Cornell
CHRONICLE
MAGAZINE

October 2007

A new home for physical sciences

From the Publisher

Cornell's physicists, chemists and engineers, among the best in the world, will soon have a new building to call home. The physical sciences building, scheduled for completion in 2010 and located between Clark and Baker halls, marks the beginning of a new era at Cornell. With the latest technology and instrumentation in its state-of-the-art laboratories, new space for teaching and collaborative work and beautiful atria and common areas for studying and meeting, the facility will play a major role in Cornell's ability to recruit the most promising researchers and students.

Outstanding facilities have always made Cornell's physical sciences among the world's strongest, and this building will continue that tradition. The 92,000-square-foot facility, designed in large part by the scientists who will use it, will foster teaching, collaboration and research in basic and applied science that affect the most important areas in today's society: sustainability, human health and energy.

The building will also complement Cornell's strong tradition of collaborative multidisciplinary science, and part of the new building will house shared research facilities and equipment. These facilities will complement existing facilities in Duffield Hall and the Life Sciences Technology Building and will further integrate collaborations across departments and colleges.

From its basement – shielded from vibration and electromagnetic fields to an unprecedented degree – to its striking design, open gathering spaces and shared facilities, the new building will encourage important alliances and major discoveries.

But the building's greatest strength will be the people inside its walls. Meet a few of them in the following pages. Chances are you'll hear much more from them, and their colleagues, in the years to come.

Tommy Bruce

Thomas W. Bruce
Vice President
University Communications

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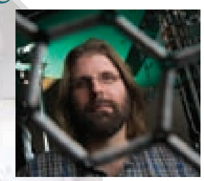

On the cover: Visiting student Pinshane Huang works on a vacuum chamber in the laboratory of AEP professor and vice provost for research Robert Buhrman.

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SHAKE IT UP

Cornell researchers have demonstrated a new way to make tiny silicon resonators – potentially useful for detecting bacteria, viruses and other molecules – vibrate side to side, and they have shown that this can serve a vital function: shaking unwanted materials off of biosensors. Applied and engineering physics professor Harold Craighead's group at Cornell and other researchers have shown that by binding antibodies to resonators – silicon cantilevers that can vibrate up and down – they can cause pathogens to attach to them and detect the change in mass. By shaking the resonator side to side, the researchers were able to shake off loosely adhered, unwanted materials, while whatever was tightly bound to the antibody stayed put.

BAIRD STUDIES CELL MEMBRANES AT THE NANOSCALE

Cell membranes may look like mere wrappers, but the layers of lipid and protein molecules that make cells into tidy packages also can dictate what goes on inside them. Cornell researcher Barbara Baird and colleagues are using the tools of nanotechnology to investigate just what role they play – knowledge that could lead to new drug therapies to treat allergies and a variety of other conditions.

Baird, the Horace White Professor of Chemistry, works with immunoglobulin E (IgE) antibodies, which mount membrane proteins on mast cells (specialized cells that act as the gatekeepers for the allergic response) to form receptor complexes that sense the environment and sensitize the cell to allergens. Typically, two or more receptors cluster together when they bind with an antigen (allergen or foreign body), and this activates enzymes across the membrane and within the cell, ultimately leading to the release of histamines in an allergic response.

By engineering materials as tiny as single molecules, Baird and researchers at the Nanobiotechnology Center recently learned that shorter ligands, or molecules that bind specifically to receptors, were better at stimulating the processes. Using Y-shaped DNA chains as building materials with arms of specified lengths, or patterning ligands onto a surface, the scientists found that they could stimulate the release of histamines and trigger other basic cellular processes.

PHYSICS ON THE WING

Leif Ristroph, a graduate student with the Itai Cohen Group on Complex Matter Physics, studies bio-locomotion – how animals move – using a camera that can capture images at 100,000 frames per second. His test subjects are fruit flies, wasps and other insects. Because insect wings are flexible, the physics of insect flight is very complex: the wing moves the air, which in turn changes the shape of the wing, which changes how the wing moves the air. By watching whether they have to flap more or change their stroke pattern, Ristroph is gaining new insights into the physics of insect flight.

CORNELL ENGINEERING PHYSICS RANKED NO. 1

For undergraduates looking for the top program in engineering physics, Cornell is the best place to go, according to U.S. News and World Report. In its annual university and college rankings issue, the magazine has given the Cornell program top billing for the third year in a row in the category Engineering Science/Engineering Physics under Specialties for Best Undergraduate Engineering Programs. The College of Engineering also fared well in overall rankings, placing seventh in Best Undergraduate Engineering Programs at schools whose highest degree is a doctorate, up from 10th place last year.

SCHROEDER EXAMINES THE STRUCTURES OF LIFE'S SMALL MOLECULES

Cornell assistant professor Frank Schroeder is a pioneer in the nascent field of chemical ecology – the study of chemicals involved in the interactions of organisms. Schroeder is among a handful of chemists focusing on "small molecules" – terpenoids, lipids, alkaloids and steroids, for example – whose structures and functions have been widely ignored, despite their significant roles in biological systems.

"Small molecules play important roles as signaling molecules that regulate protein function in all life forms," says Schroeder.

He developed a breakthrough nuclear magnetic resonance technique that allows scientists to identify the structures of novel small molecules in complex mixtures. Among his discoveries so far: a natural antibiotic produced by bacteria widely used as a model organism in laboratories; a new human signaling molecule that regulates the excretion of sodium through the kidneys without inducing water or potassium loss; and small molecules in spider venom that bind to and inhibit specific neurotransmitter receptors.

These findings could lead to new drugs that fight infection, treat hypertension or help understand disease-relevant biological pathways, says Thomas Eisner, the Jacob Gould Schurman Professor Emeritus of Chemical Ecology.

"Frank Schroeder is a real dynamo," Eisner says. "He's the perfect scientist, driven by curiosity and guided by good judgment and technical skill."

Discussing the physical sciences at Cornell

The physical sciences encompass a range of fields, each with its own structure and perspective. Cornell's new physical sciences building will be shared among three departments: **Physics, Chemistry and Chemical Biology,** and **Applied and Engineering Physics.**

Insights from Arts and Sciences Dean G. Peter Lepage and Engineering Dean Kent Fuchs, in conversation with Lauren Gold

How are the three departments interrelated?

LEPAGE: Historically, Cornell has seen much crossover among the physical sciences and between the colleges of Arts and Sciences and Engineering. Strong ties benefit both sides. Cornell has had tremendous success with its multidisciplinary research centers, for example, beginning with the Cornell Center for Materials Research and including, more recently, the Cornell Laboratory for Accelerator-based Sciences and Education, the Cornell NanoScale Facility, the Developmental Resource for Biophysical Imaging and Opto-electronics and many others.

These centers have a tradition of being able to put together teams, pooling resources and grant-raising capital and ultimately taking on projects that far exceed the capacity of any single department.

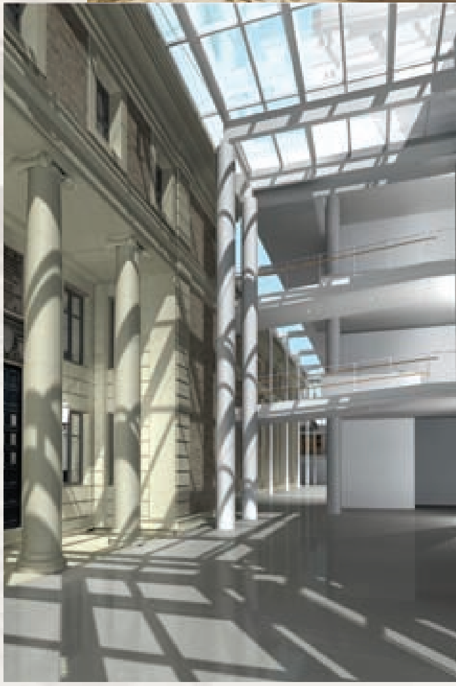
FUCHS: When the School of Applied and Engineering Physics (AEP) was founded, the decision to locate it with the physical sciences and not with the rest of engineering was not obvious. But it was, in retrospect, the very best decision. By sharing facilities and courses, the department – and by extension, the College of Engineering – has developed a strong connection to physics and chemistry. It also provides an enormous advantage to the rest of the physical sciences, because many of the most important problems in science now, such as nanoscience and biophysics, are questions that AEP addresses.

What are the most important features of the new physical sciences building?

FUCHS: First, its location. Because the building is located in the center between Baker, Rockefeller and Clark and shared by three departments, it is by its nature meant to be collaborative.

At the same time, it will give more identity to the School of Applied and Engineering Physics by giving students a more identifiable home as part of their major. Currently, while AEP is located very successfully alongside physics in Clark Hall, the layout makes it difficult to identify the department as a unique entity. In the new building, the department will have a recognizable base – and yet it will be in the context of shared space. The goal, therefore, is to achieve both identity and collaboration.

Second, the new building will include large seminar and lecture rooms and an



A computer-generated illustration of the glass-enclosed Baker Lab portico. Framed with two-story columns, the portico will be a dramatic gateway between Baker Lab and the new physical sciences building. Beyond the portico is the three-story north atrium, one of the building's important gathering spots for discussions, studying or dining.

(Left) Kent Fuchs, professor of electrical and computer engineering and Joseph Silbert Dean of Engineering, College of Engineering, and (above) G. Peter Lepage, professor of physics and Harold Tanner Dean, College of Arts and Sciences

auditorium that will be a great feature space for showcase lectures and invited speakers.

LEPAGE: We also hope with the new building to replicate the successes in Clark Hall, particularly the Clark Hall basement. That space is flexible, it is easily reconfigured, and it enables outstanding science. The new building also is designed for flexibility. Each lab will share a wall with a utility corridor for easy access to compressed air, helium, vacuum pumps and other services. And because a lot of science requires isolation from vibration and electromagnetic fields, much care has gone into making the basement extremely highly buffered.

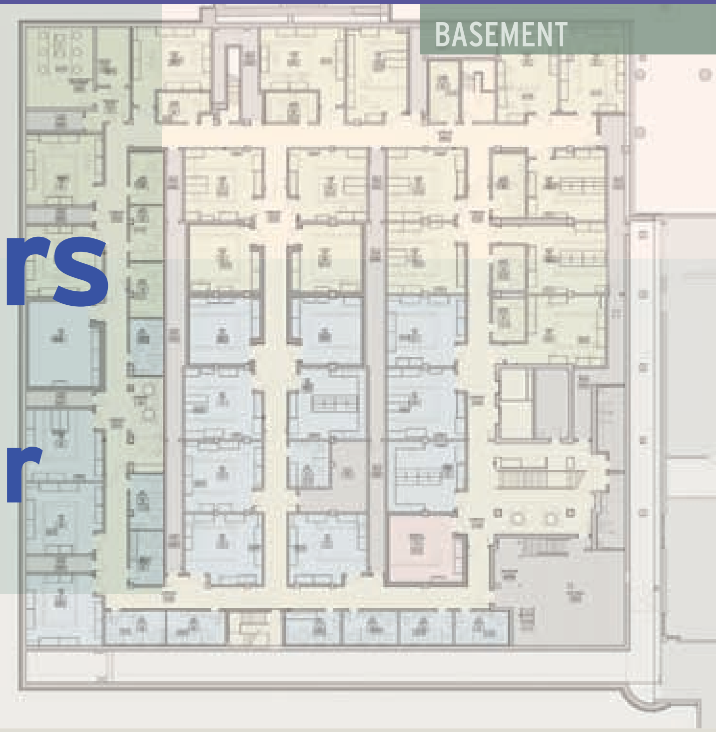
Open space is important too, as we've seen in the success of the Duffield Hall atrium. The new building will be welcoming and student centered, with space in and around the atrium where students can study together, meet with faculty and relax between classes.

Cornell, like its peer institutions, is preparing to hire a new generation of faculty in the coming years to replace retiring baby boomers. Will the new building have an effect on faculty recruitment? What about student enrollment?

FUCHS: All three departments have the need and the resource capacity to grow in research and faculty size and also in student size. But both colleges actually have had to give up space for the physical sciences over the last 40 years as we've moved out of old buildings. Meanwhile, science has evolved such that teaching and research are more space intensive per faculty and per student than they were in the past. One faculty member typically now has twice as many people working in his or her group as in the past. Equipment also takes up more space. So the departments have positions to fill but not space to put them in.

LEPAGE: With its location on the hill overlooking the Arts Quad, the building will be highly visible on campus. That's very much a statement about the focus and the excellence in the physical sciences at Cornell, and it will be a very attractive location for researchers to start their careers – and for undergraduates and graduate students to work on some of the most exciting problems in science, today and well into the future. ■

Imaging superconductors in the highest magnetic field ever



By Bill Steele

When J.C. Seamus Davis joined the Cornell physics department as a professor in 2002 his first project was to construct a scanning tunneling microscope (STM) of unprecedented precision – in the basement of Clark Hall.

Now, with substantial funding from the National Science Foundation, Davis will build another unique STM in the basement of the new physical sciences building. It will be contained inside a specially built vibration-resistant laboratory that will be acoustically insulated and shielded against radio-frequency radiation.

An STM enables the forming of an image of a surface with resolution down to the width of a single atom or less. By measuring the current flow through the tip of an STM, and with an instrument of sufficient precision, it is also possible to observe the energy levels of electrons and see how the electrons are arranged in a solid.

An STM probe – so fine that its tip is just one atom across – is suspended above a surface, and a voltage is applied between the surface and the tip. A tiny current called a tunneling current flows as electrons jump between the surface and the tip. The vertical and horizontal positions of the tip are controlled by a piezoelectric crystal that expands and contracts in response to an electric signal, allowing the tip to be moved in steps smaller than the width of an atom.

If you scan the tip across the surface and adjust its height to keep the tunneling current constant, you get an image in which individual atoms appear as little round bumps. If, on the other hand, you keep the tip height constant and analyze the current flow, you get information about the energy levels of the electrons associated with the atoms.

The new instrument will be at least as precise as the one in Clark Hall but will include a 20-Tesla superconducting magnet to subject samples to the highest magnetic field available in any STM. (The magnets on your refrigerator have a field of around .001 Tesla. The ones used to pick up automobiles in junkyards are around 1 Tesla. The most powerful sustained magnetic field in the world is 45 Tesla, created by a 35-ton magnet at the National High Magnetic Field Laboratory in Florida.)

To achieve its high precision, the new STM, like the one already in use in Clark Hall, will be mounted on three massive columns filled with lead shot, which support a leadshot-filled tabletop resting on air springs. For experiments the STM head will be lowered into the center of the magnet, which in turn is housed in a chamber cooled with helium-3 (which boils at a slightly lower temperature than everyday helium-4) to maintain superconductivity.

Special vibration-resistant control cables will allow experimenters to control the instrument from a distant control room.

Construction and testing is expected to take about two years. As the new instrument is developed, Davis will work with the National High Magnetic Field Laboratory to build an exact copy for a user facility for other researchers. ■

Left, Professor J.C. Seamus Davis and postdoc Jinho Lee. Above, graduate student James Slezak loads a new high-temperature superconductor sample into the scanning tunneling microscope in Clark Hall.

CHASING THE HOLY GRAIL: HIGH-TEMPERATURE SUPERCONDUCTORS

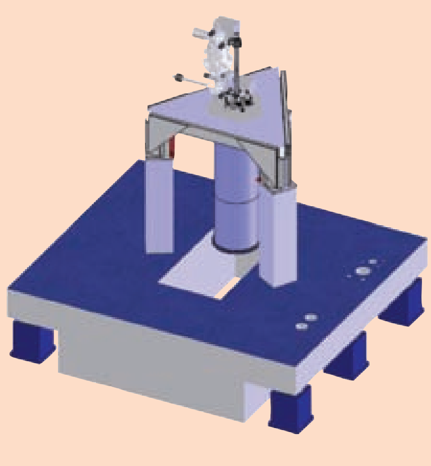
By Bill Steele

For the last several years physics professor J.C. Seamus Davis has been using a scanning tunneling microscope (STM) to study the unusual behavior of electrons in high-temperature superconductors – materials that can conduct electricity with little resistance.

Davis has turned out a series of discoveries about the behavior of electrons in a class of high-temperature superconductors called cuprates. He has verified that in the superconducting state the electrons are bound into pairs, and he has shown that electrons in cuprates form themselves into a sort of grid independent of the arrangement of their atoms. Studies of "transition" cuprates that are not quite superconductors are informing and sometimes confounding theorists – and hopefully leading to new understanding of how high-temperature superconductors work, perhaps someday leading to new materials that will superconduct at even higher temperatures.

A catch-22 of superconductivity is that superconducting magnets are limited in strength, because their own high-magnetic fields quench superconductivity. Davis plans to use the new STM he will build in the basement of the physical sciences building to see how the electronic structure of high-temperature cuprate superconductors changes in strong magnetic fields. Other studies will examine the ability of certain manganese oxides to change their electrical resistance in the presence of a magnetic field and the so-called "electronic supersolid" structure that may exist in cuprate semiconductors.

Davis also is studying Josephson junctions created in superfluid helium-3 and helium-4 in nanoscale devices and developing nanomechanical force sensors for research in fundamental physics, including measurements of gravity at very short distance scales.



Seeing potential in small things

By Bill Steele

Paul McEuen studies the curious physics of devices so small that they exhibit quantum effects – often working at the growing interface between physics, nanotechnology and biology. His primary interest? "Anything," he says. "As long as it's small."

Much of McEuen's work focuses on carbon nanotubes. Shortly after the structures were discovered by Japanese researcher Sumio Iijima, McEuen showed that they behave as "quantum wires," in which electrons move only along the length of the wire. For this work he shared in the 2001 Agilent Technologies Europhysics Prize. At Cornell his research group makes nanotubes into transistors and capacitors and uses them as biological probes.

Nanotubes are made of carbon atoms joined in hexagonal patterns. The carbon atoms link to one another using three of their four valence electrons, leaving the fourth electron free to jump from atom to atom – and allowing nanotubes to conduct electricity.

If the chicken-wire lattice of a tube is lined up straight, the tube is a good conductor. If it is twisted into a spiral, the tube becomes a semiconductor and can be used as a transistor. A typical nanotube is a few microns (millionths of a meter) long and just a few nanometers (billionths of a meter) in diameter, suggesting possible future uses in incredibly small electronic circuits.

McEuen's group manipulates and observes the tubes with an atomic force microscope, which scans a tiny tip across a sample and uses a sensitive cantilever mechanism to measure up and down movements. In McEuen's work, a positive voltage is applied to the tip and the electrostatic attraction between the tip and the electrons in the nanotube is measured. Turning up the voltage can cause a single electron to move into the tube; this in turn increases the electrostatic attraction, pulling the tip down. McEuen has found that the addition of a single electron to the tube causes a measurable dip, making it possible to count electrons as they enter or leave the tube.

Among McEuen's other projects, he and colleagues are exploring the use of nanotubes as biosensors, or probes to detect biochemical signals. They also have built a transistor from a single cobalt atom surrounded by a support structure of carbon and hydrogen. That structure offers possibilities as a chemical sensor, because a change in the environment around the molecule could cause a measurable alteration of the conductance of the device.

THE ABILITY TO WATCH ATOMS MOVE

By Anne Ju

When excited, atoms move at impossibly small length and time scales – too small and too fast to have been observed in years past.

A new generation of X-ray sources is allowing scientists to watch individual atoms move. And as a consequence, says applied and engineering physics professor Joel D. Brock, the way scientists understand matter is changing.

Brock is part of a Cornell team that is jockeying for leadership in this X-ray technology by building an Energy Recovery Linac (or

linear accelerator), ERL. Still in design stages, the ERL would produce X-ray beams that pulse up to 1 billion times a second, or a thousand times faster than ever before.

The technology could give scientists a window on atomic-scale processes that happen almost instantaneously: the changes in a cell as it turns from healthy to cancerous, for example, or the interaction between photons and the atoms at the surface of an optical device.

The ability to observe and document the atomic activities, a domain of research known as sub-picosecond science, is now holding promise with the advent of linear accelerator–based X-ray sources, which produce shorter-than-ever pulses. "These new machines are magnificent," Brock says. "They're mind-boggling in what they'll be able to do."

The ERL is also designed to maximize efficiency by recovering and reusing approximately 99 percent of the energy needed to accelerate electrons to nearly the speed of light.

Cornell has garnered about $18 million in support from the National Science Foundation, as well as $12 million from New York state for preliminary work. The entire project, among the most ambitious undertaken at Cornell, would amount to a $300 million to $400 million investment.

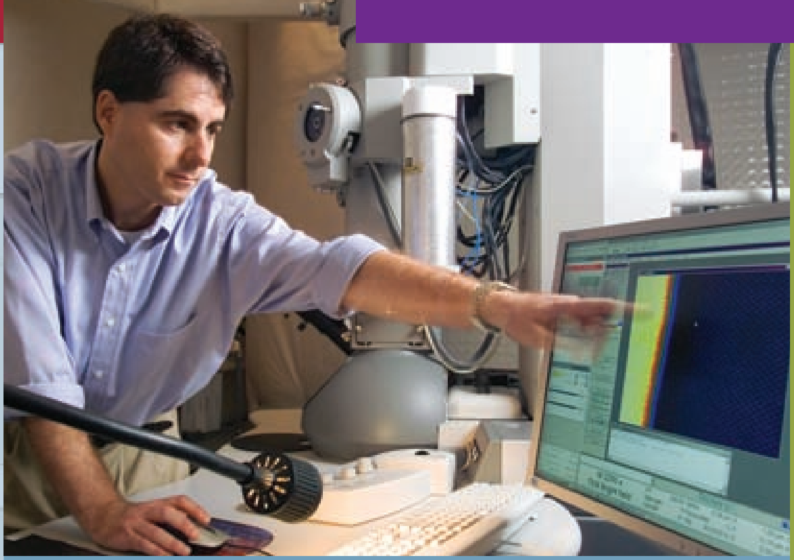
Brock says that the potential applications across disciplines, from physics and engineering to chemistry and biology, are enormous. For example, traditional X-ray diffraction technology has long allowed scientists to observe viruses, but through snapshots only – still pictures, limited by the speed of the X-rays.

Using the greatly improved X-ray sources, scientists could someday watch a virus move, see how it grabs on to a cell, and discover why it is harmful. That observation could lead to processes by which to disable the virus.

"We've seen the snapshot," Brock says. "Now let's see the movie."

courtesy LEPP

ERL photo-cathode electrodes



ATOMIC-SCALE IMAGING OF INDIVIDUAL ATOMS

By Anne Ju

By paying close attention to how two materials behave when a single layer of atoms touch, a Cornell physicist's research potentially could lead to simpler, less costly electronic devices.

David A. Muller, Cornell professor of applied and engineering physics, has shown how some interfaces can be manipulated to remain stable by moving only single layers of atoms. His research shows that two particular oxides, lanthanum aluminate and strontium titanate, are good examples of this ability.

"One of the things we're trying to do when miniaturizing electronics is to shrink things to the atomic scale," Muller explains. "You have to control the material at the atomic scale to get a perfect interface. And if you don't, you'll notice it in the properties of the system you're trying to make."

The results of Muller's research, in collaboration with Naoyuki Nakagawa and Harold Y. Hwang of the University of Tokyo, appeared in the March 2006 issue of Nature Materials. The paper recently was chosen by the journal as one of its "Top 10" papers of 2006.

A commentary piece by Knut Urban of the Institute for Solid State Research calls the collaborative research "a landmark in modern quantitative atomic-resolution electron microscopy."

Using a scanning transmission electron microscope, the scientists studied the interfaces between lanthanum aluminate films grown on strontium titanate crystals. They showed that by changing only the final layer of atoms in either material before it touched the next material, the properties could be changed – making the materials either insulating or conducting.

"We think we know how to improve the performance of devices made from these materials, because you need to switch the interface termination in order to get a good device," Muller explains.

Muller and his colleagues have long studied oxides for increasing the functionality of silicon or other conventional materials for semiconductors.

Oxides could prove useful in the electronics world, whether as memory storage devices, filters or surge protectors for cell phones, because of their ability to display many different properties. The challenge that scientists face, Muller says, is to make the materials as defect-free and as high-quality as semiconductors used in electronics today.

Promoting undergraduate research

By Melissa Rice

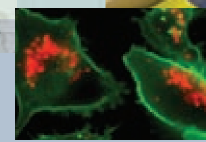
For undergraduates in the sciences, participating in research is the best way to see what doing science is really like. Often it's an experience in a faculty research laboratory that leads undergrads to choose a career in science. The new physical sciences building will allow more Cornell undergraduates to have these invaluable experiences.

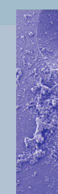
The first floor of the new building, which is devoted to undergraduate teaching, will house state-of-the-art laboratories for coursework in chemistry, physics and applied and engineering physics. All students enrolled in organic chemistry (approximately 600 at a time, mostly undergraduates) will be taught on this floor, interacting with faculty members who have their research labs upstairs.

Students most often learn about research opportunities through their classes, and faculty teaching undergrad classes on the first floor will be encouraged to advertise open positions in their labs.

The building will accommodate 8-10 research groups in chemistry, physics and applied and engineering physics. "There will be enormous opportunities for research here," says Héctor Abruña, E.M. Chamot Professor of Chemistry and Chemical Biology. "All three departments are currently strapped for space, but the new building will create more opportunities for students to participate in research projects. Each faculty member will typically have two to three undergraduate students in their lab," he says.

Cornell President Emeritus Hunter Rawlings created an initiative to get more undergrads involved in research, and President David Skorton has been working to build on this vision. In his inaugural address in September 2006, Skorton said that the first of his basic propositions would be: "To continue and accelerate the transformation of the undergraduate experience at Cornell, to achieve our goal of making Cornell the finest research university and provider of undergraduate education in the world."



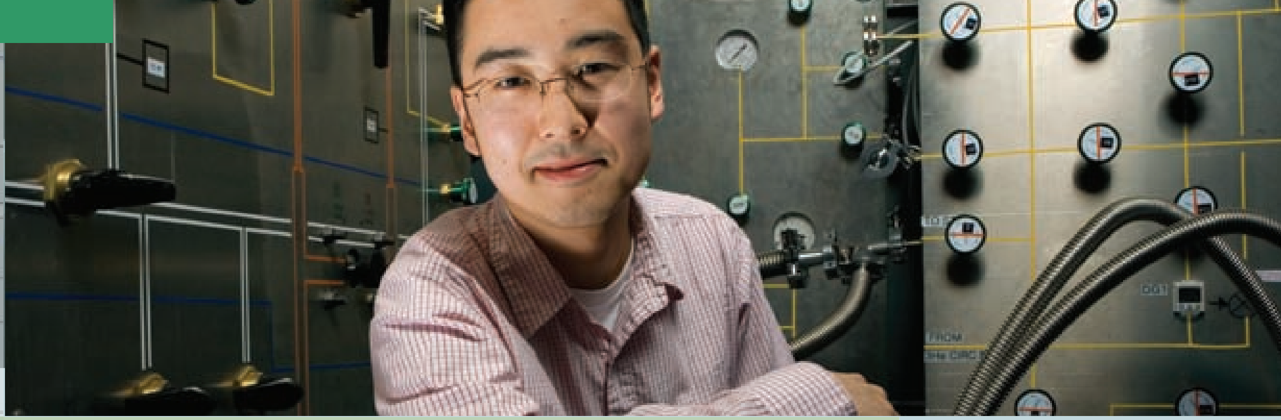


The new building is a step toward this goal. "As a university, Cornell's primary mission is education," says Abruña, "and we service mainly undergrads. Research projects are a chance for these students to learn far more than they can in the classroom."

Seth Jacobson, a senior applied and engineering physics major, can attest to the value of undergraduate research. He joined a research group as a freshman and has since been involved in projects in three different fields. Those experiences, he explains, have been pivotal in shaping his goals for the future.

"Having met professors and graduate students outside of class, I know what to expect if I choose to pursue a career in the physical sciences," Jacobson says. "Getting a first-hand understanding of what academic research is like has prepared me to make choices about my future plans, which now include graduate school in planetary astronomy – a decision I could not have reached without undergraduate research." ■

Astronomy graduate student Melissa Rice is an intern with the Cornell Chronicle.



‘Cool’ teaching labs expand student horizons

By Alex Kwan

For more than 60 years, Cornell’s engineering physics undergraduate curriculum has been the nation’s top program. Now, with the planned construction of the physical sciences building and its modern teaching laboratories, the best is becoming better.

Nine new teaching laboratories are planned for the building’s first floor, which will also hold a 120-seat lecture hall and a spacious atrium. Along the south wall, a roofed pedestrian walkway is designed to accommodate the students who make daily treks between buildings on the Arts and Agriculture quadrangles.

“We want the classrooms to be a place where people can walk by and see something cool,” says Joel Brock, professor of applied and engineering physics (AEP), who served as director of the department from 2000 to 2007. To recruit new students, some of the teaching laboratories will be windowed so anyone can look in and see the undergraduates working on interesting projects, such as controlling a robotic arm or building a temperature controller.

Four AEP classes will be taught at the new building, including Introduction to Nanoscience and Nanotechnology, Lasers and Photonics, Computer Instrumental Design and a senior project course. Currently, classes are held in several different locations on campus. Brock says that the new, centralized laboratory space will enable the department to provide more integrated support and instruction.

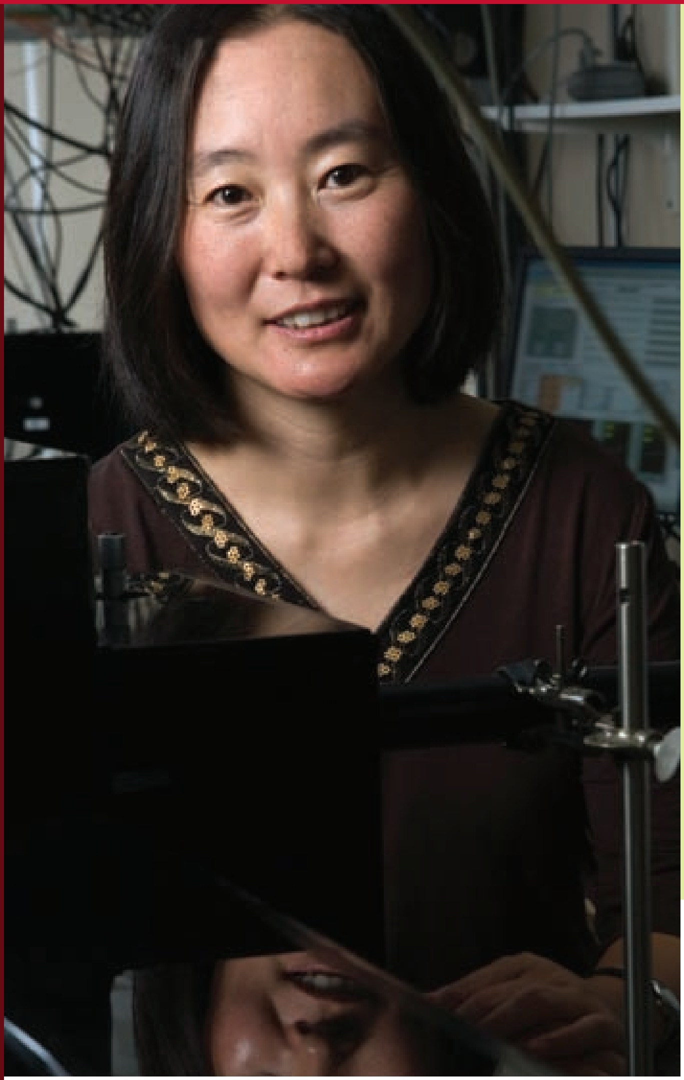
The other five teaching laboratories will be used for undergraduate organic chemistry classes offered by the Department of Chemistry and Chemical Biology. One innovation is that each workbench will be ventilated by its own fume hood, part of the total 150 fume hoods in the building.

“We want to promote interdisciplinary interactions, so for every floor of the building, we’ll have more than one department. On the first floor, it’s almost 50-50 chemistry and AEP,” says Brock. ■

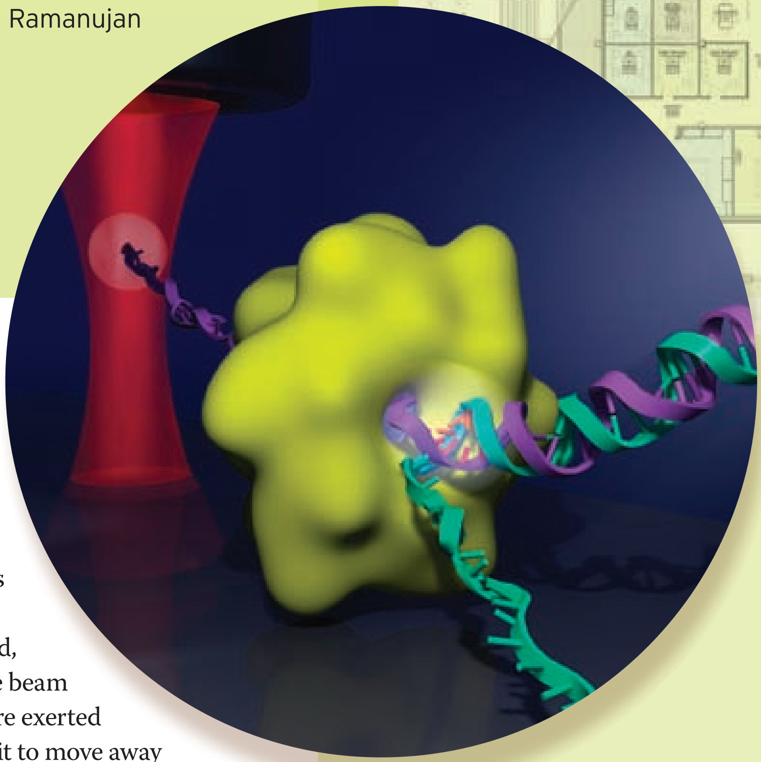
AEP graduate student Alex Kwan is an intern with the Cornell Chronicle.

Enzymatic forces unwind DNA

By Krishna Ramanujan



Michelle Wang



Chris Pelkie and Daniel Ripoll, Cornell Theory Center

This image shows a DNA double helix (green and purple strands) being separated by a helicase enzyme (yellow globule) at the junction where the two strands fork.

Michelle Wang and her students have invented a novel way to measure the infinitesimal movement of an enzyme as it unwinds a double stranded DNA.

In recent research, the technique was used to answer a fundamental question about how two strands of DNA – a double helix – are separated by the enzyme helicase to start the process of replication, in which genes copy themselves.

Wang and colleagues wanted to test whether helicase played an active or passive role in the DNA unwinding process. Scientists have known that helicases bind to the area of a double helix where the two strands fork away from each other, like the free ends of two pieces of thread wound around each other. But scientists have debated whether helicases actively separate the two strands at the fork or if the enzymes wait passively for the fork to widen on its own.

To find out, Wang's team anchored one end of one of the strands in a double helix to the surface of a microscope slide's cover slip and the corresponding end of the other strand to a micron-sized plastic bead. The researchers then focused a laser beam on the tiny bead, trapping it within the beam of light. As forces were exerted on the bead, causing it to move away from the laser beam's center ever so slightly, light was deflected. The researchers used measurements of the deflected light to calculate the position and force on the bead, creating a very precise sensor of the helicase motion.

As the helicase moved toward the fork and the double helix unwound, the tension on the two strands lessened. Using statistical mechanics models, the researchers could then compare actual measurements of movement with predictions based on both active and passive scenarios.

"The unwinding has to have some active component to it, and based on our data we can tell you exactly how active it is," Wang says. "Basically, it is an active unwinding motor."

INTERDISCIPLINARY SPACE

By Bill Steele

The 1,400-square-foot space in three rooms at the southeast corner of the ground floor of the new physical sciences building will include a variety of tools available to every user in the building.

"Many of these things exist now in various researchers' labs, but if it's not your specialty you don't have access to it," says Paul McEuen, a professor of physics who engages in nanobiotechnology research and other cross-disciplinary work.

What goes in the space will depend on future funding, but on the wish list are tools to build microfluidics devices with soft lithography, advanced electronic and spectroscopic and force instruments, optical spectroscopy equipment, electronic tweezers, cell-culture facilities and cellular and DNA purification equipment.

APPLYING NANOTECHNOLOGY TO BIOLOGY

By Bill Steele

Nanodevices comparable in size to cells, DNA, viruses and protein molecules are opening new doors in basic life science research. Harold Craighead, the Charles W. Lake Professor of Applied and Engineering Physics and director of the Nanobiotechnology Center, leads a research group exploring many of the possibilities.

Microfluidics

The same techniques that can draw electronic circuits on the surface of a silicon chip can carve channels in a chip so narrow that only one molecule can pass through at a time. Such microfluidic channels also can be cast into glass or plastic. A light beam passing across the channel can count molecules or measure their size as they go by, and the right combination of narrow channels can separate DNA strands by length – a faster and potentially portable alternative to the gels now used to analyze DNA.

Nanoresonators

A strip of silicon a few microns long vibrates at radio frequencies and could replace the quartz crystals used to generate high frequencies in electronic devices. Because such nanoresonators are so tiny, the added mass of a bacterium, virus or even a single protein molecule is enough to change the resonant frequency. Researchers can affix an antibody to a nanoresonator, then use a laser to measure any changes in frequency if an additional mass binds to the antibody. An array of resonators, each carrying a different antibody, could form a detector to identify environmental pathogens.

Microarrays

Another way to detect biological molecules is to distribute antibodies or DNA molecules across a flat surface and observe the changes in the diffraction of light off of the surface after something binds to it. Craighead's group is exploring ways to create surfaces on which neurons can be attached and interfaced with electronic circuits for basic research on nerve function.

New techniques for nanofabrication

Craighead's group uses electrospinning to create glass or plastic fibers only a few hundred micrometers in diameter. Spreading many parallel strands of microfibers across a silicon surface offers a less precise but far cheaper alternative to conventional resists for making a series of microchannels.

THE INTRICATE MOLECULAR DYNAMICS OF LIFE

By Lauren Gold

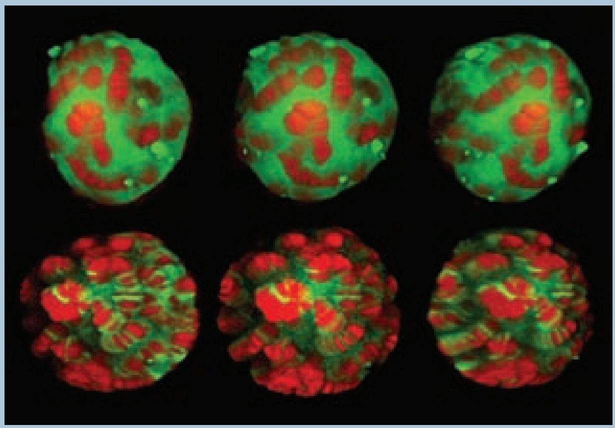
How do neurons convert chemical signals into intelligent thought? What are the molecular disruptions behind devastating neurological disorders like Parkinson's and Alzheimer's diseases? What happens in a cell nucleus when an environmental threat prompts messenger proteins to activate genes – and how do those genes direct the production of new cell-protecting proteins?

Watt W. Webb, Cornell professor of applied physics and the S.B. Eckert Professor in Engineering, is driving a wide group of collaborative projects to investigate these and other biological processes in molecular detail. Webb's research uses innovative imaging techniques developed in his laboratory, including multiphoton microscopy (MPM) and fluorescence correlation spectroscopy (FCS), to image living cells deep within tissue – to high precision, in real time, and without damaging the tissue.

With collaborators at Cornell, Weill Cornell Medical College in New York City and around the world, Webb is incorporating the use of MPM into medical endoscopy instruments to provide on-the-spot, in situ diagnostic imaging that could ultimately supersede slower, more traumatic tissue biopsies. Endoscopes fitted with optical fiber to illuminate laser scanning multiphoton microscopy could aid in the screening, early diagnosis and treatment of bladder, ovarian and gastrointestinal cancer, and other diseases.

Webb also is working with colleagues at Weill Cornell Medical College to apply MPM and FCS to study protein folding and aggregation in Alzheimer's, Parkinson's and other neurodegenerative diseases. These studies, which use MPM to image brain tissue and FCS for enzyme function and molecular aggregation, could give researchers a stronger understanding of what causes these disorders and how to mitigate them.

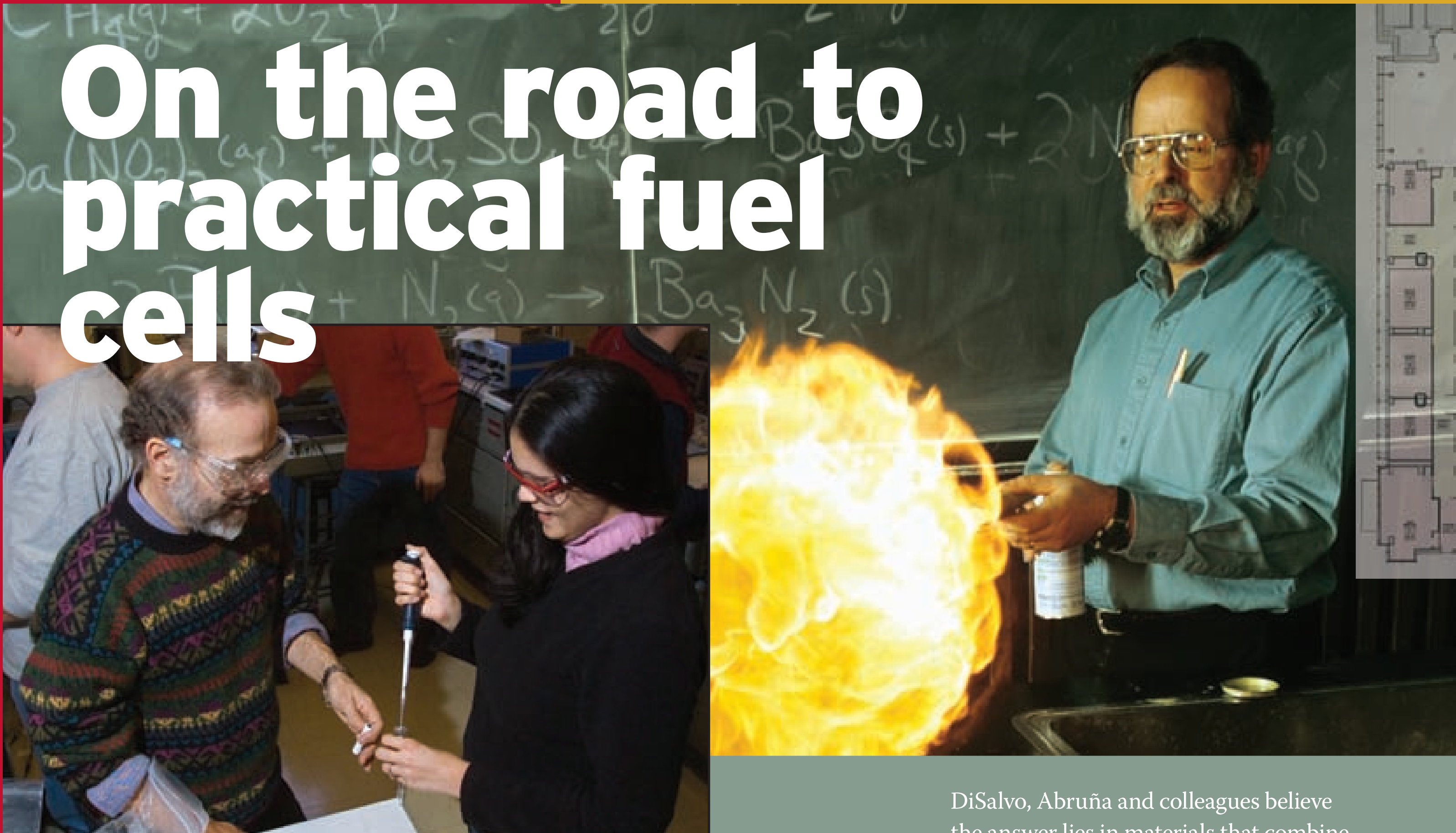
And there is potential for much more, Webb says. The key to it all is also one of Cornell's greatest strengths: the power of interdisciplinary collaboration in research. "The sciences are interlocked. We're looking into the dynamics of the chemical physics of life," he says. "So tune in. We will know more in the coming years."



Jie Yao © Cornell University

With two-photon laser-scanning microscopy, giant polytene chromosomes in living salivary gland tissue from *Drosophila* larvae can be examined in 3D, in real time with high resolution.

On the road to practical fuel cells



By Bill Steele

A team of Cornell researchers, working closely with industry, is trying to make cheap, reliable fuel cells that can turn fuel into electricity with less waste and pollution. But it will take time.

"It's unlikely that we will all be using fuel cell cars in 15 years," says Frank DiSalvo, the J.A. Newman Professor of Chemistry and Chemical Biology and co-director of the Cornell Fuel Cell Institute (CFCI). "Most people researching alternative energy solutions today expect to have major market penetration by 2040 or 2050. The role of research, and our work, is to put as many options on the table as possible."

Like a battery, a fuel cell has two terminals: the anode (positive) and cathode (negative), separated by an electrolyte. The anode contains a catalyst that binds to molecules of hydrogen or a hydrocarbon fuel, separating the fuel's hydrogen atoms, removing their electrons to make protons and oxidizing any carbon to carbon dioxide. The electrodes are separated by a membrane that selectively allows protons to seep through, creating an excess positive charge at the cathode. The electrons pass through a wire from the anode to the cathode, creating an electric current to drive a motor or other device.

At the cathode, another catalyst combines the protons, electrons that traveled from the anode and oxygen from the air to form water.

Presently, the most efficient fuel cells are those fueled by extremely pure hydrogen, with platinum as the anode catalyst. But very pure hydrogen is difficult and expensive to make, store and transport, and platinum is expensive – fuel-cell "concept cars" contain about $10,000 worth of platinum.

With hydrocarbon fuels and even unpurified hydrogen, though, impurities literally gum up the works. The platinum catalyst that binds to hydrogen atoms binds even more strongly to impurities like carbon monoxide or sulfur, so the surface becomes "poisoned." The holy grail, says Héctor Abruña, the E.M. Chamot Professor of Chemistry and Chemical Biology and co-director of CFCI, is an inexpensive catalyst that completely breaks down common hydrocarbon fuels like methanol or ethanol and rejects poisoning by impurities.

DiSalvo, Abruña and colleagues believe the answer lies in materials that combine two, three or four different elements in ordered arrays.

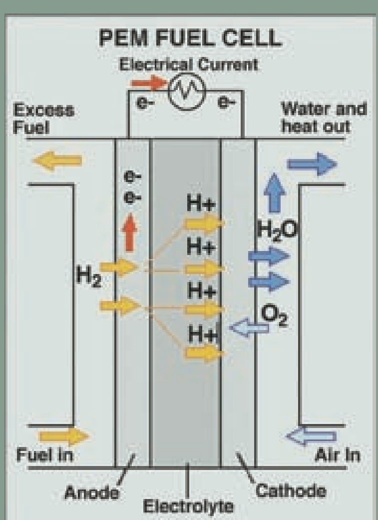
To test different combinations, CFCI researchers are using a device in which three guns pointing inward from each corner of a triangle spray atoms of three different elements onto a silicon wafer. Near any one gun you get nearly a pure deposit of just one element; at the center you get an even three-way combination; and over the rest of the wafer you get every other possible proportion. (A four-gun version recently has been brought online.)

Hundreds of wafers made this way have been tested in a test cell containing a chemical that fluoresces wherever catalytic activity happens. When a part of the wafer glows, the researchers determine the exact chemical composition and molecular structure of the deposit in that region. Promising candidates then are sent to industrial partners to test in fuel cells under realistic conditions.

Thus far, results have been mixed. The researchers have found moderately good catalysts for methanol, but the chemical is toxic and presents distribution challenges. Ethanol, promoted as the fuel of the future, contains an extra carbon-carbon

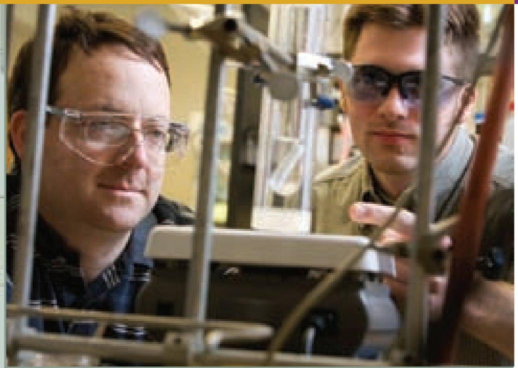
bond that is notoriously hard to break. Strip off the hydrogen from ethanol without breaking that carbon-carbon bond and you get what Abruña calls "very expensive vinegar." CFCI researchers are still looking for good catalysts for ethanol and other fuels.

Other CFCI researchers are exploring the use of self-assembling polymers to distribute catalysts properly in the electrodes, new and better membranes and alkaline fuel cells that work in reverse – transporting hydroxyl ions, instead of protons, across the central membrane. ■



Graphic adapted from U. S. Department of Energy

Chemistry of a fuel cell: In the polymer electrolyte membrane (PEM) fuel cell, a catalyst in the anode separates hydrogen atoms into protons and electrons. The membrane in the center transports the protons to the cathode, leaving the electrons behind. The electrons flow through a circuit to the cathode, forming an electric current. In the cathode, another catalyst helps recombine electrons, hydrogen nuclei and oxygen from the air.



SEARCH FOR GREEN POLYMERS BEARS FRUIT

By Lauren Gold

Plastics, the wonderfully moldable, impermeable, versatile polymers like polyethylene and polypropylene, are used to make everything from manufacturing equipment to office supplies to medical instruments.

They are irresistibly handy. But producing them requires petroleum, which may not always be plentiful. And once made, they last – filling landfills, polluting oceans and cluttering the planet.

So chemistry professor Geoff Coates and colleagues are developing alternatives: biodegradable polymers made from orange peels, for example, instead of oil. And from carbon dioxide (CO_2), whose overabundance is a major contributor to global warming.

Coates' lab is working to find catalysts (substances that lower the amount of energy needed for a chemical reaction) that entice otherwise aloof, inert molecules like CO_2 into unusual alliances – creating polymer chains that share the useful properties of plastic but that discreetly biodegrade once their usefulness is over.

One agreeable molecule for such alliances, Coates found, is limonene oxide – a waste product from citrus peels. With the right catalyst, it can arrange itself with CO_2 to form a waterproof, Styrofoam-like material.

The group also is looking for ways to make elastomers – rubbery, stretchy, moldable polymers like car tires and sneaker soles – that can be melted down when they wear out and molded a second time.

The group already has had success creating new kinds of elastomers – including some that could be lifesaving.

THE CHEMISTRY BEHIND THE ESSENCE OF LIFE

By Krishna Ramanujan

How do lowly bacteria sense environmental changes as small as 0.1 percent, the equivalent of one drop diluted in a pool of 1,000? How do the biological clocks in some blooming plants prompt them to open their petals at night and close them in the day?

Finding answers to such questions is what drives Brian Crane, associate professor in Cornell's Department of Chemistry and Chemical Biology.

Crane seeks to uncover how molecular mechanisms and chemical reactions lead to behavioral responses in organisms. His focus lies in areas of biological chemistry that involve redox chemistry, in which molecules lose and gain electrons – processes he describes as the essence of life.

"Such processes underlie energy production and biosynthesis in all cells but are also important for sending information and trans-ducing signals from the environment," he says.

Recently, Crane and colleagues discovered how an enzyme known as CheA works in bacteria to convert signals from outside the organism into an internal response and an action, such as changing how the flagella (or tails) spin and move the bacterium.

Crane also studies biochemical interactions that are related to light, known as photochemistry, and the enzymes that catalyze these reactions.

He has shown how circadian clocks become activated by particles of light to turn on or off cellular responses. In one study, Crane and colleagues revealed how a fungus *(Neurospora crassa)* uses circadian-clock light sensors to control production of carotenoids, which protect against damage from the sun's ultraviolet radiation just after sunrise. The researchers studied a protein called vivid, which contains a chromophore – a light-absorbing molecule. The chromophore captures a photon or particle of light, and the captured energy from the light triggers a series of interactions that ultimately lead to conformational changes on the surface of the protein that kick off a cascade of events affecting expression of genes.

"I get great pleasure in determining new structures of proteins. You literally get to see something that no one else has seen before," Crane says.

Ritchie Patterson

Particle physicists turn their eyes to Switzerland

By Bill Steele

Particle physicists are, quite literally, trying to find out what the universe is made of – and how all the quarks, leptons and things perhaps yet undiscovered work together to make stars, planets, earth, air, fire, water and people. What was around just after the big bang that we haven't seen since? What does dark matter consist of?

For the next 10 years or so, many Cornell physicists, along with others worldwide, will be exploring such mysteries with the Large Hadron Collider (LHC) at the CERN laboratory in Geneva, Switzerland. The LHC, which will smash together billions of protons at a time with energies seven times greater than any previous instrument, will go into operation in 2008.

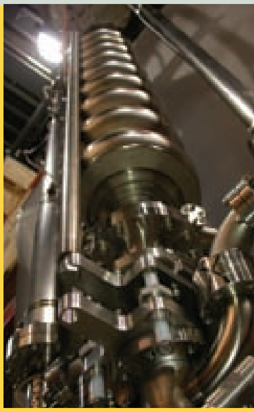
Cornellians are on the team designing and building the Compact Muon Solenoid (CMS), one of two detectors that will examine what comes out of the LHC's collisions. Six stories high (but on its side), the CMS surrounds a collision point of the LHC's proton beams with a huge superconducting magnet to force charged particles into curved paths that reveal their charge, mass and other properties. Particles created by the collisions will pass through several layers of detectors arranged in what Ritchie Patterson, Cornell professor of physics, likens to the layers of an onion. Each layer is composed of thousands of detectors optimized to measure a particular feature of the particles. Since subatomic events are far faster than electronics, only about one event in 40,000 can be recorded; a key feature, being developed by a team that includes Cornell assistant professor Peter Wittich, is the "trigger" that decides which events to record.

"I'm not worried that we'll see something that is not in nature," Patterson says. "I am worried that nature will have something in store for us and we may miss it."

Cornell associate professor Lawrence Gibbons leads a team contributing to computer programs that will dig through the data (2 petabytes per year, the equivalent of one million gigabytes) to find meaningful patterns. The patterns will be the "signatures" of subatomic particles, and Patterson expects that the LHC will find new ones – including the much-sought Higgs boson (the hypothetical particle that endows other particles with mass) and perhaps components of the "dark matter" needed to explain the mass of the universe.

Current theory, known as the Standard Model, nicely explains all the particles seen so far, but the Standard Model breaks down at the energies the LHC will produce. It is a special case for lower energies, just as Newtonian physics is a special case of relativity for things moving slowly. ■

THREE MAJOR PROJECTS



Courtesy Cornell LEPP

Setup for an International Linear Collider cavity test at Cornell.

In addition to working on the LHC, Cornell physicists also are involved in the design of the International Linear Collider (ILC), an electron-positron collider, also at CERN, which is expected to come online a few years after the LHC.

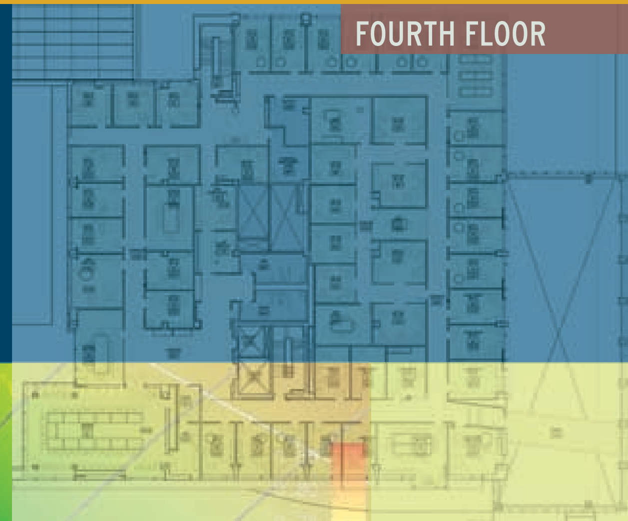
The ILC will operate at lower energies than the LHC but will measure the masses and other properties of particles with more precision. Cornellians are working on the physics of the ILC design and designing detectors that they hope will be built to work with it.

For the next few years many Cornell physicists will have one foot in the Cornell Electron Storage Ring (CESR) and the other foot in either the LHC or ILC. Research with CESR has focused on the decay of two of the basic constituents of matter – the quarks known as charm and bottom – to better understand the strong and weak nuclear forces.

Along with many other high-energy physics programs around the world CESR, which operated throughout the 1990s as the world's highest luminosity electron-positron collider, will shut down its physics program in 2008, when the LHC turns on. CESR will continue as a source of high-energy X-rays for materials science and biology and may be used as a test bed for proposed features of the ILC.

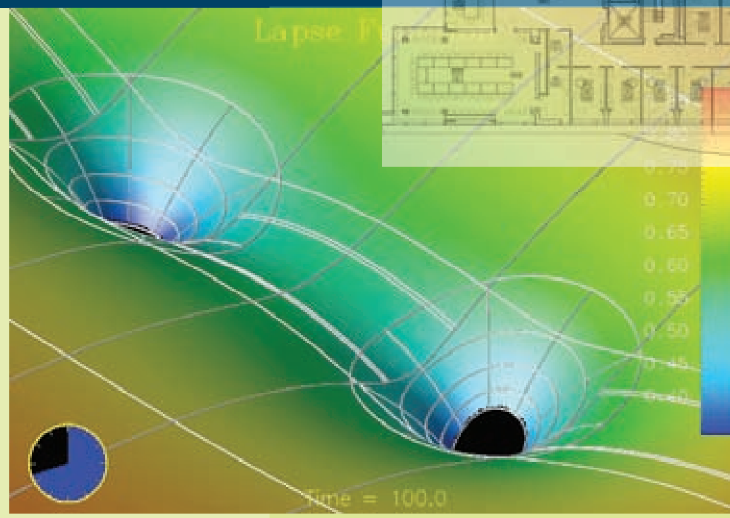
© CERN

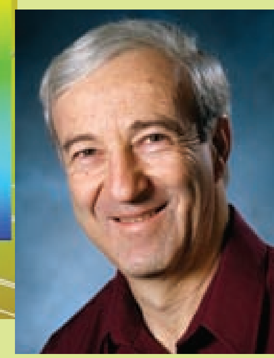
The Compact Muon Solenoid experiment at the Large Hadron Collider at CERN in Geneva, Switzerland.



Relativity revisited

By Lauren Gold





Saul Teukolsky

Almost a century ago, Einstein changed the course of physics with his theory of general relativity. The theory says, in part, that gravity – traditionally considered an ill-understood Newtonian force – is actually an effect of geometry, caused by the warping and stretching of an intermeshed fabric of space and time.

But what, exactly, does that imply – about the properties of black holes, the existence of gravitational waves and the formation of galaxies? The answers, says Cornell physicist Saul Teukolsky, may be just on the horizon.

The first supporting evidence for Einstein's theory came during a 1919 solar eclipse, when scientists observed the predicted deflection of starlight around the sun. General relativity also offers the only satisfying explanation for the quirky shift in Mercury's orbit, the observed slowing of time on a 1976 gravity probe, and the precise rate of energy loss measured in a binary pulsar – two neutron stars orbiting each other – known as PSR 1913+16. (Astronomers Russell Hulse and Joseph Taylor were awarded the 1993 Nobel Prize in physics for discovering and interpreting that system.)

But key elements of Einstein's theory have yet to be observed – or fully understood. And as technology improves to allow ever more precise measurements, theoretical physicists around the world are working to understand exactly what different measurements could indicate.

Most notably, general relativity predicts the existence of gravitational waves: ripples in the space-time fabric that carry energy away from an accelerating mass or system of masses, like ripples on the surface of a pond. The energy loss in the Hulse-Taylor binary system offers indirect evidence of their effect, but the waves themselves never have been detected directly.

That could change soon, says Teukolsky, Cornell's Hans A. Bethe Professor of Physics and Astrophysics, thanks to two detectors known as LIGO (the Laser Interferometer Gravitational-Wave Observatory, in operation since 2001 and slated soon for a sensitivity-enhancing upgrade) and LISA (the Laser Interferometer Space Antenna, LIGO's orbiting counterpart, which is scheduled for launch in 2015).

Both observatories use lasers to measure the precise distances between three test masses, spaced evenly and protected from vibrations. Passing gravitational waves, caused by massive collisions between two black holes spiraling inward, for example, are expected to cause infinitesimal changes in the distances between the test masses – like corks bobbing on the surface of a pond.

Teukolsky and colleagues use computer modeling to piece apart the possible signals LIGO could detect – and to predict what it should see, based on Einstein's theory, in various scenarios (the most important of which is the collision of two inspiraling black holes). It's a worldwide effort, but Cornell is in the lead with simulations that run about 10 times faster and more accurately than any others.

So, will the experimental results match the predictions?

"At this stage, everybody expects that Einstein will be right," says Teukolsky. "Everything fits so well. Einstein's theory is, in a way, the simplest way to explain everything we already know."

But that might not mean as much as we're tempted to think it does, he adds. "From the point of view of fundamental physics, it really is important to emphasize that we have little experimental reason to say that, except for psychological prejudice. We've built up this glorious edifice about black holes – it's part of the public consciousness … but it's really a house of cards until we test the fundamentals."

And if the house falls? "If that turns out not to be correct," he adds, "that would probably be the most exciting discovery since the 1920s." ■

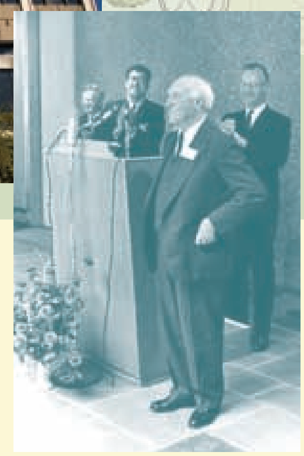
Clark family legacy continues

James McConnell Clark Atrium designed to invite collaboration

By Sharon Tregaskis

Over the last century, members of Cornell's physical sciences and engineering faculty have won eight Nobel Prizes and earned international renown in areas such as imaging and nanoscience, X-ray and accelerator physics, chemical biology and biological physics. To give such scientists – and budding scientists – a place to mingle and brainstorm, the new $142 million physical sciences building will include the eight-story, 6,700-square-foot James McConnell Clark Atrium.

The space will include a café, alcoves with tables and chairs, pedestrian bridges connecting buildings and a floor-to-ceiling wall of glass providing year-round natural lighting.



Clark Hall of Science replaced Rockefeller Hall in 1965 as the center for the physical sciences at Cornell. At left, W. Van Alan Clark '09 speaks at the building's dedication ceremony.

The atrium is named for James Clark '44, whose $10 million campaign gift marks the continuation of a family legacy that has helped shape the physical and academic landscapes at Cornell. Clark's parents, W. Van Alan Clark, Class of 1909, and Edna McConnell Clark, provided funds for both Clark Hall and its Edna McConnell Clark Library.

Beyond his family connections, Clark says inspiration for his own lifelong support of Cornell – as a trustee and presidential councillor and through the Cornell Annual Fund and the endowment of the Hays and James M. Clark Director of Undergraduate Biology – grew out of a strong conviction. "Knowledge is the pathway to improvement of the human endeavor," says Clark, who studied engineering on the hill and, after a stint in the Navy, worked in banking and finance. "It's all about increasing knowledge."

In keeping with Cornell's collaborative tradition, the Clark Atrium is designed to invite the kinds of casual conversations and chance encounters that often lead to important new insights and partnerships.

"Given the thousands of students who congregate in this corner of campus for physics and chemistry classes, we expect the Clark Atrium to be a major asset of the physical sciences building," says G. Peter Lepage, the Harold Tanner Dean of the College of Arts and Sciences. "Places where students can meet one another, where a faculty member can say after class, 'Let's go get a cup of coffee and talk about it,' are extremely popular. It adds tremendously to the Cornell experience if you encourage this extra dimension of interaction in and around the regular classroom setting."

Sharon Tregaskis '95 is a freelance writer in Ithaca.

An artist's rendering looks northward through the eight-story Clark Atrium, capturing the anticipated daily rush of activity.

Cornell – long a leader in the sciences

By Dale R. Corson, eighth president of Cornell University (1969–1977), provost (1963–1969), dean of the College of Engineering (1959–1963), member of Cornell's physics faculty since 1946

It's an exciting time to be a scientist at Cornell.

With some of the world's best theorists and experimentalists in dozens of fields, the university is poised to play a leading role in the discoveries and innovations that will shape the next century.

Many of those discoveries are likely to take place in the new physical sciences building, where researchers will have the ability to test phenomena to extraordinary precision. But while the building is new and vital – as the physics department's move from the aging Rockefeller Hall to Clark Hall was vital in the 1960s – the spirit of excitement is not new, or incidental.

Cornell has a long tradition as a leader in the sciences. Graduates and faculty in chemistry and physics here have together earned 20 Nobel Prizes, as well as many other prestigious honors. The Physical Review and the Journal of Physical Chemistry both began here, as did the international scientific research society Sigma Xi.

As with many great traditions, Cornell's leadership role can be traced back to the vision of a very few dedicated people. Of the first four faculty members at Cornell, two – G.C. Caldwell and J.M. Crafts – were chemists. These men, along with the early physics faculty, most notably William A. Anthony, E.L. Nichols, Ernest G. Merritt and Frederick Bedell, shared a significant role in shaping the university as a whole.

It was Anthony who first emphasized the importance of laboratory courses and demonstrations to accompany textbooks in teaching science. A tremendously popular lecturer, he also built the first self-excited Gramme ring dynamo in the United States, featured in the 1876 Centennial Exhibition in Philadelphia.

Anthony was the force behind the 1887 Ithaca Railway short line, as well as the installation of the first electric lighting of its kind in the country – in front of Cornell's Morrill Hall. In 1885 Anthony proposed the electrical engineering curriculum, and as a result Cornell granted the first Ph.D. in that discipline in the country.

E.L. Nichols, once a student under Anthony, oversaw the growth of the physics department from three faculty members in 1887 to 38 in 1919. Along with Bedell, an expert in alternating current, and Merritt, Nichols founded the Physical Review in 1893 and published it on campus for 20 years.

At the turn of the century Cornell was instrumental in the sciences – not necessarily in making the big discoveries but in developing the kind of organizational structure that would allow for big discoveries to happen. The concept of tying research with the graduate school was a new movement in American higher education at the time, and Cornell's physics and chemistry faculty were leaders in shaping the system we know today.

Engineering at Cornell owes much of its development to the vision of engineering dean Solomon Cady Hollister and to Lloyd Smith, who in 1945 established the School of Engineering Physics (now Applied and Engineering Physics) to better prepare students for the increasingly technological world. Chemistry saw much of its growth in the first half of the 20th century as well, particularly under the leadership of Nobel laureate Peter Debye.

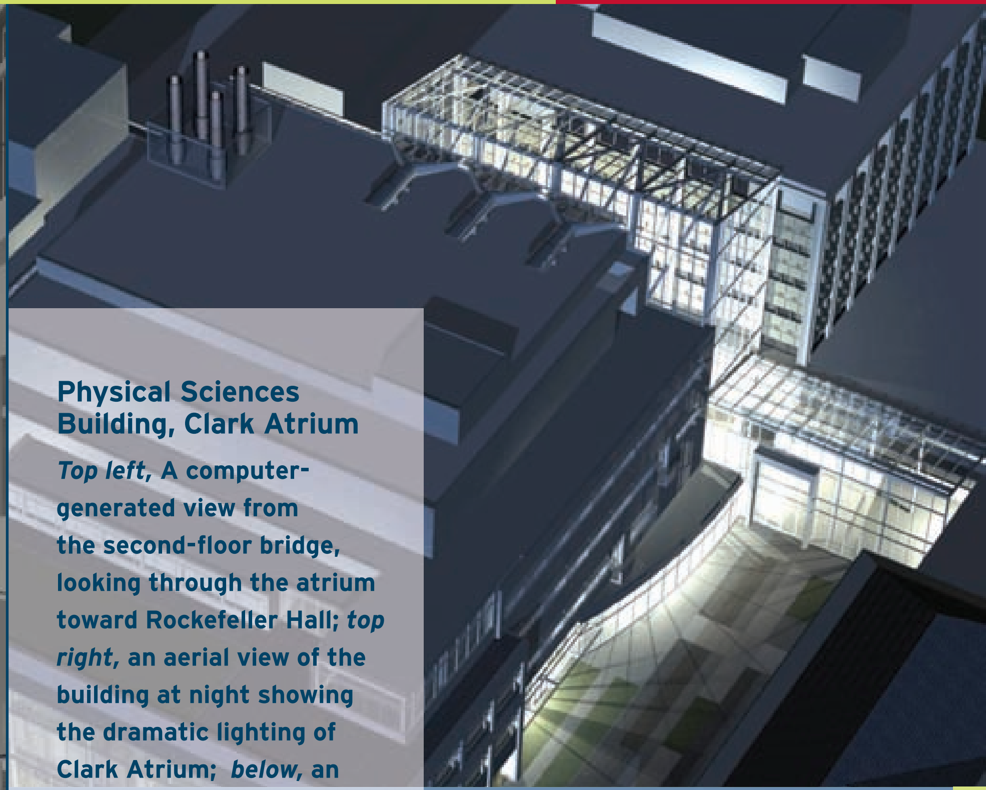
In 1936 Hans Bethe came to Cornell. It would be difficult to overstate Bethe's contribution. With his unique insight and genius, Bethe quite simply raised physics at Cornell to the highest level.

Bethe also was a magnet for a generation of scientists: Ed Salpeter, Ken Wilson, David Mermin, Robert Wilson and many more.

For that reason and others, the period after World War II was one of the most exciting times in the history of science at Cornell. Newman Laboratory was built, and Clark Hall followed. With the Materials Research Center, established in 1960, Cornell led a nationwide movement for interdisciplinary collaboration. It was in these years that the broad, multidisciplinary flavor that has served Cornell so well over the years appeared with great intensity.

Science moves forward, and needs change. The new physical sciences building not only will meet the needs of science today but also attract the best students and researchers of the next generation.

The people today who work in the exciting fields of nanoscience and biophysics – especially where they intersect – feel some of the same spirit that researchers felt in the most exhilarating days of the last century. That spirit is a way of life at Cornell. The possibilities are phenomenal. ■



Physical Sciences Building, Clark Atrium

Top left, **A computer-generated view from the second-floor bridge, looking through the atrium toward Rockefeller Hall;** ***top right,*** **an aerial view of the building at night showing the dramatic lighting of Clark Atrium;** ***below,*** **an architectural rendering of the east elevation of Clark Atrium.**