THE SPECTROGRAPH

Volume 24, Number 2 Spring 2008

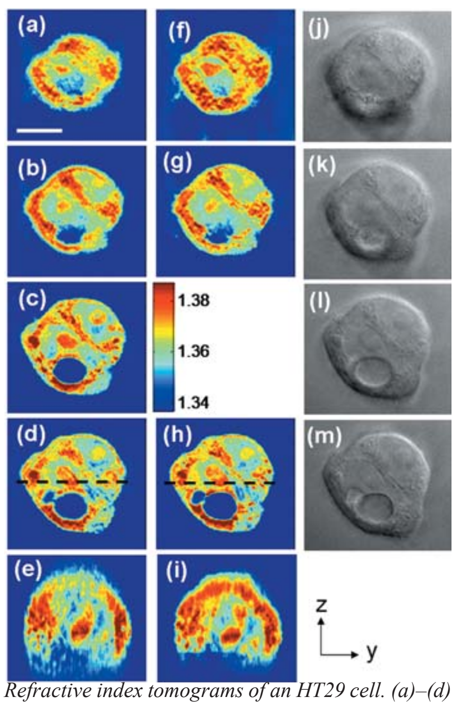
George R. Harrison Spectroscopy Laboratory

Massachusetts Institute of Technology

NSF Support for Novel Phase Microscopy

NSF has awarded Spectroscopy Laboratory Director Michael Feld and Principal Research Scientist Kamran Badizadegan a three-year grant to further develop quantitative phase microscopy for biological research.

Quantitative phase microscopy developed at the Spectroscopy Laboratory over the past decade offers significant advantages over traditional phase-contrast microscopy. Although this latter technique has been an essential tool in nearly every



Refractive index tomograms of an HT29 cell. (a)–(d) are x–y slices of the refractive index tomogram at 2-µm intervals in the axial direction; (f)–(h) x–y slices corresponding to (a), (b), and (d) after applying certain corrections. (e) and (i) x–z are slices along the dashed lines indicated in (d) and (h), respectively. The color bar indicates refractive index at λ=633 nm. (j)–(m) are bright field images with the image focus corresponding to (a)–(d). Scale bar = 10 µm.

biology laboratory for more than half a century and is uniquely able to reveal live cells and their internal structures without any special preparation of the cells, it has

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Reasons to celebrate

By Geoffrey O'Donoghue

The professors, staff, and students of MIT's George R. Harrison Spectroscopy Laboratory have moved into their new laboratory and office space in building 6, and it's time to celebrate! Save the date: on **Wednesday, February 27 2008** we will have a series of talks from distinguished visitors and a luncheon. (See the program details on center page.)

The new space provides new offices, common space, and much-needed modern laboratories for all the Spectroscopy Laboratory core researchers – the groups of professors Feld, Dresselhaus, Kong, van Oudenaarden, Bawendi Nelson, Tokmakoff, and Green.

The now demolished old Spectroscopy Laboratory in building 6A was built in 1931. It was the first building in the world built specifically for high-resolution spectroscopy. To reduce vibration and temperature fluctuations the building was windowless, had 4.5-ft thick cork-lined concrete walls, and rested on isolated pilings. The building served its purpose admirably for decades. The famed MIT wavelength tables, a Depression Era WPA project, were published by George R. Harrison in 1939. These tables presenting 110,000 seven-figure wavelengths assigned to their elements of origin were based on experiments performed in the Spectroscopy Laboratory. From 1940-1946 the laboratory spectrochemically analyzed thousands of uranium samples for the Manhattan Project using the 10-meter grating spectrograph.

By the 21st century, however, the building was showing its age. Core researcher Prof. Bill Green remembers sharing his lab with certain uninvited "guests": "Prior to the renovation project, we were attempting to run our mode-locked laser experiment in the original large grating room built as a WPA project during the Depression… In addition to the dust, there were

New space, continues on page 3

MLK Leadership Awards to Feld and Queen

By Charles H. Holbrow

Prof. Michael Feld and Zina Queen

Spectroscopy Laboratory Director Michael Feld and Administrative Assistant Zina Queen have received 2008 Martin Luther King Leadership Awards. They, along with Leo Osgood, Jr., Lorlene Hoyt, Assistant Professor of Urban Studies and Planning, and Ali Wyne `08, have been chosen for this year's MLK awards by the MIT Campus Committee on Race and Diversity. These awards recognize their extensive and persistent efforts to make MIT a more open, more welcoming and more harmonious workplace.

Michael Feld has a long history of vigorous pursuit of racial equality and diversity at MIT. As chair of MIT's Equal Opportunity Committee for many years, he forthrightly brought institute shortcomings to the attention of administrators and colleagues. He was a natural choice

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two important limitations. First, traditional phase microscopy provides only qualitative information about cell structures. Second, its images are only two-dimensional projections of the cell's three-dimensional structure, so phase microscopy is of limited use when it is important to identify the precise location of subcellular structures.

The NSF's support enables the Feld group to continue developing new approaches and instruments that overcome these limitations. This work, in which Post Doctoral Associate Wonshik Choi is playing a major role, is significantly broadening the value and scope of phase microscopy for biological research.

Using several different techniques, researchers in the Feld group extract from interferograms quantitative phase information from which they construct images of live cells and their internal structures. The complicated intensity pattern that is an interferogram is produced by the interference of the signal and reference beams. The intensity pattern depends both on phase variations and on the amplitudes of the two beams. In the past decade there have been important advances in ways to extract the phase information separately from the amplitude information by modulating the relative phase between the signal and reference beams; these advances have made quantitative phase microscopy possible.

Spectroscopy Laboratory researchers call this approach "field-based" phase microscopy to distinguish it from standard intensity-based microscopy. Combining their field-based approaches with advanced methods of optics and spectroscopy, they have pioneered the development of some novel instruments for quantitative phase microscopy. Choi's research report in the Fall 2007 issue of *The Spectrograph* describes how he has used a method similar to x-ray computed tomography (CT scan) to convert quantitative phase images into a 3-dimensional image of a live cell in real time, where the contrast features of the tomogram are variations in index of refraction.

"...The Spec Lab is particularly suitable for work toward this grand goal... "

The tomogram is constructed from ~100 phase images produced by passing a laser beam through the sample at various angles of illumination. These transits of the beam are stepped at intervals of ~1.2 degrees by a piezo-driven galvanometer mirror. Choi has recently described steps the group is taking to improve field-based tomographic microscopy:

• Improve resolution: The first tomographic images had an axial resolution of ~0.75 μm and a lateral resolution of ~0.5 μm. By changing the mirror mechanism to provide wider angle coverage by the laser beam, axial resolution can be reduced to ~0.6 μm. The group is already improving resolution by constraining analysis of their data to match known features of a sample. Finally, by modifying their data processing to include the diffraction of light by the sample, they will be able to improve the transverse resolution to ~100nm, a factor of two better than the diffraction limit.

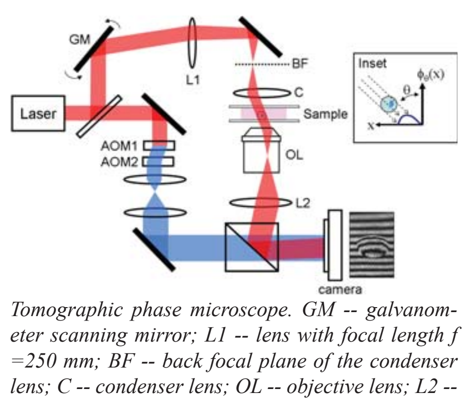
• Increase the speed at which data are recorded to permit data collection at video rates: Already the Feld group has successfully used a technique known as Hilbert phase microscopy to record a phase image from a single interferogram. Combining this technique with fast response detectors will allow continuous scanning of the galvanometer mirror that directs the laser beam through the sample. With these improvements tomograms can be taken at rates as high as 50 Hz.

• Increasing the speed with which data are processed: The construction of a tomogram from 100 phase images is computer intensive. Generation of a single tomogram takes about 30 minutes on a desktop computer. A recently installed small cluster computer will reduce this time by about a factor of 10.

• Improve the contrast of features in their images: Refined measurements using several different wavelengths of light should make it possible to identify with great specificity different molecular species and their concentrations in a cell. From such information it should be possible to increase the effective contrast with which features of the cell are imaged.

• Understand light scattering properties of live cells: Disease in a cell can show up by changes in how internal cell structures such as the nucleus, the nucleolus and mitochondria scatter light. At present these effects may be masked by scattering from any other heterogeneity of the refractive index, but now, with field-based tomographic microscopy, it is possible to produce a 3D map of the refractive index, distinguish between the different sources of scattering in cells and tissues, and determine the contribution of organelles to the light scattering. This will be done by calculating the forward light scattering using the Born approximation in conjunction with the Fourier transform of the 3D index map.

• Extract quantitative information from a large number of cells in a short period of time: Tomography may be performed quickly on large numbers of cells by flowing them through a tightly focused sampling beam and using a synthetic aperture algorithm to construct the to-



Tomographic phase microscope. GM -- galvanometer scanning mirror; L1 -- lens with focal length f =250 mm; BF -- back focal plane of the condenser lens; C -- condenser lens; OL -- objective lens; L2 -- lens, f = 200 mm; AOM -- acousto-optic modulators. The frequency-shifted reference laser beam is shown in blue. The diagram (a) describes the phase projection geometry; θ is the illumination angle.

THE SPECTROGRAPH

Published by the George R. Harrison Spectroscopy Laboratory at the Massachusetts Institute of Technology, Cambridge, MA 02139-4307. Comments, suggestions, and inquiries can be directed to the editor.

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GEORGE R. HARRISON SPECTROSCOPY LABORATORY

Director: Michael S. Feld

Assoc. Director for Scientific Coordination: Robert W. Field

Associate Director: Ramachandra R. Dasari

The Spectroscopy Laboratory houses two laser research resource facilities. The MIT Laser Research Facility provides shared facilities for core researchers to carry out basic laser research in the physical sciences. The MIT Laser Biomedical Research Center, a National Institutes of Health Biomedical Research Technology Center, is a resource center for laser biomedical studies. The LBRC supports core and collaborative research in technological research and development. In addition, it provides advanced laser instrumentation, along with technical and scientific support, free of charge to university, industrial, and medical researchers for publishable research projects. Call or write for further information or to receive our mailings.

(617) 253-4881

http://web.mit.edu/spectroscopy

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mograms. Such an instrument will make possible experiments to gather statistical information about cell morphology.

The NSF grant is supporting research and development that will provide biologists with tools to reveal, measure, and monitor the structure of live cells in ways that have not been possible before. Quantitative characterization of cellular structures in their native state, without chemical or physical alterations, is a grand goal for biological microscopy. The Spectroscopy Laboratory is a place particularly suitable for work toward this grand goal. Its stimulating interdisciplinary academic environment facilitates such research, and its scientists, engineers and physicians are uniquely qualified to guide and oversee the successful design and adaptation of these novel instruments for the needs of biology and medicine.

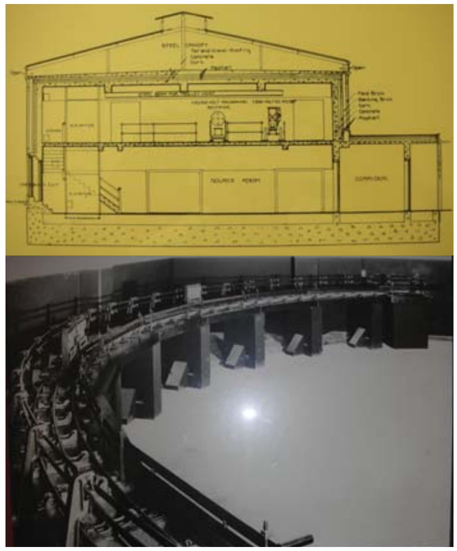
New space, continued from page 1

noticeable temperature variations in the room; cumulatively this caused the laser to frequently lose the mode-lock, requiring realignment and often cleaning of the optics. Even more annoying were the mosquitoes, which apparently were breeding in some corner where stagnant water had accumulated. It takes extreme perseverance and self-control to finish carefully adjusting the laser oscillator mirror a tad while you feel a mosquito biting you on the cheek! With these troubles, we never succeeded in getting our experiment to work properly while we were in Building 6A."

"...Within two months of moving in my students Huzeifa Ismail and Paul Abel had the experiment built, aligned, and working for the first time ever..."

Perhaps the perseverance needed to work in building 6A inspired Prof. Green and his students to be the first to move into a new lab in building 6. The move quickly paid off: "The environmental conditions in the new lab are much, much better. Within two months of moving in my students Huzeifa Ismail and Paul Abel had the experiment built, aligned, and working correctly for the first time ever, and the laser has continued to operate more or less continuously since that time with minimal problems. The Spec Lab renovation was a key to our success."

Others in the Spectroscopy Laboratory

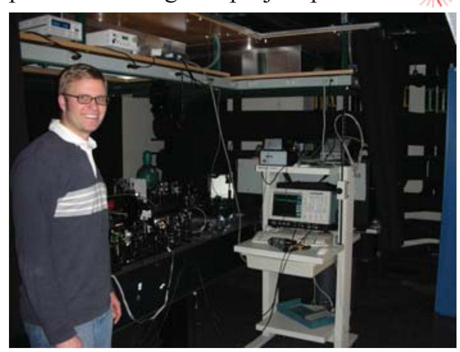


(T) Schematic of the old Spectroscopy Laboratory, building 6A, built in 1931. (B) The 40-ft walk-in spectrograph in 6A

echo Prof. Green's sentiments. Dr. Ramachandra Dasari, Associate Director of the Spectroscopy Laboratory for over a quarter century, remembers that the old building "was great for high resolution atomic and molecular spectroscopy when it was built, but it had no sunlight, no restroom access, and needed drastic changes in order to conform to new electrical and biological codes. And the new physical plant goes beyond just fixing the aesthetic problems in building 6A - it is also better suited than 6A for the biomedical research we're doing today." To conform to modern standards and to support the current biomedical research done in the lab, the new space includes dedicated areas for biological and chemical preparations, e.g., a chemical fume hood, a biological hood, and a new microtome for frozen-sectioning of human tissues. In total, the renovation includes 14 new spectroscopy labs dedicated to a wide range of research, including tomographic phase mapping of human cancer cells, Raman spectroscopy of carbon nanotubes, and 2D IR spectroscopy of peptides. The lab also includes space for an outreach program for high school students led by Prof. Keith Nelson. This program allows interested high school students to participate in independent research using state-of-the-art equipment otherwise unavailable to them.

Students, faculty, and staff are enjoying their new, modern labs. Jeremy Johnson, a graduate student in the Nelson group, moved into his new lab in 6-009 just a few weeks ago and is already collecting data. He remembers being more crowded in his old lab in building 2, "in the old lab we had maybe 2-3 feet between our tables; now we have 10. The extra space is really nice, and now we have laser curtains!"

It's perhaps no surprise that Huzeifa Ismael, the hardy grad student who endured mosquito bites in building 6A, thinks that the new space is, "absolutely fantastic." His move into the new space had some surprises: a 1-ton optical table mysteriously disappeared for two weeks; when cleaning his old lab, he found a bottle of chemical waste from 1953! Some researchers are still unpacking boxes and trying to remember where all their tools are, but, overall, research is again under way and people are happy to be in their new home away from home. Core researcher Prof. Andrei Tokmakoff sums it up nicely, stating, "We have ended up with beautiful new space that will allow us to develop the next generation of …spectroscopies, and we are indebted to Michael and Ramachandra for the sustained effort that they put into making this project possible."



Grad student Jeremy Johnson enjoys his new lab

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to lead the re-invigoration of the committee charged with celebrating the Life and Legacy of Martin Luther King, Jr., and for more than a decade he co-chaired this body with Leo Osgood, then Assistant Dean of Students and head of the Office of Minority Education. Under their leadership the annual MLK breakfast flourished as an occasion for fostering understanding across racial and ethnic boundaries. One committee member recalls with admiration "Michael is great. He is so direct; he does not worry about who he's talking to; he brings up all the difficult issues." Feld and Osgood also led the committee to a larger view of what it should be doing. Feld is

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Research Report

Depolarized Impulsive Stimulated Brillouin Scattering and the Shoving Model of the Glass Transition

Darius H. Torchinsky, Jeremy A. Johnson, and Keith A. Nelson

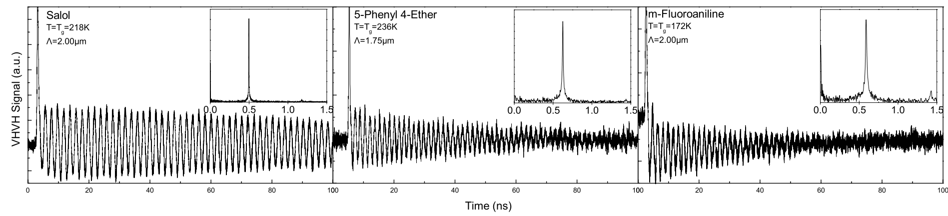

Figure 2: *Shear waves in a variety of liquids at their glass transition temperatures T_g. The inset shows the Fourier spectrum on the GHz scale.*

Elastic Properties of the Glassy State

One of the foremost puzzles of the glass transition continues to be the origin of a glassformer's "fragility", which is a measure of the departure of its relaxation behavior from Arrhenius activated kinetics. This departure is apparent in the behavior of viscous liquids observed in ordinary activity such as honey or molasses. If such a liquid is perturbed, its response and relaxation back toward equilibrium can include fast components, but on progressively slower time scales one observes that the response is continuing, in contrast to single-exponential relaxation kinetics that are observed in simpler materials. In addition, the whole range of time scales varies sharply with temperature, moving slower as the glass transition is approached. Recent developments aimed at addressing this mystery have centered around the relationship of the elastic properties of the glassy state to the fragility of the supercooled liquid.

It has been proposed that the instantaneous shear modulus (G_∞) controls the fragility, as the activation energy at all temperatures is controlled by the energy cost associated with a non-compressional rearrangement of molecules via the "shoving aside" of their neighbors. In such a model of glassy systems, collective relaxation is viewed as a series of individual relaxation events between configurational minima. This perspective recalls landscape activated models for the glass transition.

Conceptually, the shoving model predicts that the temperature dependence of the activation energy arises solely from that of the instantaneous shear modulus G_∞. One arrives at this result via the core assumptions that the average relaxation time is dictated only by flow and that during a rearrangement as occurs during this flow event, the molecules do not rearrange at constant volume – the energy cost arising from the strongly anharmonic repulsive piece of the intermolecular potential renders this too costly. Rather, it is more energetically favorable for the rearrangement to occur with a change in volume as the molecules do work on their neighbors. Since the motions involved take place at very short length and time scales, they are necessarily mediated by the instantaneous modulus.

In the absence of a predictive theory of the glass transition that is widely accepted, the basic and intuitive shoving model provides a practical framework that can be subjected to direct experimental tests. It also may provide a steppingstone to a more complete picture of the glass transition.

Test of the Shoving Model

Experimentally, the assertions are best tested with a technique that can probe the shear modulus at a high frequency so slower relaxation processes don't influence the measurement. Unfortunately, a majority of the data in the literature were collected at low acoustic frequencies (Hz to low MHz), and unreliable extrapolations were needed to estimate G_∞. Depolarized Brillouin scattering data also were used to make a direct test at higher frequencies (low GHz), but due to extremely small scattering cross sections, such data are sparse.

We have developed and used an alternative approach, impulsive stimulated Brillouin scattering (ISBS), in which crossed picosecond laser pulses generate coherent acoustic waves that are observed through time-resolved diffraction of probe laser light. See figure 1. With perpendicularly polarized excitation pulses, a polarization pattern results that generates two counterpropagating shear waves.

While somewhat lower in frequency than Brillouin scattering, ISBS holds the significant advantage that the scattered light arises from coherently generated phonons, rather than those that are thermally present, resulting in better signal-tonoise ratios and much quicker data acquisition times. Additionally, the data are recorded in the time domain, and avoid the problem of overlap of central peak phenomena with the dynamics of interest. Consequently, we are able to detect shear waves in a collection of liquids that have previously remained unstudied. This enables a direct test of the shoving model.

Samples of triphenyl phosphite, DC704 (tetramethyl tetraphenyl trisiloxane), m-fluoroaniline, Ca(NO3)2•4H2O, diethyl phthalate, m-toluidine, phenyl salicylate (salol), 2-benzylphenol, and Santovac 5 (5-phenyl 4-ether) were cooled to their respective glass transition temperatures and the elastic moduli directly measured at the highest accessible shear frequencies. The shear modulus was then measured every 2K as deeply as permitted into the liquid state for all liquids. In figure 2 we see shear acoustic waves in a variety of liquids at their glass transition temperatures. From the acoustic oscillation frequency and damping rate, the complex shear modulus may be calculated.

In figure 3 we see shear acoustic waves for three temperatures as the sample is warmed from the glass transition tempera-

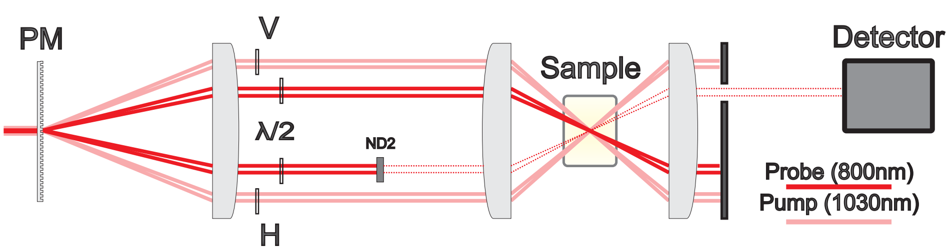

Figure 1: *Schematic illustration of the ISBS setup. Both the pump and probe beams are incident on the phase mask (PM) and their ±1 diffraction orders are recombined at the sample. In the case of a depolarized experiment, waveplates in the path of each of the four beams are used to create a polarization grating pattern.*

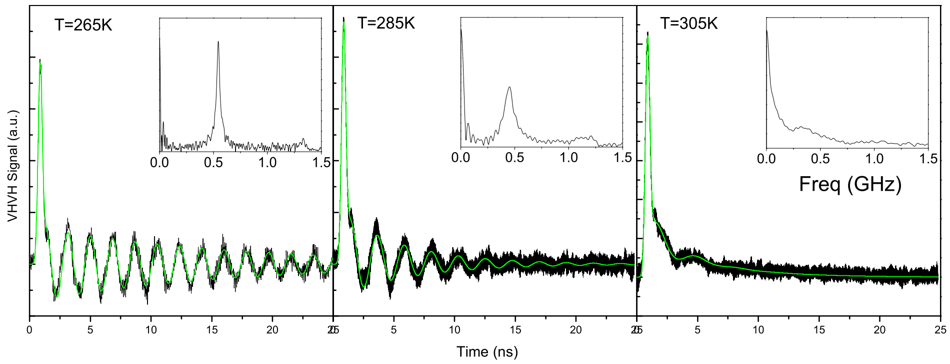

Figure 3: *Shear waves in 5-phenyl 4-ether at three characteristic temperatures, displaying weakly damped, moderately damped, and strongly damped behavior respectively.*

ture. The acoustic response can be monitored even at elevated temperatures where it is nearly over-damped.

To show a test of our data against the shoving model we plot the average relaxation time (obtained from the literature) vs. the normalized argument (obtained in our experiments). See figure 4.

$$X = \frac{G_\infty(T)T_g}{G_\infty(T_g)T}$$

If the model is correct, the data will fall along the straight line, indicating the activation energy of a relaxation process is entirely dependent on G_∞.

When plotting this for average relaxation times obtained from dielectric relaxation data, we see that the shoving model gives good correlation to the experimental data as shown to the right. Efforts to quantify departure from the model show that the departure is greater as fragility increases for dielectric relaxation data. This potentially means that as fragility increases there are more degrees of freedom than G_∞ governing the dynamics, or that there is a larger deviation between dielectric and mechanical degrees of freedom in these liquids.

The shoving model of the glass transition is generally supported by our data when used in conjunction with literature data on average relaxation times in glass forming liquids. This supports the suggestion that the elastic properties of a glassy solid reveal important information about the dynamics of the corresponding liquid at far higher temperatures. Depolarized ISBS has provided unique access to shear acoustic waves and the insights they provide for understanding the liquid-glass transition.

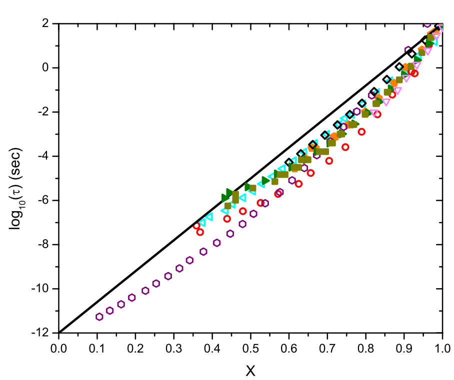

Figure 4: *Test of the shoving model for 8 glass forming liquids using dielectric data. The straight line is a plot of log10(τ) = 14X – 12, which represents Arrhenius activated kinetics.*

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particularly proud of how they invented the MLK Visiting Professor program and got it adopted against considerable resistance. Since it was begun, this program has brought more than 70 minority professors to work as faculty members at MIT.

Any visitor to the Spec Lab knows Zina Queen's cheerful, welcoming personality. She is the third generation of Queens at MIT: Her grandmother worked here for 25 years, her mother for 15, and now she herself has been here 18 years – a royal line. While Feld co-chaired the MLK committee, Zina provided valuable administrative and logistical support and played a central role in organizing the breakfasts. But the MLK honor really recognizes her other extensive efforts to help MIT respond to the human needs of Institute staff and support staff. As one admirer notes "She is a lioness when it comes to defending the rights of others…" And she does this on the MIT Child Care Committee, on the Medical Consumer Advisory Committee, and, for nearly a decade, on the MIT Working Group on Support Staff Issues. Her positive, cheerful, can-do efforts to make MIT a better place have made her widely known and much appreciated across the MIT community.

Dresselhaus wins Oersted Medal

Adapted from AAPT's news release

Institute Prof. Millie Dresselhaus

In recognition of her outstanding, widespread, and lasting impact on the teaching of physics, Mildred S. Dresselhaus, MIT Institute Professor of Physics and Electrical Engineering, has been awarded the Oersted Medal by the American Association of Physics Teachers (AAPT).

The Medal and $10,000 were presented to Millie at the AAPT Winter Meeting in Baltimore, Maryland last month, where she spoke to a large audience about "Expanding the Audience for Physics Education." Her talk was a biographical account of the obstacles women of her generation overcame to become scientists. Inspired by the support she received from friends and mentors – such as Nobelist Rosalyn Yalow – Millie has made it her lifelong mission to encourage and help women and underrepresented minorities to study science, particularly physics. She is also justly proud of her sustained effort to expand the audience for physics by teaching more physics to engineering students, particularly to electrical engineers needing to know more about condensed matter and materials physics.

Millie's reaction was typically modest: "I was truly surprised to be chosen for the Oersted Medal in view of the list of stellar past recipients. But now I am further inspired to bring the love and appreciation of physics to new audiences."

Ken Heller, AAPT Past President and Chair of the AAPT Awards Committee, said, "Dr. Dresselhaus is a dynamo in her support of physics in all of its aspects. Her research is on the cutting edge of materials physics and currently focuses on nanoscience. By words and deeds she has had

Oersted, continues on page 10

Celebrating the Harrison Spectroscopy Lab's New Space

MIT's Spectroscopy Laboratory: The Next Eighty Years

Wednesday, February 27, 2008

IN TWO SESSIONS:
9:30 am – 12:15 pm; MIT's Grier Room 34-401; 50 Vassar St, Cambridge, MA
12:30 pm – 3:30 pm; Cambridge Marriott, Kendall Square, Cambridge, MA

9:30 am: *Subra Suresh,* Ford Professor of Engineering; Dean of the School of Engineering; Massachusetts Institute of Technology

Multidisciplinary Research at the Intersections of Engineering, Sciences and Medicine

10:10 am: *Phil Bucksbaum*, Professor of Physics; Professor of Applied Physics; Director, Ultrafast Science Center, SLAC; Stanford University

Ultrafast imaging and control of atoms and molecules

10:50 am: Coffee Break

11:10 am: *Xiaowei Zhuang*, Howard Hughes Medical Institute Investigator; Professor of Chemistry and Chemical Biology; Professor of Physics; Harvard University and Howard Hughes Medical Institute

Nanoscopic imaging of biomolecules and cells

11:50 am: Tours of the renewed George R. Harrison Spectroscopy Laboratory

12:30 pm: Break for lunch

1:15 pm: *Teruo Hiruma,* Chairman of the Board and Chief Executive Officer, Hamamatsu Photonics, K.K.

Interactions between photon and substance: What the photon can do

2:00 pm: *Fleming Crim*, John E. Willard and Hilldale Professor of Chemistry; University of Wisconsin -- Madison

From high resolution spectroscopy to chemical reaction dynamics

PLEASE POST

MIT's George R. Harrison Spectroscopy Laboratory invites you to a celebration February 27, 2008 from 9:30 am – 3:30 pm

Come celebrate with us on Wednesday, February 27, 2008. We have moved into our new space with its renovated and up-to-date laboratories, and we're looking toward the future. The theme of the celebration: MIT Spectroscopy Laboratory: The next 80 years.

Five outstanding speakers will help us mark the event. Their talks will provide an interdisciplinary perspective that is especially appropriate given the Spectroscopy Laboratory's longstanding and vigorous tradition as a center for research that crosses discipline boundaries. Physics, chemistry, biology, and materials science will be central in talks by Phil Bucksbaum, Fleming Crim, Xiaowei Zhuang, and Subra Suresh. Teruo Hiruma, Chairman of the Board and CEO of Hamamatsu Photonics, will share his broad vision of how growing mastery and understanding of light will shape the future of all the scientific disciplines.

Reserve the day. Talks will be at MIT between 9:30 am and 3:30 pm and Spectroscopy Laboratory researchers will host tours of the new facilities.

The Speakers

Teruo Hiruma is Chairman of the Board and CEO of Hamamatsu Photonics, K.K.

Through his leadership he has made Hamamatsu a major participant in the progress of research that studies light and uses it to advance our understanding of life processes and many other aspects of science.

His is a vision of interdisciplinary work that is creating new technologies and new industries, that is leading to better comprehension of the essential nature of the photon and its crucial role in tying electrons and atomic nuclei together, that is bringing us to a deeper understanding of matter and of life itself as we learn to manipulate atoms and molecules in any way we like. The prospects for the future are dazzling and challenging; photonics technology promises to make major contributions in a broad spectrum of fields including communications, information processing, metrology, biotechnology, medical care, the mind-brain sciences, energy, robotics, cosmology, physics, and spectroscopy.

Subra Suresh is Dean of the School of Engineering and Ford Professor of Engineering at MIT. His research is in the nanomechanics of biological cells and molecules with the goal of finding connections between properties of mechanical structure and the states of diseased human cells. Particular subjects of attention are P. falciparum malaria, hereditary blood cell disorders, and cancer. Studies are carried out with high-force optical tweezers and with computational simulations of cellular and molecular deformation and shape thermodynamics. He also studies nanostructured materials, nanoindentation, and microindentation.

Phil Bucksbaum is Professor of Photon Sciences, Physics, and Applied Physics; Director of the Stanford Center for Photon Ultrafast Laser Science and Engineering (PULSE) at Stanford University. He is a member of the National Academy of Sciences; his research focuses on fundamental light-matter interactions and, especially, the control of quantum systems using ultrafast laser fields. He develops new sources of ultrafast laser light in the infrared, visible, ultraviolet, and x-ray regions of the light spectrum. "The Future of Attosecond Spectroscopy," Philip H. Bucksbaum, Science 317, 766 (2007).

Xiaowei Zhuang is Howard Hughes Medical Institute Investigator and Professor of Chemistry and Chemical Biology and Professor of Physics, Harvard University. She is the recipient of the 2008 Coblentz Award, the 2006 Pure Chemistry Award, 2005 Camille Dreyfus Teacher-Scholar Award, and in 2003 a MacArthur Fellowship. The Zhuang lab develops optical imaging techniques to monitor the behavior of individual biological molecules and complexes in vitro and in live cells. Her current research has three major goals: (1) to develop super-resolution optical imaging techniques that allow imaging of cells and tissues with molecular-scale resolution, (2) to use single-molecule approaches to probe how biomolecules function, especially how proteins and nucleic acids interact; (3) to develop live-cell imaging techniques and to investigate virus-cell interactions

Fleming Crim is John E. Willard and Hilldale Professor of Chemistry at the University of Wisconsin, Madison. He is a member of the National Academy of Sciences and the 2006 recipient of the Irving Langmuir Award in Chemical Physics. His research on the molecular dynamics of reactions and photo-dissociation reveals essential features of chemistry in gases and liquids. He uses molecules prepared in vibrationally excited states and spectroscopically monitored with ultrafast laser techniques to trace the flow of energy within a molecule and to study vibrationally driven reactions in liquids. Discovering the controlling aspects of chemical reactions at a fundamental level is the central focus of this research.

Lester Wolfe Workshop in Laser Biomedicine

"Shining light on melanoma"

Tuesday, April 22, 2008
4:00-6:00 pm
Simches 3110 conference room,
Richard B Simches Research Center, Charles River Plaza
Refreshments served at 3:30pm

The rapid increase in the incidence of malignant melanoma and its high associated mortality necessitates improvements in diagnosis and therapy. This workshop will feature the contributions that can be made in managing this disease by biomedical optics. Although melanoma is highly visible macroscopically, non-invasive optical imaging techniques can improve microscopic detection. Laser-induced thermotherapy can give effective local control and at the same time stimulate the host immune response.

Framing the problem of melanoma diagnosis
Arthur J. Sober, Assoc Chief of Dermatology, MGH

Photoacoustic imaging of melanoma
Lihong Wang, Gene K. Beare Distinguished Professor of Biomedical Engineering, Washington University in St. Louis

Clinical imaging of melanoma,
Zeina S. Tannous, MGH Dermatology

Laser Immunotherapy for melanoma
Mark F. Naylor, University of Oklahoma Health Science Center

Sponsored by the GR Harrison Spectroscopy Laboratory, MIT, MGH Wellman Center for Photomedicine, the Harvard-MIT Division of Health Sciences and Technology, and the Center for the Integration of Medicine and Innovative Technology (CIMIT)

Seminar on

MODERN OPTICS AND SPECTROSCOPY

Spring 2008

March 4	Christopher Cheatum, University of Iowa **Watching the protein mambo: Fast enzyme dynamics**
March 11	Wonshik Choi, MIT **Field-based 3D microscopy for live cell imaging**
March 18	Edward Boyden, MIT **Optical control of normal and pathological neuronal circuit dynamics**
March 25	Don Eigler, IBM **The quest for spin cascade logic circuits**
April 1	Isaac Chuang, MIT **Planar ion traps for quantum information science and spectroscopy**
April 8	Katherine Stone, MIT **Multi-excitonic coupling in semiconductor nanostructures studied by multidimensional electronic Fourier transform spectroscopy**
April 15	Michael Strano, MIT **Spectroscopy for probing the chemistry of carbon nanotubes and graphene**
April 22	Martin Gruebele, University of Illinois Urbana-Champaign **STM-assisted single molecule absorption spectroscopy**
April 29	Audrey Vilesov, University of Southern California **Spectroscopy of molecules and clusters in helium**
May 6	***17th Annual Richard C. Lord Lecture:*** Mildred Dresselhaus, MIT **Raman spectroscopy of nanotubes and other nano-carbon systems**

Tuesdays, 12:00 - 1:00 p.m., Grier Room (34-401)

Refreshments served following the seminar

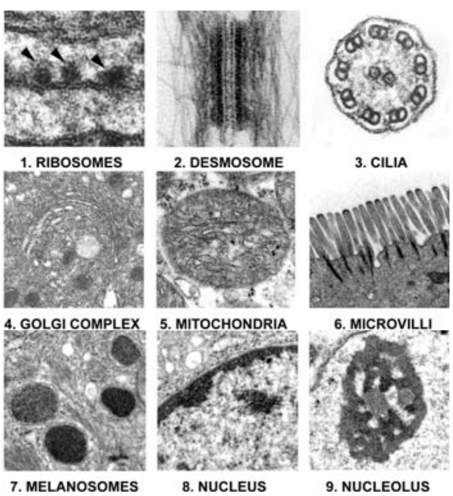
Sponsored by the George R. Harrison Spectroscopy Laboratory, the Department of Electrical Engineering and Computer Science, and the School of Science, MIT.

Oersted, continued from page 5

a profound influence on advancing opportunities in science for women and under-represented minorities."

AAPT's Executive Officer, Toufic Hakim, noted that "It is difficult to see how Millie can fit all her activities into one lifetime! In addition to her research and public service, she has maintained a great sensitivity and commitment to her teaching and physics education."

The Oersted Medal is AAPT's highest award. It goes to a person who has had outstanding, widespread, and lasting impact on the teaching of physics. It is named for Hans Christian Oersted (1777-1851), the Danish physicist, who, while preparing a demonstration for his class, discovered that an electric current produces a magnetic field. His research discovery while teaching makes Oersted a particularly appropriate name for this award. Since 1936, when the award was established by AAPT, there have been 76 recipients. Millie Dresselhaus brings the number of Oersted recipients closely associated with MIT to eleven, by far the largest number received by the faculty of any university. A list of past recipients is at http://www.aapt.org/Grants/oersted.cfm.



The winner of the Fall 2007 Spectrograph crossword challenge, "It pays to enrich your cell power", is Seungeun Oh. Congratulations, Seungeun!

This issue's puzzle is a pair of "Fermi questions":

How many college students are there in boston? And, for the grand prize, how many photons are there in the universe? Send your answers to Geoff at gpo@mit.edu.

Spec Lab Grad Students Win Poster Prizes

By Seungeun Oh

Every January following a program of talks sponsored by the Spec Lab as part of MIT's Interterm Activities Program (IAP), Spec Lab graduate students present posters describing their current research work. Faculty judges decide which posters are the best in three or four different categories. These categories are sometimes less serious than the posters, but the awards do always recognize real merit. This year's successful day-long event was organized by Prof. Moungi Bawendi and held on January 17.

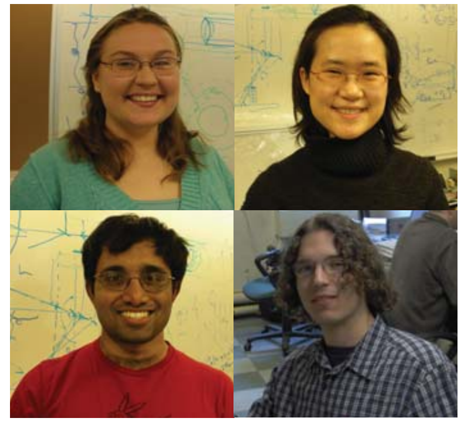
The prize winners are listed below, along with a short paragraph describing his or her poster.

The prize for the most artistic poster went to Gautham P. Nair, a chemistry grad student in Prof. Bawendi's research group. His poster title was "An assessment of carrier multiplication in semiconductor nanocrystals by transient photoluminescence."

"This work explores carrier multiplication (CM), a physical process that could significantly boost the efficiency and variety of future solar technologies. In recent years, measurements on semiconductors in nanocrystalline form have suggested large and universal enhancements of CM. In this study, we used the specificity of transient photoluminescence to assess CM yields in CdSe and CdTe nanocrystals as part of our effort to understand the mechanism. Contrary to previous reports, we observed no CM in these materials. Using a simple physical framework, we have begun to explain why CM is less universal and less efficient than has previously been thought."

The prize for the "most dimension-shattering spectroscopy" went to Katherine W. Stone, a chemistry graduate student in Prof. Keith Nelson's group. Her poster title was "Multidimensional electronic Fourier transform spectroscopy for disentangling exciton interactions in GaAs nanostructures."

"We have recorded direct observations of biexciton coherence in GaAs quantum wells through two-quantum multidimensional Fourier transform electronic spectroscopy, the optical analogue of multiple-quantum NMR, using a novel spatiotemporal pulse shaping technique. Signatures of microscopic multi-exciton



Prize winners Katherine Stone, Seungeun Oh, Gautham Nair, and Sean Roberts

interaction mechanisms are evident in the exciton and biexciton complex 2D spectral lineshapes."

The prize for the poster exhibiting the most spectroscopy went to Sean Roberts, a chemistry graduate student in Prof. Andrei Tokmakoff's research group. His poster title was "Probing the dynamics of aqueous proton transfer via ultrafast nonlinear infrared spectroscopy"

"We present the results of ultrafast 2D IR and other time resolved infrared measurements of HOD dissolved in concentrated NaOD solutions. Being a strong base that can accept protons from water, NaOD represents a case where the distinction between a hydrogen bond and a covalent bond is blurred. Through the use of 2D IR spectroscopy we hope to gain an understanding of how intermolecular motions of the surrounding water bath modulate the interaction between the hydroxide ion and its solvation shell and ultimately how these molecular motions act to push a proton from one water molecule to another."

The prize for the most originality went to Seungeun Oh, a graduate student in the Department of Physics who is working in Prof. Michael Feld's group in the Spectroscopy laboratory. Her poster title was "Study of cell electromotility by quantitative phase microscopy."

"A living cell maintains an electrical potential of about -70 mV across its plasma membrane. The electrical state of the cell affects the mechanical state of the cell; motion, i.e., electromotility, is generated by changes of the cell membrane potential. Using diffraction phase microscopy, I can detect small electromotile motions with high sensitivity. From my measurements of the voltage and frequency dependence of cell electromotility, I hope to reveal the underlying processes of electromotility."

Peace through Mind/Brain Science at Hamamatsu

by Wonshik Choi

From Feb. 5 to Feb. 7, 2008 I attended "The 12th Conference of Peace through Mind/Brain Science" at Hamamatsu, Japan. The Conference was sponsored by Hamamatsu Photonics K. K. to improve understanding of brain function and to realize peace in the world with acquired knowledge. Most talks at the meeting had to do with studies of brain images obtained with positron emission tomography (PET). Some other imaging techniques such as MRI and diffuse optical tomography were discussed as complementary approaches.

My talk was rather different from the others. Entitled "Spectral Interferometry in Biology and Medicine: Past, Present, and Future." It began with an introduction to quantitative phase microscopy techniques that can determine the thickness of biological samples with nanometer precision. After describing our use of this technique to find the mechanical properties of membranes in malaria-infected red blood cells, I described our development and use of tomographic phase microscopy to construct a 3D map of the refractive index in live cells and tissues. At the end of the talk, I touched upon our long range plan to 'see through the skin' with photons. Such a development would be very important to the biomedical field, because it would allow accurate disease diagnosis and non-invasive laser treatments.

During the meeting, I had a chance to talk with Hidenao Iwai and Takahiro Ikeda, two Hamamatsu researchers who have worked at our laboratory as visiting scholars. As Michael Feld had told me, they are very warm and friendly and, at the same time, hard workers.

During his stay at MIT in 2002 Hidenao made a major contribution to the development of actively stabilized low-coherent phase-shifting interferometry by suppressing external noise in the interferometer with an active feedback loop. He is now making a compact version of this system with future biomedical applications in mind.

(From L to R) Wonshik Choi, Toyohiko Yamauchi, Takahiro Ikeda, and Hidenao Iwai

When Takahiro worked at our laboratory in 2004-2005, he developed what we call Hilbert phase microscopy. This technique, which makes it possible to extract a quantitative phase image from a single interferogram, has become the basis of our recent development of the common-path Hilbert phase microscope. Now he has started a company named "Pi Photonics Inc." which manufactures a quantitative phase imaging unit that is an accessory to convert an ordinary microscope into a quantitative phase microscope. I was quite impressed by their efforts to bring these recently developed techniques to market.

On my last day in Japan, they gave me a tour of the central research laboratory where I saw many research ideas in the process of commercialization. For example, they will soon launch into the medical field a near-infrared time-resolved spectroscopy unit based on diffuse optical tomography that will help surgeons measure cerebral hemodynamics. Their research laboratory also has both a PET center to develop new PET systems and a positron medical center where they image brain tumors in patients. They intentionally mix research, manufacturing technologies and medical applications all in the same complex in order to generate synergy among them. They see their research as of key importance for understanding how to improve their products in order ultimately to promote human wellness.

Fermi, continued from Back Page

On a more day-to-day basis, in every class that he taught, the mundane details of the topic of the day were stripped off, and emphasis was given to the essence of the physical phenomena involved, often expressed in terms of a few simple equations. From this approach came the expression "back of the envelope calculation," whereby the essence of a physical phenomenon could be captured in about 5 lines of equations and text. This amount of text could fit on the back of an envelope that he would pull out from his shirt pocket. Fermi did carry around such envelopes which presumably came from recent correspondence. These small envelopes could then be reused for the informal discussion of physics concepts.

Fermi's grave in Oakwoods cemetery, Chicago, IL.

An objective of his classroom teaching and research seminars was that each student should feel confident of having understood the content of the lecture when it was over. He spoke very slowly, and he handed out lecture notes so that students would be fully attentive in class. He found it distracting for students to take notes vigorously while he spoke. He therefore provided hand-written class notes on a special kind of paper that could be laboriously duplicated using what was called a mimeograph process. In fact, he operated the mimeograph machine himself in the early morning hours to produce the requisite number of student copies of class notes before each class started. Each class ended with a challenging, required problem that the students were expected to solve before the next lecture. This problem was intended to help the student gain ownership of the material of the lecture. His teaching was methodical and the topics to be covered were planned at the outset of the course. Every course had a syllabus of topics that every student was expected to know. The syllabus did change from year to year to reflect the progress of physics.

He was a strong believer of comprehensive exams because of his belief in the unity of physics. Here too he was methodical and developed a syllabus of topics that a graduate student should know for preparing for the comprehensive exams. Studying for such comprehensive exams was considered good preparation for independent thesis work. Each student was expected to choose his/her own thesis topic and how to work it out, while doing research with others to learn techniques for doing research. The actual thesis requirements were sole authored, refereed papers in *The Physical Review*, giving students the feeling of entry into the professional world upon graduation with a PhD degree.

When Fermi died of cancer at age 53, he was highly active in both physics research and education. We can only wonder what he would have created had he lived a normal life span. The simplicity of the epitaph on his tombstone reflects the elegant simplicity and clarity of his physics and his teaching.

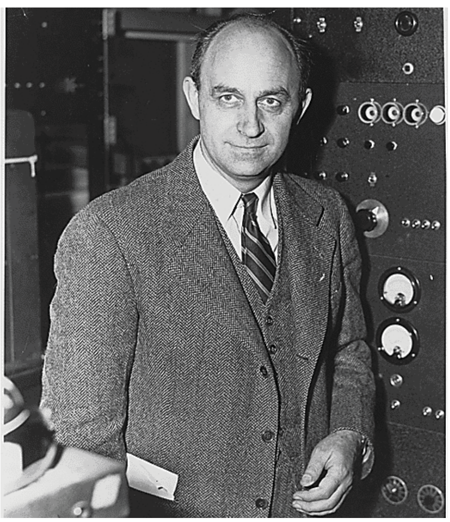
Remembering Fermi as a Teacher

by Millie Dresselhaus

The following remembrance is taken from Millie's address on the occasion of receiving the American Association of Physics Teachers' Oersted Medal. See the news item on page 4.

In 2001 when asked to give a lecture on Enrico Fermi as a teacher on the occasion of the celebration of what would have been his 100th birthday, I realized what a great role Enrico Fermi had played in physics education at the University of Chicago and internationally.

Fermi was appointed a full professor of physics in Rome at the age of 26. There he not only became a leader in physics research at the University, but also a leader of physics education. In a short time, Rome became a worldwide center of physics education. Subsequently, he spent some years at Columbia University, Los Alamos, and the University of Chicago. Wherever he went he profoundly influenced the development of the local physics education program. And because he had such a distinguished collection of students who became established at universities and research institutes around the world, his influence on physics education became widespread.



Enrico Fermi, winner of the Nobel Prize in Physics in 1938 and a leader of the Manhattan Project

Students often felt that they had a special place with Fermi. I felt that my special place was connected with the fact that I was 6 weeks older than his daughter, and I was studying physics seriously. Fermi's wife Laura Fermi was also a physicist; his daughter became an artist. My special feeling was strengthened by the numerous occasions when I would be walking to the University in the morning, and he would be coming in on his bike. When he saw me, he would stop cycling and would walk with me and talk to me about our physics class or more general topics, usually related to physics.

Physics was very central to his life. By the time I saw him in the morning, he had already been working for a few hours. He loved to start his day early, and his best time for personal creative work was at home early in the morning. He also liked to teach at the earliest possible class time, so that he had the rest of the day available for doing physics, largely with students and with the many visitors who came to work with him.

He said that teaching physics to freshmen was the biggest opportunity available to a physics professor. He found physics in everything he saw and was enamored with the concepts of physics and the physical essence behind all physical phenomena. In his opinion, this approach could be taught to beginning students, and that is precisely what he did. Thus graduate students felt it was an honor and privilege to have a chance to teach introductory physics to undergraduate students within the context of the Fermi approach. I must say that I also felt this way and did a lot of volunteer teaching just because I felt so good about teaching physics to beginning students.

"...He said that teaching physics to freshmen was the biggest opportunity available to a physics professor..."

Another strong opinion that he had was that graduate students should have a broad competence in physics so that when completing the required examinations, which were difficult and thorough, one could in principle start thesis work in any of the areas of physics that were current at that time. He himself had not only worked in every major physics research area of his time, but he had made seminal contributions to each. Even though few of his students succeeded in contributing significantly to many areas of physics, many made use of the breadth of our physics education. Many of his students led scientific programs ranging from an academic department head, laboratory director, to heading up a large national program. I personally benefited from this broad physics background when I had responsibilities in these areas.

Fermi, continues on page 11

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