2 + B_x^2}{2B_z^2} + \cdots\right)$$

Since B_x/B_z is of order 10^{-5}, we can ignore the second term of the expansion and consider only B_z. The field was mapped in the completed magnet via NMR along a helix about the z axis near the midplane. This was accomplished by mounting the NMR probe 5 mm off the axis of a screw of pitch 1.27 mm/thread. As the screw is turned the sample sweeps a helix. The sample starts 15 mm below the nominal field center. Three NMR field measurements are typically taken at each point and averaged. The screw is turned 74 degrees counterclockwise, the sample moves 74 degrees counterclockwise about the z axis and 0.26 mm up the axis and another set of data is taken, etc. The results of such a map are shown in Figure 3 and can be fit using Legendre polynomials. The dominant terms are presented in cartesian coordinates where $R^2 = x^2 + y^2$:

$$B_z = B_o + B_1 z + B_2 x + B_3 y + B_4\left(z^2 - \frac{1}{2}R^2\right) + B_5 zx + B_6 zy + B_7\left(z^3 - \frac{3}{2}zR^2\right) + B_8\left(z^4 - 3z^2 + \frac{3}{8}R^4\right)$$

The coefficients of the fit are presented in Table 1, column 1. We see that the dominant terms are the *x* and *y* terms, which give a net effect (root of sum of squares) of 3.4 ppm/mm or 34 ppm over 10 mm. Furthermore, we can search a 1 cm DSV centered at the nominal field center using the fit coefficients and determine that the uniformity is 48 ppm, much greater than the 1 ppm required. This substantial inhomogeneity is due to misalignments of the various coils with respect to each other and the current not being perfectly axisymmetric in each coil.

Table 1. Coefficients of Field Inhomogeneities

Term	No shims	Shims 0°	Shims 28°
z	-0.331	0.0915	0.0856
x	2.92	-0.414	-0.210
y	1.76	1.71	0.0868
z2	-0.0170	0.320	0.233
zx	0.181	-0.0301	0.0756
zy	0.0607	0.0629	0.0606
z3	-0.00219	0.0162	0.01714
z4	-0.00136	-0.00117	-0.00094
total linear transverse	3.41	1.76	0.227

There are at least two methods to shim such a magnet at this point. The standard procedure is to install wire-wound correction coils in the bore of the magnet. An alternative approach is to place small pieces of ferromagnetic material in the bore of the magnet. Resonance Research of Billerica, Massachusetts, a company specializing in shimming NMR magnets, was contacted. While they felt it was possible to shim the magnet using correction coils, they believed a two-step approach of using ferroshims to get from 50 to 10 ppm and correction coils to get from 10 to 1 ppm would require less space. A bore tube was shipped to Resonance Research who designed and built the ferroshim system consisting of numerous pieces of ferromagnetic material imbedded in the glass-epoxy on the outer surface of the bore tube.

The ferroshimmed bore tube was returned and installed. Unfortunately, at that time there was an unexpected problem in the C coil of the magnet requiring said coil to be disassembled, cleaned, and reassembled. The repaired C coil was reinstalled along with the A and B coils and the ferroshimmed bore tube. Rebuilding the C coil introduced some significant changes into the inhomogeneity. Consequently, the bore tube as designed did not reduce the inhomogeneity as well as expected (Figure 3). By fitting the field maps with and without the ferroshims, we were able to

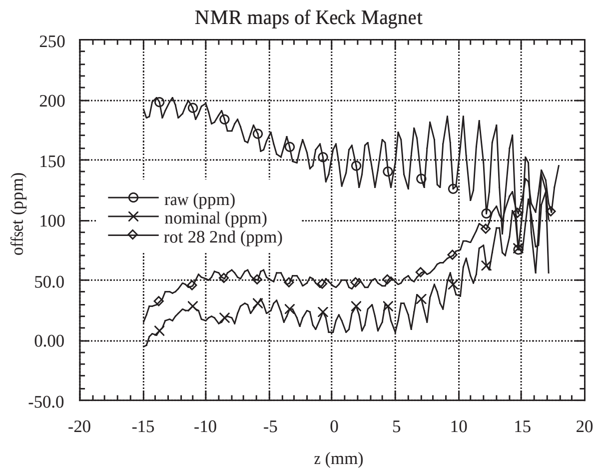


Figure 3. B_z from helical NMR maps for three cases: (1) magnet without ferroshims (raw), (2) magnet with ferroshims installed as designed (nominal), (3) magnet with ferroshims rotated 28 degrees counterclockwise (rot 28 2nd).

isolate the contributions from the coils and from the ferroshims and reoptimize the position of the ferroshims. By rotating the bore tube 28 degrees counterclockwise we obtained a new, improved field profile as show in Figure 3 and Table 1.

The ferroshimmed system presently has inhomogeneity of 12 ppm over 1 cm DSV as determined from the fit coefficients. Thus, even after rebuilding the C coil we obtained an improvement of a factor of 4. The dominant term of the inhomogeneity in the unshimmed system was the linear transverse terms, *x* and *y*. The net effect of these two terms is presented in Table 1. We see that it has improved by a factor of 15.

The present plan is to send to Resonance Research field maps of the magnet with the new C coil along with a second bore tube. Resonance Research will then install a new set of ferroshims on the new bore tube along with a basic set of field correction coils. This approach allows the magnet to be used for science in its present configuration while a next generation shimming system is built.

Temporal Stability

Perfect spatial uniformity is of little value without sufficient temporal stability. It has been previously shown[1] that the field ripple in a unstabilized resistive magnet at the NHMFL is about 10 ppm. This ripple comes from at least two sources: ripple in the power supplies and water temperature variations. Ripple from the power supplies translates into field ripple in a straightforward manner. Water temperature change is less obvious: a 1 degree water temperature increase results in a 22 ppm expansion of the copper conductor; a proportionate drop in current density and, consequently, magnetic field. By installing a flux stabilizer (pickup coil, active coil and feedback system) to provide high frequency stability and an NMR lock for low frequency stability, better than 1 ppm has been attained. Since that time, improvements in the power supplies have resulted in less ripple and the locked system is expected to be still better.

Linewidth

With the magnet in its present configuration (ferroshims installed), NMR linewidths of 0.8 ppm have been observed for magic angle spinning of NaCl samples of 1.5 mm outer diameter and 9 mm length (Figure 4).

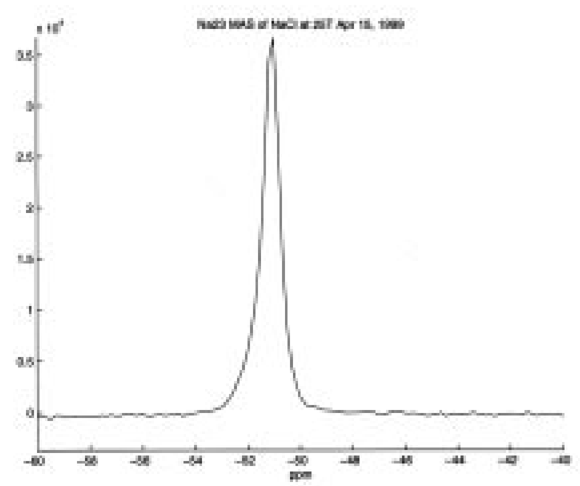


Figure 4. Na23 MAS of NaCl in 1.5 mm diameter, 9 mm long sample at 25 T.

Conclusion

Ferroshims have provided a factor of four improvement in the homogeneity of the Keck magnet only using 1.0 mm of space on the radius. The present system is down to 12 ppm over 1 cm DSV and is expected to be substantially improved over the next few months. The magnet is available for science at 25 T with linewidths demonstrated as small as 0.8 ppm. Interested users should contact Bruce Brandt (brandt@magnet.fsu.edu) or Merry Ann Johnson (johnson@magnet.fsu.edu).

Reference:

1 Soghomonian, Cotten, Rosanske, Cross, "Field Stabilization and ^{2}H NMR Spectroscopy in a 24.6 T Resistive Magnet," *J. Magn. Reson.*, 125, 212-215 (1997).

This article was contributed to NHMFL Reports *by Mark Bird of the NHMFL Magnet Science and Technology Group. Dr. Bird may be contacted at 850-644-7789 or bird@magnet.fsu.edu for further information.*

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