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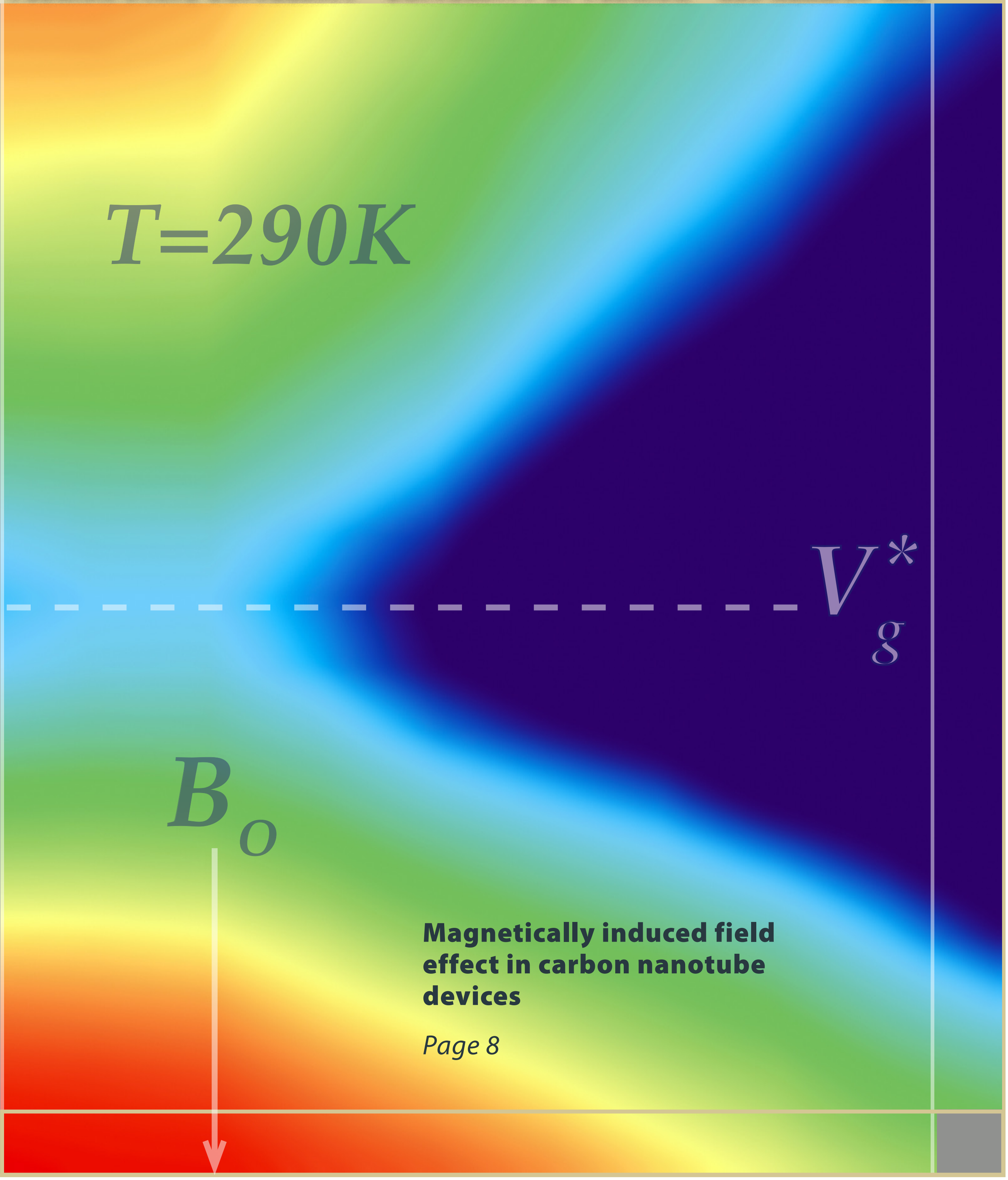

Magnetically induced field effect in carbon nanotube devices

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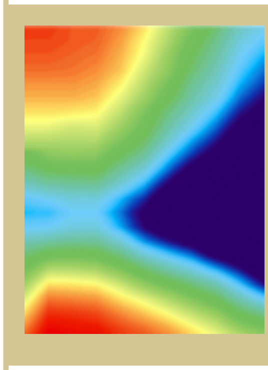

On the covers:

FRONT: This figure, shown in Dmitry Smirnov's piece on page 8, shows the conductance of a carbon nanotube field effect transistor measured with the magnetic field applied parallel to the nanotube axes.

BACK: Science Quest students from across North Central Florida visited the University of Florida.

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More electricity, users, and productivity lie ahead

GREG BOEBINGER

Well, the National Science Board has recommended that MagLab funding increase over the next five years (2008-2012). This very welcome news comes after years of work by many people. My sincere thanks to everyone who helped make such a strong case for the MagLab, in particular our External Advisory Committee who met twice to review the proposal and our NSF Site Visit presentations.

Although the exact amount is still to be determined, the expected increase over the present $128 million funding level acknowledges the growth of our user programs, the excitement of our scientific vision and, alas, the breathtaking increase in the price of electricity. By the very nature of the beast, if we are not struggling to keep up with scientific demand and its associated costs, then we could probably do more for our users.

Addressing the increasing demand for DC magnet hours remains our top priority. In the next five years, we expect to buy more electricity to provide more DC magnet hours and to service experiments like NMR and specific heat that sit at fixed (and typically maximum) magnetic fields for many hours.

We are exploring other ways to further improve our scientific productivity. One idea is to introduce "flex-time" to our DC magnet program: Experiments that are working well and collecting high quality data would be allowed to keep running … through the night if necessary. To manage the electricity costs, users might be required to give up a similar number of magnet hours scheduled for later in the week. The hope is that flex-time will provide those magnet hours when the user's experiment needs them the most.

Another idea is to unify our proposal process for the DC and Pulsed Field user programs. The two facilities already maintain a strong scientific connection, and many experiments now conducted in DC fields, such as magneto-transport, magnetization and photoluminescence, also can be successful using pulsed magnetic fields.

Since its inception, the MagLab has led the development of new experimental techniques using pulsed magnets. Yet pulsed magnets still suffer from an outdated reputation as an unreliable and downright brutish way to do honest scientific research. In reality, they've become quite civilized!

Pulsed magnet experiments now match the quality of many DC experiments, and can offer a few advantages: the cost of electricity for a pulsed magnet is negligible so the user can typically keep pulsing away until a desired data set is complete; and when user demand is particularly high, we can always (often) launch another experiment by time multiplexing with ongoing experiments. As a result, the pulsed magnet user queue is typically much shorter than the user queue for DC magnets.

Under a unified system, the magnet time review committee will evaluate proposals for DC magnet time to determine which can be performed well in pulsed fields. The scientific staff at Los Alamos, world leaders in conducting experiments in pulsed magnets, will bring users up the learning curve to collect the best data possible. The pulsed data can then be augmented as necessary using DC magnet time.

The goal is more high-quality data collected in both our DC and pulsed magnet user programs.

Another high priority is an increased investment in materials research to assist in the development of next-generation magnets. Preliminary efforts have already yielded success: in July, the MagLab and industrial partner SuperPower together achieved a new world record for magnetic field created by a superconducting magnet.

The new record – 26.8 tesla – was reached with a test coil wound with SuperPower's yttrium barium copper oxide (YBCO) tape conductor. Based on bench-top measurements of this conductor, our magnet engineers say this YBCO tape might go many teslas higher. At the risk of counting our teslas before they are hatched, one can now imagine matching the performance of our DC resistive magnets using cost-effective all-superconducting magnets. Read more about our latest world record on page 14.

Rock 'n' Roll,

Gregory S. Boebinger

Persistent spin dynamics in "stuffed" spin ice

By Chris Wiebe and Haidong Zhou

The topic of spin ices has dominated much of the current literature in geometrically frustrated magnetism. These unusual materials have the general formula $A_2B_2O_7$, where A is a rare earth magnetic ion, and B is a non-magnetic transition metal. The A sites form what is called a pyrochlore lattice, or a sublattice of corner-shared tetrahedra (see Figure 1). This arrangement of the magnetic spins gives rise to an unusual ground state, since the system cannot order in a conventional way. Instead, the spins freeze out at low temperatures into a short-ranged ordered state where each tetrahedra has a 2 spin-out, 2 spin-in arrangement. Since this has an analogy with how the protons freeze in water (that has a similar configuration of two short bonds, and two longer bonds on each oxygen atom), these materials are called "spin ices." At low temperatures, there is a considerable amount of disorder in both water ice and spin ices, which seems to contradict the third law of thermodynamics.

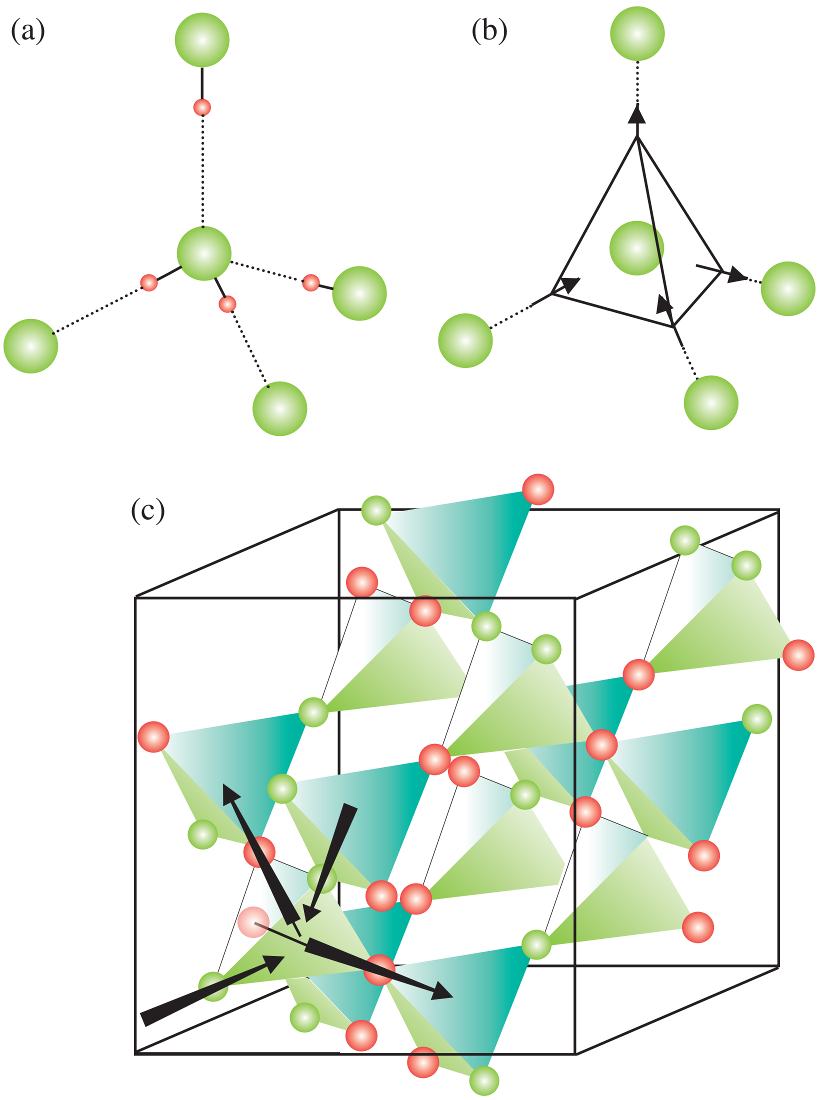


Figure 1.
(a) Hydrogen bonding in water ice. The protons (small circles) have two short bonds and two long bonds with each oxygen atom (large circles). (b) In spin ices, each tetrahedron has two spins pointing inward and two spins pointing outward at low temperatures. (c) The pyrochlore sublattice in spin ices, which form a network of corner-shared tetrahedra.

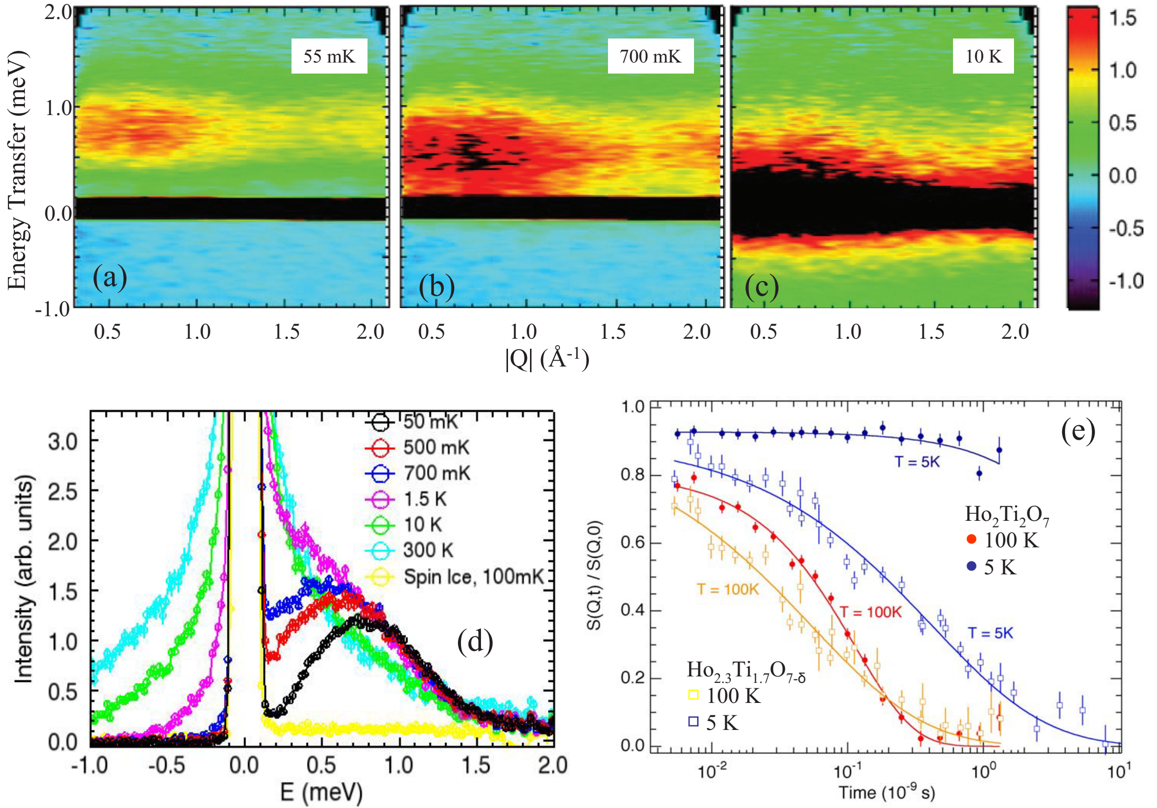


Figure 2.

(a)-(c) Inelastic neutron scattering on stuffed spin ices shows that at low temperatures, an inelastic responses develops that is clearly different from unstuffed spin ices (see figure (d)). Neutron spin echo data in figure (e) illustrates that while unstuffed spin ices $Ho_2Ti_2O_7$ have a frozen ground state (with almost no relaxation), the stuffed spin ices $Ho_{2.3}Ti_{1.7}O_7$ have a dynamic state that is almost indistinguishable with the high temperature paramagnetic state.

The "stuffed" spin ices are materials where extra magnetic spins are inserted within the pyrochlore lattice. These new compounds provide a means for testing how delicate spin ice states are. Remarkably, it is found that the increase in the density of spins results in very little change in the residual entropy.

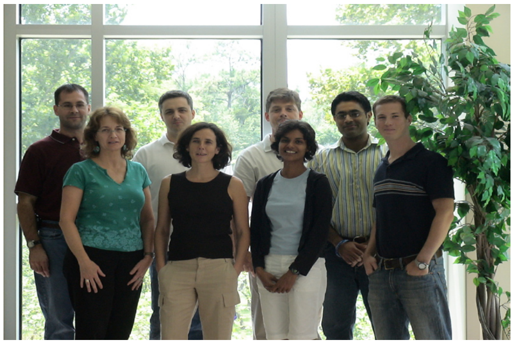
Our recent work on the stuffed spin ices features the growth of the first stuffed spin ice crystals $Ho_{2.3}Ti_{1.7}O_7$ to observe how the spins order at low temperatures. Neutron scattering measurements show that the stuffed spin ices are not frozen at all – their spins are still dynamic at low temperatures (see Figure 2). "Stuffing" the lattice with extra spins melts the spin ice state, much like doping water with impurities raises the melting point in ice.

Future studies of stuffed spin ices will be able to determine whether or not the ground state is truly a spin "liquid" of tumbling spins at low temperatures that never finds an ordered state. Examples of spin liquids represent one of the "holy grails" of condensed matter science – they have been predicted to exist decades ago, but until recently there have been very few confirmed cases of this elusive magnetic state. As well, future research in frustrated magnetism has ties to research in the fields of liquid crystal phase transitions, surface science, stripe formation in high temperature superconductivity, and protein folding.

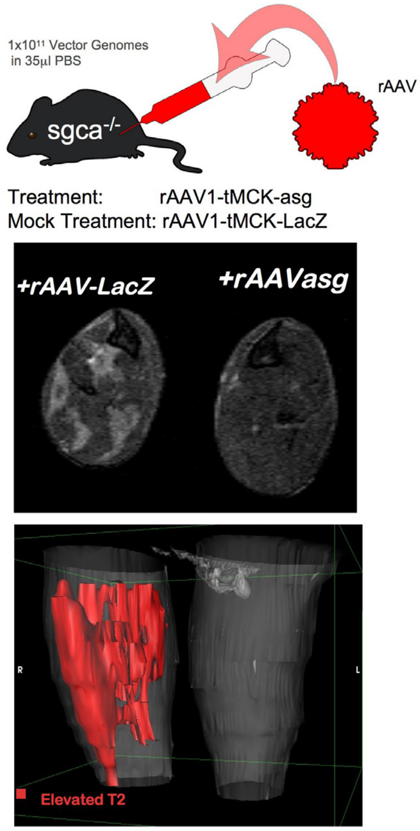
The complete version of this paper can be found in the IOP Publishing journal, *Journal of Physics: Condensed Matter.* The paper, "The origin of persistent spin dynamics and residual entropy in the stuffed spin ice $Ho_{2.3}Ti_{1.7}O_{(7-d)}$ appears in the online edition and is freely available. The paper is also featured in the August 2007 print version of *JPCM*.

From small molecules to treatment of neuromuscular diseases in children

Glenn Walter, Sunita Mathur, Donovan Lott, Raveneet Vohra, Sean Germain, Nathan Bryant, Claudia Senesac and Krista Vandenborne.



Several neuromuscular disorders display cellular muscle damage and loss of membrane integrity. One such condition is Duchenne muscular dystrophy (DMD), which is the most common form of the human muscular dystrophies. The cause of DMD is the absence of dystrophin, a 427kd membrane-associated cytoskeletal protein[1,4,7]. Dystrophin is normally located at the plasma membrane, on the cytoplasmic surface, and its primary role is the maintenance of plasma membrane integrity. DMD is characterized by progressive muscle weakness that is first apparent in the large hip and shoulder muscles, and later spreads to the distal extremities and the trunk. By their late teens or early 20s, children with DMD experience respiratory muscle weakness that leads to recurrent episodes of aspiration and eventual death from pulmonary insufficiency. The etiology of other forms of muscular dystrophy, including the limb girdle muscular dystrophies (LGMD), is linked to the loss of dystrophin-associated proteins.



Pacak *et al.* 2007

Figure 1.

MRI can be used to follow muscle correction for the muscular dystrophies using gene therapy. MR images from a mouse treated with the virus to restore the missing gene (asg), which results in the dystrophy, and a marker gene (LacZ) as a control. Areas of muscle damage in the uncorrected leg are visualized by T$_2$ imaging (middle) and by 3D rendering of the lower limb muscles where area of elevated T$_2$ are pseudocolored red (bottom).

Transgenic mice are commonly used as pre-clinical models for the study of therapeutic intervention in the muscular dystrophies. Muscles from the dystrophic mice exhibit critical hallmarks of the human form of the disease including: a high susceptibility to contraction-induced muscle damage, a significant degree of muscle fiber degeneration and regeneration, and increased fibrosis and cardiac pathophysiology in the latter stages of life[2,10]. Investigations performed in these mice provide proof of concept studies and set the stage for future clinical studies exploring novel treatments and interventions for children with DMD.

The goal of the definitive therapy for dystrophy is to re-establish the entire dystrophin protein complex. Ideally, these proteins would be delivered or turned on with a normal distribution, at normal levels, and be fully functioning. Various approaches (i.e. stem cell therapy, direct DNA injection, and viral-mediated gene transfer) have all been shown to restore dystrophin and dystrophin associated glycoproteins (DAGs) in dystrophic animal models, with varying degrees of success[7]. Alternatives to gene/cell transfer therapy include the use of pharmacological agents for premature stop codon suppression[12], oligonucleotides to redirect splicing of the dystrophin mRNA[5], or protease inhibitors to increase or preserve muscle mass[6].

Currently, assessment of therapeutic approaches in both children with DMD and animal models rely heavily on muscle biopsies. This invasive technique is problematic in evaluating the efficacy of interventions in patients who have extensive muscle damage or cardiac involvement. Therefore, it is imperative to develop noninvasive techniques capable of evaluating changes in muscle integrity in both clinical and pre-clinical studies. With this goal in mind, researchers at the Magnet Lab and their collaborators are using magnetic resonance imaging (MRI) and spectroscopy (MRS) as noninvasive measures to quantify disease progression and treatment for muscular dystrophies. Using two different mouse models of LGMD, Pacak et al[9] and Walter et al[11] have shown that MRI can serve as a sensitive tool to noninvasively monitor muscle correction using gene therapy (Figure 1) based on changes in proton transverse relaxation times (T_2) and delayed contrast enhancement[11]. Using the highest magnetic fields available for live animal imaging in the world, scientists within the Mag Lab are currently investigating how to develop MR measures as surrogate markers for muscle damage and/or correction[3]. In addition, they are examining the link between structural alterations in dystrophic muscle and MR parameters. For instance, novel diffusion tensor imaging algorithms developed by Mareci laboratory[8] are being applied to image fiber structure in normal and dystrophic muscles at the cell level followed by histological verification. Studies such as this that validate the use of MRI and MRS in quantifying muscle pathophysiology and plasticity are necessary before researchers can extrapolate the findings to clinical studies, where scanners have much lower spatial resolution and diffusion weighting at short echo times.

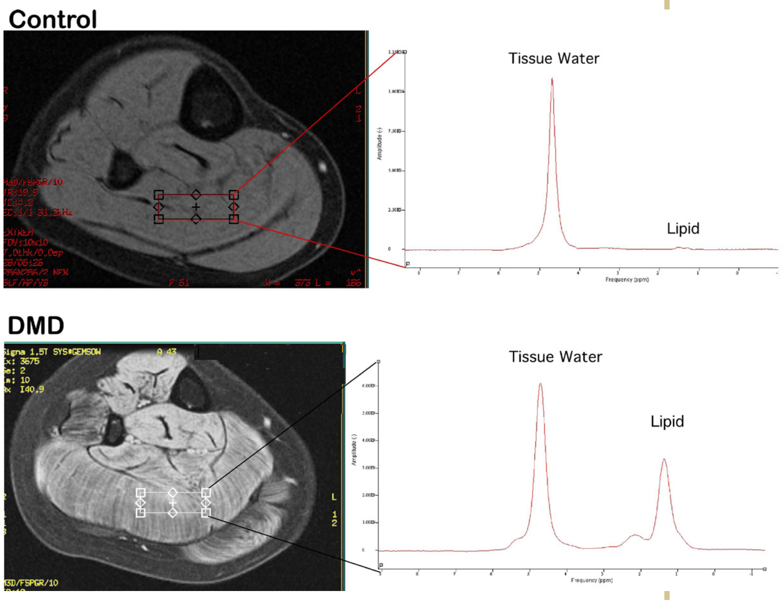


Figure 2.
Top: Fat saturated T_1 weighted MR image of healthy 11-year-old control calf used to select a region of interest for spectroscopy. The 1H MR spectra on the right was acquired from the region of interest identified on the image with a red box. Note the relatively low lipid content on the 1H spectra acquired within the soleus muscle of the healthy boy. Bottom: Fat saturated T_1 weighted MR image of the calf of 13-year-old boy with DMD. The white box indicates the region of interest from which the spectrum on the right was acquired. Note the large quantitative increase in lipid in the soleus of the boy with DMD.

As the primary target of most gene therapy or pharmaceutical interventions is the restoration of the expression of structural proteins and normal muscle membrane integrity, the ability to monitor muscle damage in vivo is extremely important. The most pressing challenge to using MRI/MRS to monitor disease progression in children with muscular dystrophy is the complexity of discriminating between fatty infiltration and damaged muscle (Figure 2). The majority of previous MR investigations have primarily relied on T_2- and T_1- weighted images to characterize skeletal muscle in patients with DMD. However, imaging techniques are hampered by the fact that one can not discriminate between shifts in relaxation times due to muscle injury or partial volume filling by fatty infiltration. With the acquisition of a 3 T whole body MRI within the AMRIS facility, Magnet Lab scientists are now able to study muscle integrity in children with DMD using T_2 imaging in combination with spectroscopic proton relaxometry. As part of a Sen. Paul D. Wellstone Muscular Dystrophy Cooperative Research Center, collaborators at the National Institutes of Health and University of Pennsylvania are working with scientists within the AMRIS facility to use the 3 T MRI to develop MRI as a clinical outcome measure for future clinical trials in patients with DMD. Studies involving MR methodology have great potential to advance the science and quality of patient care for people with muscular dystrophy by facilitating the translation of discoveries within cells and mice into the clinic.

ACKNOWLEDGEMENTS

This work was supported from grants from the NIH (RO1AR47292, R01HL78670, U54AR052646), NSF (Magnet Lab) and the Muscular Dystrophy Association. The work related to DMD is performed as part of a Sen. Paul D. Wellstone Muscular Dystrophy Cooperative Research Center (NIH;U54AR052646) under the direction of Lee Sweeny at the University of Pennsylvania. The work related to LGMDIId is performed in collaboration with Kevin Campbell at HHMI at the University of Iowa and the Powell Gene Therapy Center at the University of Florida under the direction of Barry Bryne.

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Exploring the magnetically induced field effect in carbon nanotube based devices

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Carbon nanotubes (CNTs) are cylindrical, nanometer diameter, quasi-1D objects made of a carbon monolayer (graphene) wrapped along a chirality vector (n,m). Depending on the direction in which the graphene sheet has been rolled up and on nanotube radius, a CNT can be either truly metallic or semi-conducting with energy bandgap values varying from a few meV up to about 1eV. CNTs exhibit a wealth of unusual effects and novel phenomena due to the combined effects of the intrinsic cylindrical shape, 1-dimensionality, a peculiar electronic structure, and electron-electron interactions. One of the most striking examples is the Aharonov-Bohm (AB) effect, which appeared in CNTs subjected to a coaxial magnetic field[1, 2].

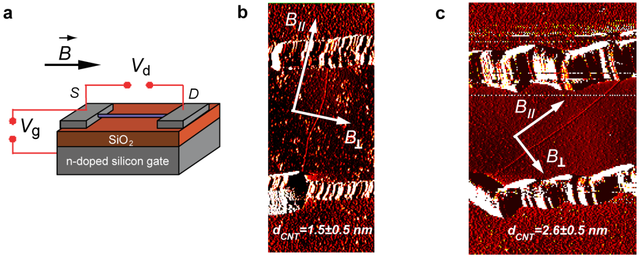

Figure 1.

(a) Schematic of a CNFET type device. We measure the linear conductance $G=I/V_d$ as a function of the gate voltage, V_g, and magnetic field B at a small DC bias voltage V_d~1 mV. (b), (c) AFM images of two studied CNFET devices. White arrows indicate direction of the magnetic field. Accuracy of the alignment was about ±3º.

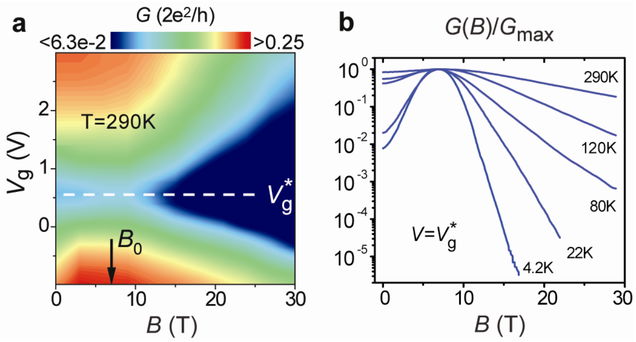

Figure 2.

(a) Plot of the sample 1 conductance versus the gate voltage and the axial magnetic field. A dark arrow indicates the value of B_0 , where $\varepsilon_g(B)$ has a minimum. (b) Off-state magnetoconductance of sample 1. At $B>10$ T the $G(B)$ curves appear as straight lines in the log-vs.-linear scale.

The AB effect is generally referred to as an action of enclosed magnetic flux on quantum states of charged particles[3]. It has been extensively studied in mesoscopic physics, where the AB leads to magnetic field-periodic weak localization corrections to the conductance of metallic cylinders or rings[4]. The AB effect on CNTs, manifested as profound modifications of the bandstructure of a nanotube, has no counterpart in mesoscopic physics. The presence of a magnetic flux through the cross-section of a nanotube leads to changes of the whole CNT's banstructure, including field-periodic saw-like modulation of the bandgap, and splitting and shifts of 1D energy bands. Ever since the original predictions of Ajiki and Ando[1,2], numerous efforts have been undertaken to use a magnetic field, a "clean" tool, to probe and continuously tune the bandstructure of a nanotube. The first experimental evidence of AB-induced band splittings in semiconducting CNTs has been obtained by J. Kono's group in optical experiments using the Magnet Lab's 45 T hybrid magnet[5]. The signatures of AB-effect on the bandgap have been revealed in magnetotransport studies performed by P. McEuen' and A. Bezryadin teams[6,7].

At the Magnet Lab, we performed a high magnetic field study of the AB-effect on transport properties of gated (quasi)-metallic single wall carbon nanotubes (SWNTs). We obtained clear evidence that a metallic SWNT can be made semiconducting by applying a magnetic field. This effect results from the AB phenomena at the origin of a band gap opening in metallic nanotubes[8].

The magnetotransport measurements were conducted using devices made in the configuration of a standard CNT field-effect transistor (CNFET), as shown in Figure 1. The conductance characteristics G(V_g) were recorded at temperatures from 1.5 K to 290 K and in magnetic fields up to 30 T.

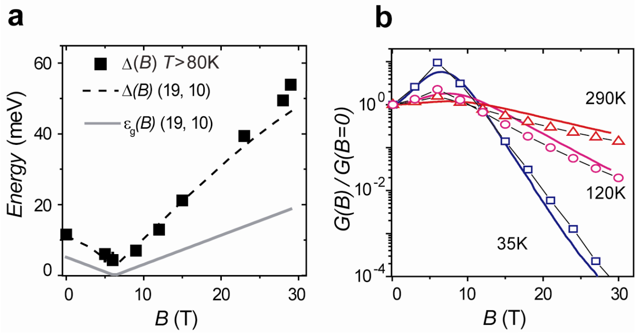

Figure 3.

(a) Transport activation energies Δ*(B)* determined from the conductance Arrhenius plots (sample 1) and Δ*(B)* calculated for the (19,10) CNT. Gray line shows calculated $\varepsilon_g(B)$ dependence. (b) Normalized off-state magnetoconductance of sample 1 compared to simulations for the (19,10) CNT.

Figure 2 shows the conductance of a CNFET device 1 measured with the magnetic field applied parallel to the nanotube axes. Perpendicular magnetic fields do not significantly change the conductance. Suppression of the conductance around V_g^* indicates the presence of the narrow gap in a quasi-metallic CNT at B=0. As the axial magnetic field increases, the gap decreases to reach a minimum value at B_0~6 T. Device 2 behaves as a truly metallic nanotube with B_0~0 T. Above B_0, a region of suppressed conductance develops, indicating a monotonous increase of a band gap in both samples. Remarkably, under high axial magnetic fields the devices operate as CNFETs with the on/off conductance ratio exceeding 10^4.

At high fields, the conductance of both samples decreases exponentially. This points to the thermally activated carrier transport, $G \propto \exp(-\Delta(B)/k_B T)$, with an effective activation energy $\Delta(B)$ scaling linearly with the magnetic field. We also measured the conductance temperature dependence at a number of the magnetic field values. The transport activation energies $\Delta(B)$ for device 1 determined from the linear parts of Arrhenius plots are shown in Figure 3a.

Qualitatively, the experimental observations agree with the predicted $\varepsilon_g(B)$ dependence, and therefore strongly favor the interpretation of our data in terms of the AB effect. A quantitative picture of CNFET magnetoconductance is achieved in the frames of a model incorporating both the AB effect on the bandstructure of the nanotubes and the AB effect on the Schottky barriers formed at the nanotube/contact interface.

For quasi-metallic CNTs it appears that the value of B_0 is extremely sensitive to the n/m ratio. For example, quasi-metallic SWNTs with a diameter in the range from 1.4 nm to 1.6 nm are found to have B_0 ranging from 5.7 T for a (13,10) CNT to 35.9 T for a (18,0) CNT. Based on diameter measurements only, one could assign 53 different chiralities for CNT 1. Comparing the calculated and measured magnetoconductance (Figure 3), we are able to assign this nanotube as a (19,10) CNT.

CONCLUSION

To summarize, we report on observation of a magnetic field induced conversion of initially metallic carbon nanotube devices into carbon nanotube field effect transistors. Strong exponential magnetoresistance observed up to room temperature is the ultimate consequence of the linear increase of the band gap with a magnetic field. The magnetic field controlled Schottky barriers significantly contribute to the CNT magnetoconductance, which may suggest new routes to engineer CNT-based devices characteristics. Moreover, this study reveals the temperature-dependent CNT magnetotransport as a new tool to explore the symmetries of carbon nanotubes.

ACKNOWLEDGEMENTS

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In vivo MR Imaging at 21.1 T

Victor D. Schepkin, Samuel C. Grant and Timothy A. Cross

INTRODUCTION

In vivo magnetic resonance (MR) imaging and spectroscopy are expanding our capability to observe and investigate many biomedical processes without invasive interventions. The unique 900-MHz ultra-wide bore (UWB) 21.1 tesla magnet built at the Magnet Lab in Tallahassee provides unprecedented opportunities to examine living systems. In this report, we present our first experiences and the results of *in vivo* MR imaging at the highest field available for such studies.

The ability to conduct *in vivo* MR imaging experiments was achieved as a result of multiple steps taken over the past few months. This work comprised designing and fabricating coils and probes, certifying facilities for animals, and gaining institutional approval for animal research. It also included the installation of an anesthesia station and animal physiological monitoring system. The Magnet Lab now has its own animal facility conveniently located in close proximity to the MR scanners and consists of animal housing rooms and animal procedural spaces. These accomplishments afford opportunities for internal and external users to run a variety of MR imaging experiments using the Magnet Lab world-record 900 UWB magnet.

EXPERIMENTAL

Testing the *in vivo* MRI capabilities of the 900 UWB system was performed using two animal models, C57BL/6J mice and zebra finch birds. The animals were anesthetized during MR scanning through the use of either a gaseous isoflurane/oxygen mixture or anesthetic injections.

The MR imaging experiments were carried out using a Bruker Avance console operated by PV4.0 and TopSpin 1.5 software. Currently, the 900 UWB system is equipped with a Bruker Micro2.5 gradient set

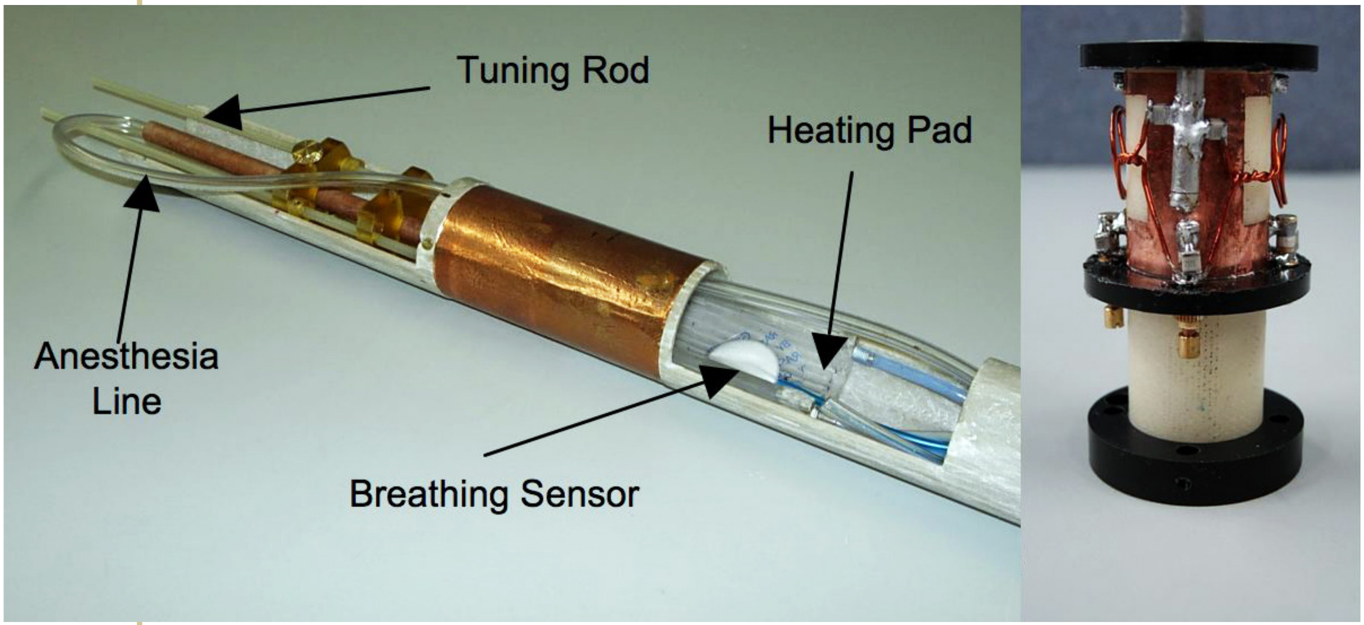


Figure 1.
Mouse *in-vivo* MRI probe and proton RF coil for the UWB 900 MRI scanner.

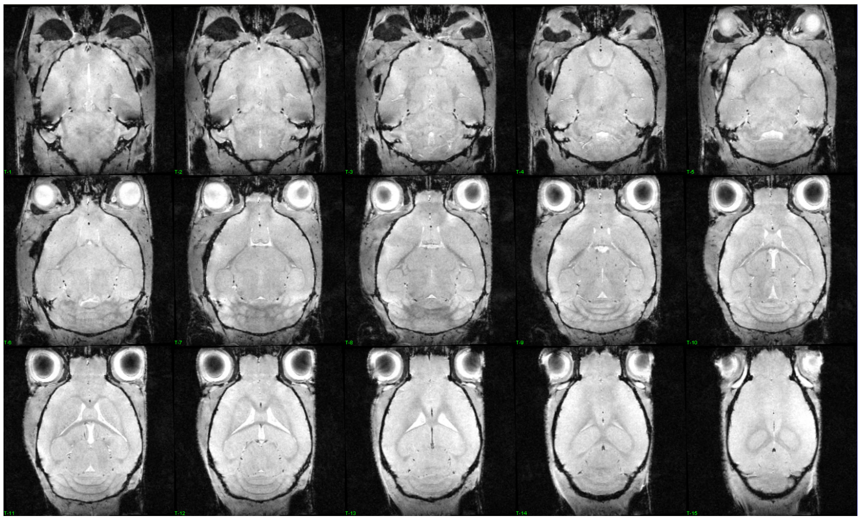


Figure 2.
Proton *in-vivo* MR images of mouse head acquired on the UWB 900 MRI scanner. Resolution in coronal plane was 62x62 µm, slice thickness was 150 µm.

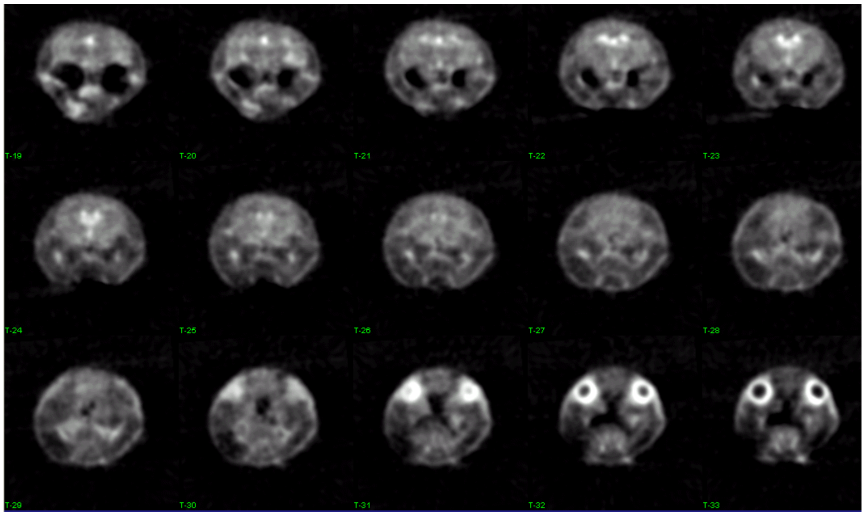


Figure 3.
Sodium *in-vivo* MR images of mouse head acquired on the UWB 900 MRI scanner. Resolution in axial plane was 500x500 µm, slice thickness 500 µm.

(ID =40 mm) and GREAT60 gradient amplifiers allowing maximum gradient strength of up to 1.5 T/m.

New RF probes were specifically developed for *in vivo* mice MR proton/sodium imaging at 21.1 T by Nathaniel Falconer and William Brey at the Magnet Lab. The RF coils were designed as single frequency Alderman-Grant coils with ID/OD = 17/25 mm (Figure 1). Both ^{1}H and ^{23}Na *in vivo* probes have an animal positioning system and a water-heated blanket to maintain body temperature inside the magnet. The probes have incorporated ECG, breathing and temperature control sensors that are connected to the Small Animal Monitoring and Gating System (Model 1025, SA Instruments, Inc.).

Gradient shimming is a well-established tool for MR imaging. For the 900 UWB system, the incorporation of FASTMAP proved more challenging because the magnet is equipped with a customized power supply and shim set (RRI, Inc.) to take advantage of the 105-mm size of the magnet bore. Recently our staff, Ashley Blue and William Brey, designed and constructed an interface for the Bruker power supply. This interface permits users to utilize Bruker software and hardware to control shimming through our customized shim coils. The FASTMAP technique has since been tested for both imaging and localized spectroscopy and is now available to users.

RESULTS AND DISCUSSION

In vivo Mouse Proton MR Imaging

The first brain ^{1}H MR images of the living mouse obtained at 21.1 T are presented in Figure 2. Fifteen images of the head of a normal mouse (C57BL/6J) were acquired using a Fast Low Angle Shot (FLASH) gradient recalled-echo sequence with TR/TE = 1000/4.3 ms, FOV = 16x16 mm and matrix = 256x256. The in-plane resolution was 62.5x62.5 µm with a slice thickness of 150 µm. The total accumulation time was ~ 18 min. The resolution of the MR images was sufficient to identify blood vessels in the mouse brain with diameter of ~100 µm, which can be seen throughout the images as the black dots in different parts of the brain.

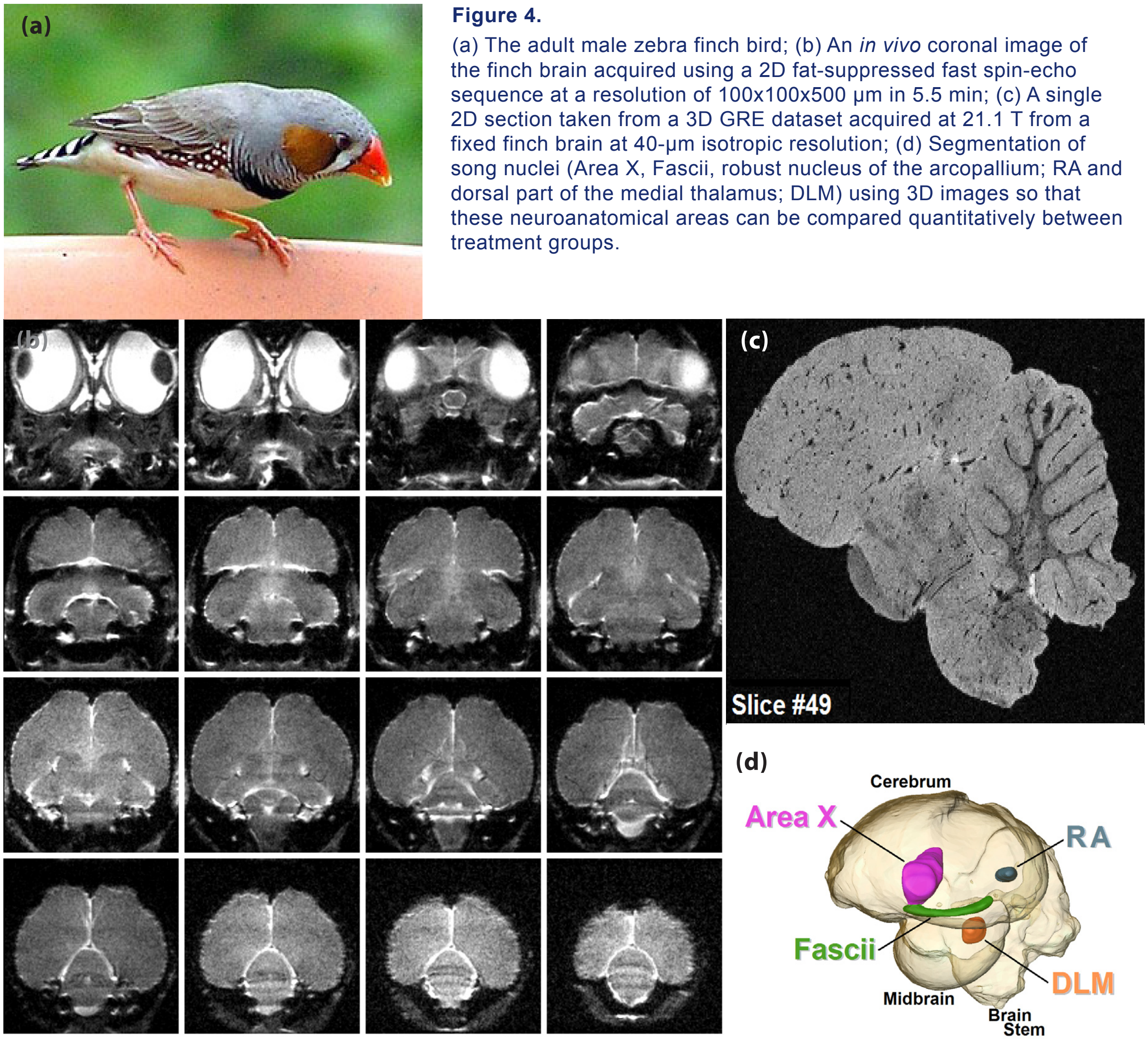


Figure 4.
(a) The adult male zebra finch bird; (b) An *in vivo* coronal image of the finch brain acquired using a 2D fat-suppressed fast spin-echo sequence at a resolution of 100x100x500 µm in 5.5 min; (c) A single 2D section taken from a 3D GRE dataset acquired at 21.1 T from a fixed finch brain at 40-µm isotropic resolution; (d) Segmentation of song nuclei (Area X, Fascii, robust nucleus of the arcopallium; RA and dorsal part of the medial thalamus; DLM) using 3D images so that these neuroanatomical areas can be compared quantitatively between treatment groups.

In vivo Mouse Sodium MRI

The first *in vivo* ^{23}Na images of the mouse brain were acquired at 21.1 T (frequency = 237.4 MHz) with isotropic resolution of 0.125 µL (Figure 3). A custom-designed 3D back-projection pulse sequence was used with the following parameters: TE = 1.5 ms, matrix = 64x64x64, FOV = 32 mm, TR = 50 ms, NA = 16 and a total acquisition time of 55 min. High resolution *in vivo* sodium and proton MR imaging is a very important tool for upcoming studies that seek to use sodium content and diffusion changes as early biomarkers for tumor response to therapy (NIH grant R21 CA119177-01).

Zebra Finch Brain MR Imaging

Recent *in vivo* work on the 900 UWB system also included a unique animal model. Susanne Cappendijk of the FSU College of Medicine uses zebra finches (Figure 4) to examine the neurochemical and behavioral effects of nicotine and Ecstasy (3,4-methylenedioxy-N-methylamphetamine, MDMA). The zebra finch model presents the opportunity to evaluate the mechanisms of memory and learning, as well as the biochemical impact of these drugs of abuse by monitoring their ability to employ songs.

Complementing these biochemical and behavioral assays, high resolution MR imaging on the 900 UWB system provides a means of assessing the pharmacological impact of nicotine and Ecstasy on brain morphology both in the living animal and the excised brain. For *in vivo* studies, imaging sessions were restricted to a total time of less than 60 minutes to limit stress on the bird. However, the sensitivity afforded by the 900 UWB permitted multiple images to be acquired with high signal-to-noise ratios at high

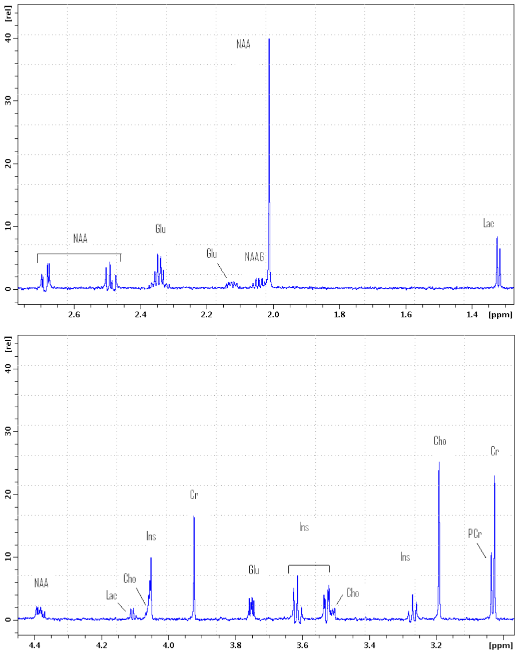


Figure 5..

Test of MR localized spectroscopy in brain phantom solution performed at UWB 900. The voxel volume was 8 μL, TR/TE = 4000/ 19 ms, accumulation time was 18 min.

Total acquisition time was 18 min.

resolutions within that timeframe (Figure 4b).

Once the longitudinal study was completed, the zebra finches were sacrificed for standard biochemical assays. However, because MR imaging is a non-destructive technique, the excised brains from these animals were first re-imaged on the 900 UWB system to achieve even higher resolutions. True 3D gradient recalled-echo (GRE) images were acquired from *ex vivo* brains at a 40-μm isotropic resolution (Figure 4c). Under the guidance of Biomedical Engineering Graduate Student Parastou Foroutan, Summer 2007 Research Experience for Teachers participants Stan Cutler and Mark Johnson assisted in segmenting regions in the song pathway of the finch brain for these studies (Figure 4d).

Localized Spectroscopy in Brain Phantom Solution

The high magnetic field of 21 T brings an extreme separation of MR spectral lines. Performance of the Point Resolved Spectroscopy (PRESS) was tested using a model brain solution (Figure 5 A, B). The solution was placed in 15-ml vial, and a localized 1D proton MR spectrum was acquired using a voxel size of 2x2x2 mm. Acquisition parameters were: TR/TE = 4000/19 ms, SW = 5 kHz. The FASTMAP shimming procedure allowed us to achieve a water line width of 18 Hz from the whole 15-ml sample.

Future Directions

Currently, we are in the process of purchasing a Bruker Mini 0.75 gradient coil. It will provide a peak gradient strength of 450 mT/m using the existing GREAT60 amplifiers. The installation of this gradient set and construction of the new large probes (now in progress) will permit numerous large rodent models to be evaluated at 21.1 T. In terms of RF coil advancements, we regularly receive valuable support from our AMRIS colleagues in Gainesville: Dan Clark, Barbara Beck, David Peterson, Steve Blackband and Art Edison. Their first proton single tuned 18-mm RF coil with remote tuning for 900 MHz is currently being evaluated. Further work is underway pursuing future MRI studies utilizing MR signals beyond proton.

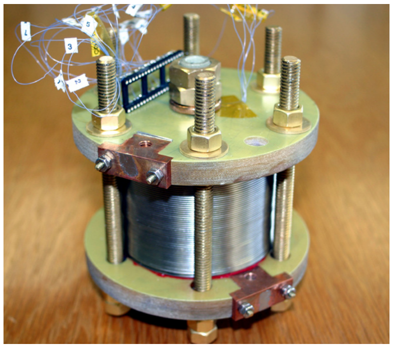
CONCLUSIONS

The first *in vivo* mouse and zebra finch bird MR images have been acquired using the 900 UWB magnet system. The novel *in vivo* MR imaging capabilities create new opportunities for Magnet Lab users around the country to investigate a host of animal models and to conduct biomedical research using proton and non-proton nuclei with sensitivity and contrast afforded by this special instrument.

ACKNOWLEDGEMENTS

Our *in vivo* MR program and Magnet Lab user's support is strongly dependent on the skill and effort of our staff. In addition to those mentioned above, Richard Desilets, Kiran Shetty and Peter Gor'kov have made valuable contributions to *in vivo* RF probe development. The *in vivo* mice studies were supported by NIH grant R21 CA119177 (PI Schepkin). Zebra finch research was supported by the State of Florida through the James and Ester King Foundation (06-NIR2) awarded to Cappendijk. The MR imaging program at the Magnet Lab is supported by Cooperative Agreement (DMR-0084173) and the State of Florida.

Mag Lab, SuperPower set new world record for superconducting magnet


World-record YBCO coil.

A collaboration between the Magnet Lab and industry partner SuperPower Inc. has led to a new world record for magnetic field created by a superconducting magnet. The new record — 26.8 tesla — was reached with a test coil in late July at the Magnet Lab's High Field Test Facility and brings engineers closer to realizing the National Research Council goal of creating a 30-tesla superconducting magnet. The development of such a magnet could lead to great advances in physics, biology and chemistry research, as well significant reductions in the operating costs of many high-field magnets.

The world-record magnet's test coil was wound by Schenectady, N.Y.-based SuperPower (www.superpower-inc.com) with a well-known high-temperature superconductor called yttrium barium copper oxide, or YBCO. SuperPower develops superconductors such as YBCO and related technologies for the electric power industry. The lab's Applied Superconductivity Center has worked with the company to determine the superconducting and mechanical properties of YBCO, as well as other materials.

Magnet Lab researchers tested a small coil (9.5-millimeter bore) in the lab's unique, 19-tesla, 20-centimeter, wide-bore, 20-megawatt Bitter magnet. The coil's world-record field was more than 1.8 tesla higher than the previous highest field of 25.0 tesla using a Bi-2212 coil wound in August, 2003 at the Magnet Lab.

"This test demonstrates what we had long hoped — that YBCO high-temperature superconductors being made now for electric utility applications also have great potential for high-magnetic-field technology," said David Larbalestier, director of the Applied Superconductivity Center and chief materials scientist at the Magnet Lab. "It seems likely that this conductor technology can be used to make all-superconducting magnets with fields that will soon exceed 30 tesla. This far exceeds the 22- to 23-tesla limit of all previous niobium-based superconducting magnets."

Venkat Selvamanickam, vice president and chief technology officer at SuperPower, said that while the company's work on the development of YBCO-based second-generation HTS wire has been primarily focused on devices for the electric power industry, the potential for application into others fields has always been in their sights.

"This demonstration opens the possibility for 2G wire to be employed in very high-field magnets in commercial applications such as nuclear magnetic resonance (NMR) spectroscopic devices that have so far incorporated only LTS-based coils," said Selvamanickam. "We are encouraged by the results of these tests at NHMFL and look forward to continuing our collaboration to more completely explore the additional possibilities in high field applications."

Scientists have been aware of the amazing properties of YBCO and its potential for magnet technology for 20 years, but only in the past two years has the material become commercially available in the long lengths needed for magnets. Scientists at the Magnet Lab are interested in the material because at very low temperatures, the conductor is capable of generating very high magnetic fields.

"In principle, YBCO is capable of producing the highest-field superconducting magnets ever possible," said Denis Markiewicz, a scientist in the lab's Magnet Science & Technology division. Based on the potential of the material, he said, it's even possible that it could one day produce magnetic fields as high as 50 tesla.

"What we learned from this test really opens the door to imagining that one day, we could use superconducting magnets in place of our resistive magnets," he said. Resistive magnets, primarily used for physics research, are more costly to operate because they are powered by tremendous amounts of electricity, while superconducting magnets require little or no electrical power to run once they are brought up to full field. The Magnet Lab's annual utility costs to run the magnets are close to $4 million a year, and the lab consumes 10 percent of the city of Tallahassee's generating capacity.

Key personnel at SuperPower were Drew Hazelton, Selvamanickam and Yi-Yuan Xie; and at the Magnet Lab, Larbalestier, Markiewicz, Ulf Trociewitz and Huub Weijers.

Scientists' support makes research experiences possible – and successful

CIRL Staff Report

A central goal of the Magnet Lab's Center for Integrating Research & Learning (CIRL) is to expand the horizons of science students and teachers; in turn, scientific institutions like the Magnet Lab have more and better scientists to work with. Giving both teachers and future scientists opportunities to conduct research lights a fire in students and encourages educators to think about teaching in new ways.

This summer, CIRL administered both Research Experiences for Teachers (RET) and Research Experiences for Undergraduates (REU) programs. Teachers were incorporated into all facets of the laboratory – conducting research and participating in ongoing projects with research mentors, and sharing their progress weekly.

The 15 participating teachers' lab experiences were supplemented with weekly seminars focusing on elements of science education, experimental design, the nature of science, process skills, communication in science, and inquiry based teaching and learning.

Mentorship is a commitment that is not taken lightly by those who participate in the research experiences programs. Because of the support of lab scientists, RET is a model program that provides the ultimate professional development experience for teachers. The following scientists and researchers mentored 15 teachers: **Jim Cao, Irinel Chiorescu, Mike Davidson, Sam Grant, Bob Goddard, Ke Han, David Larbalestier, Carol Nilsson, Vincent Salters** and **Chris Wiebe**.

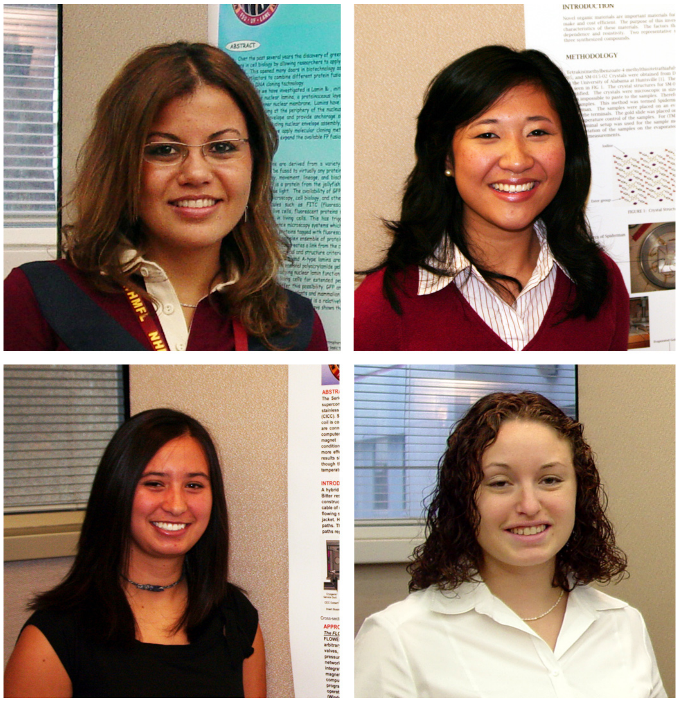
The REU program has been going strong at the Magnet Lab for 12 years. This year, 21 students from 15 different universities were selected by scientists to conduct research for eight weeks. Students were incorporated into ongoing projects or designed and developed new ones themselves. Students attended several colloquiums featuring topics such as superconductivity and solid state physics. The program culminated with the annual poster session at which students presented their research to their mentors and lab scientists.

Mentors from all three Magnet Lab sites gave countless hours, providing rich experiences for the students. Participating mentors for 2007 were: **Jim Brooks, Rafael Bruschweiler, Jim Cao, Irinel Chiorescu, Mike Davidson, Ian Dixon, Sylvie Fuzier, Ke Han, Alex Lacerda, Mark Meisel, Chuck Mielke, Al Migliori, Carol Nilsson, Arneil Reyes, Chuck Swenson** and and **Chris Wiebe**.

It's important to know how well programs like these work, so their effectiveness is being studied by recently departed graduate research assistant Crissie Grove and CIRL Director Pat Dixon.

Educational research on last year's RET program was presented at two national conferences this spring. The study, "Research experiences for teachers: Influences related to expectancy and value of changes to practice," investigated to what extent the RET program influenced teachers' science teaching practices, focusing on specific elements of the program that foster change and how these elements assist the participating teachers with science content specific to their teaching level.

The research provides a way of assessing the strengths of the program and a means to better understand what happens after teachers return to their classrooms. The study provided strong evidence that teachers make changes to their instruction such as leading



more inquiry-based activities, incorporating activities that model real-world science processes, and injecting more excitement into science instruction.

CIRL is now collaborating with researchers from the science education department at Florida State University to continue to investigate how RET influences science teaching and use of inquiry. This 5-year study looks at two programs: the Magnet Lab RET program and the Marine Sciences RET program.

CIRL researchers have also begun to turn their attention to outreach. Every semester CIRL reaches thousands of K-12 students in a 10-county area. A research project in the planning stage includes investigating how classroom outreach alone influences students' and teachers' perceptions of science and science teaching as compared with outreach combined with a tour of the lab.

A pilot study of former RET participants, "Research experiences for teachers: Sustained influences to practice, career, and retention," was also conducted this summer and has been submitted to two national conferences for presentation. The study followed RETs who visited the lab between 1999 and 2006. Future research associated with this pilot study will include a more comprehensive look at former RET participants to investigate any sustainable changes to science teaching due to participation in the RET program.

LAB DEBUTS REVAMPED SUMMER INSTITUTES

This summer, Richard McHenry, Magnet Lab Teacher in Residence, designed and facilitated two, 4-day workshops called "Lab Crawls" for elementary and secondary teachers in Leon County. These workshops, a collaborative effort between the Magnet Lab and Leon County Schools, were designed to expose the teachers to real-world lab research and to provide them with ways to translate that research into classroom activities.

Matt Guyton, a science teacher at Leon High School, and Dave Rodriguez, a science teacher at Swift Creek Middle School, presented the two workshops. Teachers went to laboratories at the Department of Environmental Protection, the Antarctic Core Laboratory at FSU, the MRI lab of Sam Grant, and Bear Creek Educational Forest.

After a morning in the lab, teachers then were led through a series of hands-on inquiry based activities related to that experience. The workshops received rave reviews from all of the teachers involved.

People

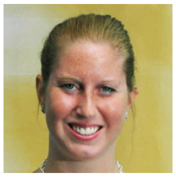
Magnet Lab alumnus **Tod Caldwell** in June returned from a year-long tour of duty in Iraq, where he was awarded the Army's Bronze Star Medal. Caldwell served in both Al Anbar Province, where he was only one of handful of Americans stationed with the Iraqi Army, and in Baghdad, where he worked with the Iraqi National Police.

The Bronze Star Medal is awarded for heroic or meritorious achievement or service. The narrative that accompanies the award states:

"Sergeant First Class Caldwell performed with remarkable clarity of thought under fire and overcame cultural and language barriers under combat conditions in one of the most dangerous provinces in Iraq. Through his actions, he has shown himself to be adaptable, diverse, and possessing all capabilities to operate in a small team where every man must be multi-talented and risk personal danger. As an advisor, he has been both a model for the Iraqi's military leadership and an ambassador of the American persona."

Caldwell received his Ph.D. in physics from Florida State University in 2004 working under the direction of **Bill Moulton** and **Arneil Reyes** in the lab's condensed matter physics nuclear magnetic resonance group. Caldwell is currently a post-doctoral associate with the Condensed Matter and Thermal Physics Group at Los Alamos National Laboratory.

Tim Cross, professor of Chemistry and Biochemistry at FSU and director of the Magnet Lab's Nuclear Magnetic Resonance program, has been named a Fellow of the Biophysical Society. Five were so named this year from a society with a membership of 8,000. The award acknowledges his "scientific accomplishments and leadership in the field of solid state NMR methods to the biophysical characterization of membrane proteins, and for service to the scientific community." Cross will be formally recognized at the joint meeting of the Biophysical Society 52nd Annual Meeting and the 16th International Biophysics Congress in Long Beach, Calif., on Feb. 4, 2008.



Crissie Grove, graduate research assistant in the lab's Center for Integrating Research & Learning (CIRL), has taken as position as Director of Institutional Assessment with Thomas University in Thomasville, Ga. In her new role, Grove will report to the university president on issues associated with accreditation. She also will teach a class in educational psychology and assist faculty in creating research agendas, conducting research and submitting results for publication.

Kimberly Lanier has joined CIRL as a graduate research assistant. Lanier, a science education Ph.D. candidate with a research interest in principal instructional leadership in science, will be working on enhancing curriculum packages produced by CIRL. She has been working with the Cawthon Hall Learning Community at FSU doing research, data collection, program evaluation, and longitudinal studies on participants of the program.

David Larbalestier, director of the Applied Superconductivity Center, received the Cryogenic Materials Award for Lifetime Achievement from the International Cryogenic Materials Conference (ICMC). He was presented with the award during a July meeting of the conference in Chattanooga, Tenn.

Larbalestier is viewed by many of his peers as the leading researcher in the United States, and possibly the world, in the basic research of practical superconducting materials for magnets and power applications. Over a 35-year career, he has profoundly influenced the development of high-field magnets for high-energy physics and other applications, such as magnetic resonance imaging (MRI), that have evolved from them. Among the highlights of his career is his election in 2003 to the prestigious National Academy of Engineering. In 2006, after more than two decades at the University of Wisconsin in Madison, Larbalestier agreed to move the Applied Superconductivity Center to FSU, where it was integrated as a new division of the Magnet Lab.



Three former postdoctoral research associates from the lab's Ion Cyclotron Resonance Program have moved on to new, permanent positions. **Sudarslal Nair** is an assistant professor at the Amrita Institute of Medical Sciences and Research Centre in Kerala, India. The Amrita Institute is the newest university in India, and Nair will be heading up its mass spectrometry/proteomics activities. **Do-Gyun Kim** is an ORISE fellow at the Center for Disease Control in Atlanta. He'll be developing mass spectrometric methods to detect and quantitate low levels of harmful pesticide metabolites in human breast milk, blood, and urine. **Greg Khitrov** is now a staff scientist in mass spectrometry at the UCLA Molecular Instrumentation Center in Los Angeles, where he will interact and collaborate with a wide range of research groups for mass spectrometric analysis of non-biological samples.

Magareta Pop, graduate research assistant, has joined the staff of CIRL to work with Director Pat Dixon on research on pre-service teachers and on teacher development and education. Pop, an international student from Romania, is a Ph.D. candidate in educational physchology and learning systems and comes to the lab from the Florida Center for Reading Research.

Chunqi Qian has joined the NMR program as a postdoctoral fellow and will serve as an interface between experimentalists in solid-state NMR and the RF engineering group and their efforts to build probes that will be designed to optimally serve the solid-state NMR user communities. Qian comes to Tallahassee from his graduate studies at Berkeley in the laboratory of Alex Pines where in collaboration with Rachel W. Martin he designed and constructed a 1H-13C double resonance variable angle sample spinning probe. His unique role at the Magnet Lab is supported by a two-year fellowship from Bruker Instruments.

Steven Van Sciver, a professor of mechanical engineering at the Florida A&M University-FSU College of Engineering and a founding member of the Mag Lab, in July became just the fifth member of the Cryogenics Society of America to be named a fellow of that organization since its founding in 1964.

The fellow honor is bestowed on a society member of distinction in cryogenics who has made notable valuable contributions to the field of cryogenics. Van Sciver is the author of more than 150 publications on low-temperature physics, liquid helium technology, cryogenic engineering and magnet technology, and also is author of the highly regarded textbook, "Helium Cryogenics." In addition, he is a fellow of the American Society of Mechanical Engineers and the American editor for the journal Cryogenics.

Science starts here

Vivien Zapf, 29

POSITION:

Scientific staff member

Los Alamos National Lab

TIME AND ROLE AT THE MAGNET LAB:

I visited the Magnet Lab several times as a "user" when I was a graduate student at UCSD, and a post-doc at Caltech. In 2004, while I was measuring at the NHMFL at Los Alamos, I was asked to stay. I received a director-funded post-doc fellowship and in 2006 I became a staff member at Los Alamos.

CURRENT WORK:

Recently I've been studying quantum magnets— magnetic systems in which quantum mechanics plays an important role in shaping the behavior. For example, the organic magnet $NiCl_{2\text{-}4}SC(NH_2)_2$ shows Bose-Einstein condensation of magnons in applied magnetic fields. This is equivalent to what happens in certain systems cold atoms at very low temperatures, except the particles that condense are magnons, and the effect happens in high magnetic fields. Quantum magnets can also exhibit frustration, reduced-dimensional behavior, superconductivity, and could even be candidates for quantum computation.

IN HER OWN WORDS:

It didn't take me long to realize that the Magnet Lab is the place for me and I have decided to remain as scientific staff. The Magnet Lab is a unique place. Unlike academic settings, it is highly collaborative and gives me the opportunity to work with many talented scientists and technicians with diverse skills and interests. It is also a mecca for physicists - through the user program and visiting scientists I am exposed to a wide range of research that is happening throughout the world and see many opportunities for new collaborations and research directions. And finally, access to unique experiments and the most powerful magnets in the world is always a plus.

HOW MENTORS MAKE A DIFFERENCE:

Alex Lacerda has been invaluable to my career and in particular has taught me the value of marketing oneself and one's ideas. Marcelo Jaime has taught me a great deal about the "people side" of physics. I am inspired by his ability to create and nourish collaborations, mentor students, and by his teamwork and leadership skills. He is always looking out for the people he works with and looking for opportunities to advance their careers.

"Science Starts Here" showcases young Scientists whose career paths have been greatly shaped by their experiences at the Magnet Lab.

ZAPF'S TOP 10 THINGS SHE'S LEARNED IN THE MAGNET LAB

TOP 10

10) Obstinacy. The equipment has to give up eventually and start working. Ditto with bureaucracy.
9) Skepticism. If the theory fits the data, one of them is probably wrong.
8) Patience. There are an infinite number of things to study and only so much time.
7) A steady course. Science is just as obsessed with fads as the fashion industry. Not to jump on the bandwagon.
6) Details. It's not hard to get things to work. You just have to do every little thing exactly right.
5) Preparation. Always give yourself the edge.
4) Curiosity. The little discrepancies could turn into big discoveries.
3) Awe. The universe will never cease to amaze with its intricate complexity yet startling simplicity.
2) Teamwork. Science doesn't thrive in isolation. The more heads the better.
1) Hope.

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Wavelengths

Although it was very hot outside, the topic inside the Microkelvin Lab and High B/T facility was ultra-low temperatures, as Science Quest students from across Florida visited the University of Florida in July.

Science Quest at the University of Florida immerses students in various science disciplines to stimulate interest in and appreciation for the range of college and career opportunities available in science. The selected students are rising 10th graders with an interest in science and are motivated and high achieving in the classroom. Students live in a campus dorm for one week, attend a variety of lectures and demonstrations, visit research laboratories and other facilities, and perform science experiments.

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