The Class of 2003 Commences

Most of the class of '03 convenes (above) for a group photo before processing down the Court of Man to receive their diplomas and to hear noted biologist Harold Varmus (right) express his hope that society would treat them well and that science would remain an "exhilarating experience" for them.

At the 109th Caltech Commencement on June 13, 242 students graduated with their BS degrees, 111 received MS degrees, and 137 earned PhDs. And they all heard Harold Varmus urge them to reflect on how society serves science and to maintain a sense of joy and awe in doing science. Varmus, president and chief executive officer of Memorial Sloan-Kettering Cancer Center in New York, and former director of the National Institutes of Health, won the 1989 Nobel Prize in physiology or medicine for his studies of the genetic basis of cancer.

Varmus had provided all the graduates with a copy of Vittore Carpaccio's 1502–04 painting of St. Augustine in his study, surrounded by the tools of his trade (books, manuscripts, laboratory equipment) as they would have appeared during the Renaissance, as well as religious objects signifying the source of his support: the Church, which was "his NIH and his Caltech." What the Church expected in return for its generosity, said Varmus, was "apparently a mixture of intense philosophical thought, broad curiosity about the arts and sciences, and possibly a bit of practical invention."

He compared this mutually beneficial situation with the present day, 500 years after the painting, when the government rather than the Church is the biggest benefactor of science. We are also "fortunate to live in a culture that values scientific inquiry highly," when "our nation's financial investments in science are large, and the political support is generally strong."

But he reminded the audience that a century after Carpaccio's painting, the Church branded Galileo a heretic for the freedom of thought celebrated in the picture. There are economic, political, and social currents today, he said, that suggest that we also are in for a change of climate. "In this environment, society's expectations for science can shift to short-range necessities at the expense of unfettered inquiry into basic truths," Varmus warned. He hoped these concerns would "prove to be short-term and even exaggerated."

Switching to a topic more in keeping with the festive occasion, Varmus spoke of the importance of science remaining an "exhilarating experience, not just a grim duty." He offered two illustrations: Canadian astronomer Rebecca Elson and "internationally revered" biologist Ira Herskowitz, BS '67. Elson wrote poems and essays about her delight and thrill in spending "my days inside a tent with such a dazzling roof," published after her death at 39 in a collection called *A Responsibility to Awe.*

Herskowitz, Varmus's friend and colleague, who died in May at 56, "never lost his simple sense of joy, his 'responsibility to awe,' about a beautiful experiment," said Varmus. "He viewed science as an aesthetic experience."

Such people "illustrate the state of science in our society," Varmus told the graduates, "just as Carpaccio's vision of St. Augustine reveals the condition of scholarship in the early Renaissance. Science and society—a relationship that is built on mutual dependencies and inherently fragile—yet together capable of remarkable achievements: an understanding of life, our planet, our universe, and even ourselves." ☐ *—JD*

A Modest Proposal

Dave Stevenson has spent his career working on "swing-by" missions to the other planets. Now he has a modest proposal he'd like to swing by some government agency with a few billion dollars in available funding.

According to Stevenson's calculations, it should be possible to send a probe all the way to Earth's core by combining several proven technologies with a few well-grounded scientific assumptions about the workings of the planet. The probe would sink straight to the core in an envelope of molten iron, sending back temperature readings, compositional information, and other data along the way.

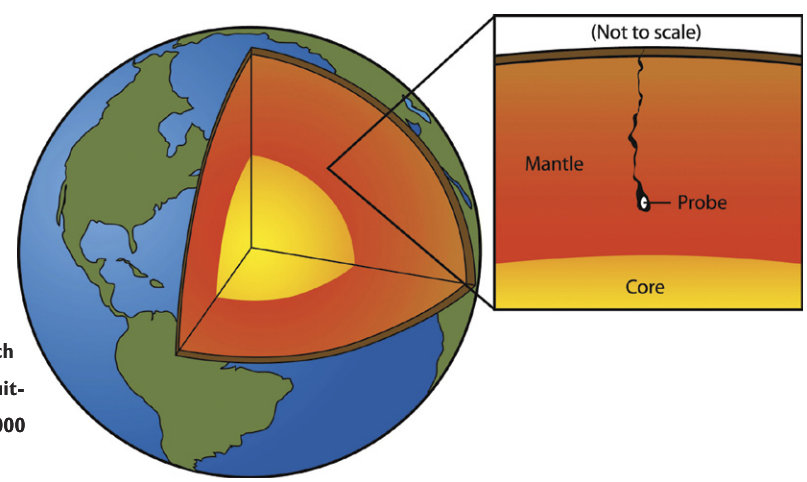
"We've spent more than $10 billion in unmanned missions to the planets," says Stevenson, the Van Osdol Professor of Planetary Science, "but we've only been down about 10 kilometers into our own planet."

The benefits to science would be significant, Stevenson says, because so little has been directly observed about the inner workings of the planet. Scientists do not know, for example, the exact composition or even the temperature of the core, and what they do know is based on inferences about seismic data accumulated during earthquakes.

Stevenson says his proposal should be attractive to the scientific community because it is of the same scale, pricewise, as planetary exploration. To date, NASA has flown unmanned missions past all the planets except Pluto (if indeed Pluto is a planet at all), has made a few highly successful soft landings on Mars, has probed the clouds of Jupiter, is getting ready to probe the atmosphere of Titan, and has sent four spacecraft into interstellar space. Sending something into Earth's core, Stevenson believes, will have comparable payoffs in the quest for knowledge.

"When we fly to other worlds, we are often surprised by what we find, and I think the same will be the case if we go down."

Stevenson's plan calls for a crack to be opened in Earth's surface, perhaps with some sort of explosion—probably a nuclear bomb. According to



Stevenson's proposal to visit Earth's interior does not include humans—unlike the recent movie *The Core*. Instead, he thinks it might be possible to open up a relatively narrow crack and pour down molten iron, which would carry along a grapefruit-sized probe while sinking 3,000 kilometers to the core.

his figures, the crack will need to be several hundred meters in length and depth, and about 30 centimeters wide, to accommodate a volume of about 100 thousand to several million tons of molten iron.

The instant the crack opens, the entire volume of iron will be dropped in, completely filling the open space. Through the sheer force of its weight, the iron will create a continuing crack that will open all the way to the planet's core 3,000 kilometers below. Anything on a smaller scale may not work; anything larger will be even more expensive, so Stevenson thinks a crack of those dimensions is about right.

"Once you set that condition up, the crack is self-perpetuating," he explains. "It's fundamentally different from drilling, where it gets harder and harder—and eventually futile—the farther you go down."

The iron will continue to fall due to gravity because it is about twice the density of the surrounding material. Riding along in the mass of liquid iron will be one or more probes made of a material robust enough to withstand the heat and pressure. The probe will perhaps be the size of a grapefruit but definitely small enough to ride easily inside the 30-centimeter crack without getting wedged.

Inside the probe will be instrumentation for data collection, which will be relayed through low-intensity mechanical waves of some sort—probably through deformations of the ball itself to send out a sort of "Morse code" of data. Because radio waves cannot propagate through Earth, this is the only way to get the data transferred.

The probe will likely operate with about 10 watts of power, and it may even be possible to replenish its energy and dispense with an on-board battery by harnessing mechanical energy from the force of the fall, just as electricity can be generated from falling water.

Such a low power rating will not make it possible to generate very strong shock waves for data transmission, but strong waves may not be necessary. In fact, Stevenson further suggests that the Laser Interferometer Gravitational-Wave Observatory (LIGO) might be recalibrated in its downtime to track the falling ball.

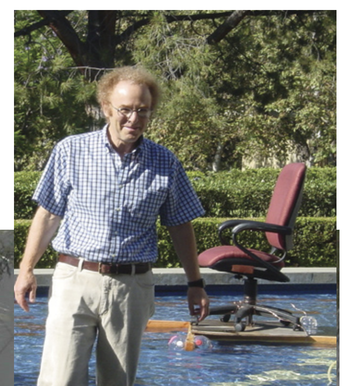
Based on the rate the molten iron would fall due to gravity, the ball would move downward into the planet at roughly human running pace (about 10 miles per hour), meaning that the entire mission would last a few weeks.

All this may sound to some like science fiction, but Stevenson says each of the principles involved is based on sound knowledge of crack propagation, fluid dynamics, mechanical-wave propagation, and "stress states." If these things didn't already work in nature, we would have no volcanoes and poorly performing bathroom plumbing, but little to fear from a pebble shattering our windshields.

"The biggest question is how to initially open the crack," says Stevenson. "Also, there's the technological challenge of having a probe that actually does what it's supposed to do."

Stevenson floated his idea in the journal *Nature* in May under the title "A Modest Proposal," taken from Jonathan Swift's famous essay. "My proposal is not as outrageous as suggesting one should eat his own children, but still combines a serious proposal with some levity," Stevenson says. "Ninety-five percent of the scientists who read the article may laugh at an enjoyable read, but if the other five percent seriously consider the goal of probing Earth's core, then I'll be happy." □ —*RT*

When he arrived at work on July 2, Bruce Brunschwig (inset) found that his entire office had been launched on floats in the "gene pool" (so called because the tiles on its bottom form a DNA double helix). Brian Leigh, Libby Mayo, and other grad students in the Beckman Institute carried out the early-morning move to welcome Brunschwig to his new post as head of the Molecular Materials Research Center. Nothing got wet—except Brunschwig, who enjoyed the stunt immensely.



Continuously changing images of exploding fireballs decorate a tympanum of the Athenaeum lobby as part of *NEURO*, an exhibition cosponsored by Caltech and Art Center College of Design. The exhibition featured six artists who created their works in collaboration with Caltech scientists. This contribution by media artist Jennifer Steinkamp, entitled *Einstein's Dilemma*, symbolizes the impact that new scientific knowledge has on human culture.

H_2 Uh, Oh

According to conventional wisdom, hydrogen-fueled cars are environmentally friendly because they emit only water vapor—a naturally abundant atmospheric gas [see *E&S*, No. 1, 2003]. But leakage of the hydrogen gas that can fuel such cars could cause problems for the upper atmosphere, new research shows.

In an article that appeared in a June issue of the journal *Science*, Caltech researchers reported that the leaked hydrogen gas that would inevitably result from a hydrogen economy, if it accumulates, could indirectly cause as much as a 10 percent decrease in atmospheric ozone. The researchers are Tracey Tromp, physics research scientist; John Eiler, assistant professor of geochemistry; Yuk Yung, professor of planetary science; Run-Lie Shia, PhD '86, planetary science research scientist; and Mark Allen, PhD '76, Jet Propulsion Laboratory scientist.

If hydrogen were to replace fossil fuel entirely, the researchers estimate that 60 to 120 trillion grams of hydrogen would be released each year into the atmosphere, assuming a 10 to 20 percent loss rate due to leakage. This is four to eight times as much hydrogen as is currently released into the atmosphere by human activity, and would result in a doubling or tripling of inputs to the atmosphere from all sources, natural or human.

Because molecular hydrogen freely moves up and mixes with stratospheric air, the result would be the creation of additional water at high altitudes and, consequently, an increased dampening of the stratosphere. This in turn would result in a cooling of the lower stratosphere and a disturbance of ozone chemistry, which depends on a chain of chemical reactions involving hydrochloric acid and chlorine nitrate on water ice.

The estimates of potential damage to stratospheric ozone levels are based on an atmospheric modeling program that tests the various scenarios that might result, depending on how much hydrogen ends up in the stratosphere from all sources, both natural and anthropogenic.

Ideally, a hydrogen fuel-cell vehicle has no environmental impact. Energy is produced by combining hydrogen with oxygen pulled from the atmosphere, and the tailpipe emission is water. The hydrogen fuel could come from a number of sources (Iceland recently started pulling it out of the ground). Nuclear power could be used to generate the electricity needed to split water, and in principle, the electricity needed could also be derived from renewable sources such as solar or wind power.

By comparison, the internal combustion engine uses fossil fuels and produces many pollutants, including soot, noxious nitrogen and sulfur gases, and the "greenhouse gas" carbon dioxide. While a hydrogen fuel-cell economy would almost certainly improve urban air quality, it has potential unexpected consequences due to the inevitable leakage of hydrogen from cars and hydrogen production facilities, and during the transportation of the fuel.

Uncertainty remains about the effects on the atmosphere because scientists still have a limited understanding of the hydrogen cycle. At present, it seems likely such emissions could accumulate in the air. Such a build-up would have several consequences, chief of which would be a moistening and cooling of the upper atmosphere and, indirectly, destruction of ozone. In this respect, hydrogen would be similar to the chlorofluorocarbons (once the standard substance used for air conditioning and refrigeration), which were intended to be contained within their devices, but which in practice leaked into the atmosphere and attacked the stratospheric ozone layer.

The authors of the *Science* article say that the current situation is unique in that society has the opportunity to understand the potential environmental impact well ahead of the growth of a hydrogen economy. This contrasts with the cases of atmospheric carbon dioxide, methyl bromide, CFCs, and lead, all of which were released into the environment by humans long before their consequences were understood.

"We have an unprecedented opportunity this time to understand what we're getting into before we even switch to the new technology," says Tromp, the lead author. "It won't be like the case with the internal-combustion engine, when we started learning the effects of carbon dioxide decades later."

The question of whether or not hydrogen is bad for the environment hinges on whether the planet has the ability to consume excess anthropogenic hydrogen, explains Eiler. "This man-made hydrogen will either be absorbed in the soil—a process that is still poorly understood but likely free of environmental consequences—or react with other compounds in the atmosphere.

"The balance of these two processes will be key to the outcome," says Eiler. "If soils dominate, a hydrogen economy might have little effect on the environment. But if the atmosphere is the big player, the stratospheric cooling and destruction of ozone modeled in this *Science* paper are more likely to occur.

"Determining which of these two processes dominates should be a solvable problem," states Eiler, whose research group is currently exploring the natural budget of hydrogen using new isotopic techniques.

"Understanding the effects of hydrogen on the environment now should help direct the technologies that will be the basis of a hydrogen economy," Tromp adds. "If hydrogen emissions present an environmental hazard, then recognizing that hazard now can help guide investments in technologies to favor designs that minimize leakage. On the other hand, if hydrogen is shown to be environmentally friendly in every respect, then designers could pursue the most cost-effective technologies and potentially save billions in needless safeguards."

If hydrogen indeed turns out to be bad for the ozone layer, should the transition to hydrogen-fueled cars be abandoned? Not necessarily, Tromp and Eiler claim.

"If it's the best way to provide a new energy source for our needs, then we can, and probably should, do it," Tromp says. □ *—RT*

Caltech is now the owner of a Pasadena landmark: the 13-acre, multi-structure St. Luke Medical Center, four miles northeast of campus, which the Institute plans, over time, to convert into a state-of-the-art research facility. The site, provisionally dubbed (CIT)^2 for Caltech Center for Innovative Technologies, will give the Institute an opportunity to expand current research programs and to contemplate new avenues for research. The purchase was consummated July 1 with the Tenet Healthcare Corporation, which had bought the facility in 1997 and closed it last year. Originally built in 1933 by the Sisters of St. Joseph of Orange (to whom the cross atop the dome will be returned), it was one of the first hospitals in the San Gabriel Valley.

Flee or Freeze

In most old-fashioned black-and-white horror flicks, it always seems there's some hapless hero or heroine who gets caught up in a life-threatening situation. Instead of making the obvious choice—to run like hell—he/she freezes in place. That decision, alas, leads to their ultimate demise.

While their fate was determined by bad scriptwriting, scientists already know that in real life, environment and experience influence defensive behaviors. Less understood are the neural circuits that determine such decisions. Now, Caltech researchers have developed an experimental model using mice that can map and manipulate the neural circuits involved in such innate behaviors as fear.

Raymond Mongeau, Gabriel A. Miller, BS '99, Elizabeth Chiang, BS '01, and David J. Anderson, in work performed at Caltech, manipulated either a flight or freeze reaction in mice through the use of an ultrasonic auditory stimulus, and further, were able to alter the mouse's behavior by making simple changes in the animal's environment. They also found that fleeing and freezing are negatively correlated, suggesting that a kind of competition exists between these alternative defensive motor responses. Finally, they have begun to map the potential circuitry in the brain that controls this competition.

"Fear and anxiety are important emotions, especially in this day and age," says Anderson, professor of biology at Caltech and an investigator with the Howard Hughes Medical Institute. "We know a lot about how the brain processes fear that is learned, but much less is known about innate or unlearned fear. Our results open the way to better understanding how the brain processes innately fearful stimuli, and how and where anxiety affects the brain to influence behavior."

Using the ultrasonic cue, the researchers were able to predict and manipulate the animal's reaction to a fearful situation. They found that mice exposed to the ultrasonic stimulus in their home cage (a familiar environment) predominantly displayed a flight response. Those placed in a new cage (an unfamiliar environment) or treated with foot shocks the previous day, primarily displayed freezing and less flight.

Anderson noted that in previous fear "conditioning" experiments, where mice learned to fear a neutral tone associated with a foot shock, the animals showed only freezing behavior and never flight, even though in the wild, flight is a normal and important fear response to predators. This suggests that the ultrasonic stimulus used by Anderson and colleagues is tapping into brain circuits that mediate natural, or innate, fear responses that include flight as well as freezing.

What causes the shift from flight to freezing behavior? Probably high anxiety and stress, say the authors, caused by an unfamiliar environment or the foot shocks. The researchers suggest that freezing requires a higher threshold level of anticipatory fear (the heroine inside a dark, spooky house) before it can be elicited by the ultrasound.

Most brain researchers believe the brain uses a hierarchy of neural systems to determine which defensive behaviors, like flight or freezing, to use. These range from an evolutionary older neural system that generates "quick and dirty" defensive strategies, to more evolved systems that produce slower but more sophisticated reactions. These systems are known to interact, but the neural mechanisms that decide which response wins out are not understood.

One of the goals of the investigators' work was to map the brain regions that control the behaviors triggered by the fear stimulus, to observe whether any change in brain activity correlated with the different defensive behaviors. They achieved this, all the way down to the resolution of a single neuron, by mapping the expression pattern of the c-FOS gene, a so-called "immediate early gene" that is turned on when neurons are excited. The switching on of the c-FOS gene can therefore be used as an indication of neuronal activation.

A map of the c-FOS expression patterns during flight vs. freezing revealed that mice displaying freezing behavior had neural activity in different regions of the brain than those that fled. Some of these regions were previously known to inhibit each other, providing a possible explanation for the apparent competition between flight and freezing observed in the intact animal.

Anderson notes that more work needs to be done to pin down where and how anxiety modifies defensive behavior. "This system may also provide a useful model for understanding the neural substrates of human fear disorders, like panic and anxiety," says Anderson, "as well as provide a model for developing drugs to treat them." □ —*MW*

More than 150 participants from across the country met June 27–28 at Caltech for "Women in Astronomy II," cosponsored by the American Astronomical Society as a follow-up to the first meeting in 1992, which endorsed a broad range of goals calling for improvements in opportunities and working environments for women in the field. Although gender equity in astronomy remains a problem, the numbers are improving, it was announced at the conference. Women now earn 22 percent of PhDs in astronomy and hold 14 percent of faculty positions. Most hopeful were the numbers for younger astronomers: in the 23–28 age bracket, nearly 40 percent were women, as well as almost 60 percent of those between 21 and 23.