

Slower than a Speeding Bullet

Lene Hau gives the inside scoop on slowing light to 38 mph

interview by Katrina Garcia

Dr. Lene Hau of the Rowland Institute was recently in the national spotlight for slowing the speed of light by a factor of 20 million. Here, in an interview with JUS, she explains her research, talks about the ups and downs of the scientific endeavor, and offers her advice to aspiring scientists.

Q: Please explain how you slowed down light.

A: When you send light into glass—glass has a refractive index of 1.5—a vacuum has 1, sort of a reference point, right? That means, since the refractive index of glass is a little bit larger than 1.5, it means that light will slow down when it goes in there, but that factor of 1.5, so it slows down 50 percent. We slow it down [by a factor of] 20 million. To do that, we need a much more subtle effect, a much more interesting effect. And it's really a quantum mechanical effect.

(Dr. Hau goes on to explain the procedure that elicits this effect.)

In the lab we have a fantastic atom refrigerator that allows us to get some really, really cold [sodium] atoms. First, we make what is called an optical molasses, a really viscous medium set up by three pairs of counter-propagating laser beams, two just a little bit below the atomic resonance frequency. In this viscous medium we cool the atoms to a millionth of a degree above absolute zero. At that point we turn all the lasers off and then we turn on a hefty electromagnet. We have designed our own special electromagnet, called a 4-D magnet. Now once we capture these atoms in this electromagnet we can use the fact that [sodium] atoms have a little magnetic dipole moment. We can use this little magnetic dipole moment to trap [the atoms in a changing magnetic field] so that we can capture this cloud of atoms. Then we start cooling with what is called evaporative cooling. This part of the process is done in complete darkness—it is totally dark in the lab.

Evaporative cooling works similar to the way you cool a cup of coffee. The hot atoms will leave and the rest will collide and it will equilibrate at a lower temperature and then the next set of hot atoms will leave and so forth. You get a colder and colder cloud with fewer and fewer atoms



Dr. Hau looks over the apparatus used to slow light.

but they get colder and colder and denser and denser also, if it is done right. But we actually don't wait for the hot atoms to leave—we kick them out. You simply apply a radio frequency, and if you tune the frequency just right, you can get the magnets of the hottest atoms to flip their direction all of a sudden. If you flip them the wrong direction—south and north poles will attract each other and south and south will repel each other—all of a sudden [they get kicked] out of the magnet[ic field]. And then the rest of the atoms—the cold ones—are still trapped, and will collide and re-equilibrate at a lower temperature because you got rid of the hot ones. And then you sweep to a little lower frequency and then you kick out the next set of hot atoms. That's evaporative cooling. Then if we sweep that radio frequency far enough down we get temperatures of just a few billionths of a degree above absolute zero, or nanokelvin. And if we cool down even further

we get a very odd state of matter called a Bose-Einstein condensate.

You can't use old Newtonian mechanics to describe the internal structures of atoms. We know that very well now; we have to use quantum mechanics, which was developed in this century. When atoms get really cold you also have to describe the motion of the whole atom, the whole translation of motion, not just the internal structure, with quantum mechanics. You can't think of them as billiard balls and use old Newtonian mechanics. So each atom has a wavelength associated with it, the de Broglie wavelength. [When this wavelength] becomes comparable to the interparticle distance then you can imagine how these atoms will lock together and behave sort of like one super-atom in a totally correlated fashion. That is the Bose-Einstein condensate. Once we have done that [created the Bose-Einstein condensate], then we're ready to slow the light down.

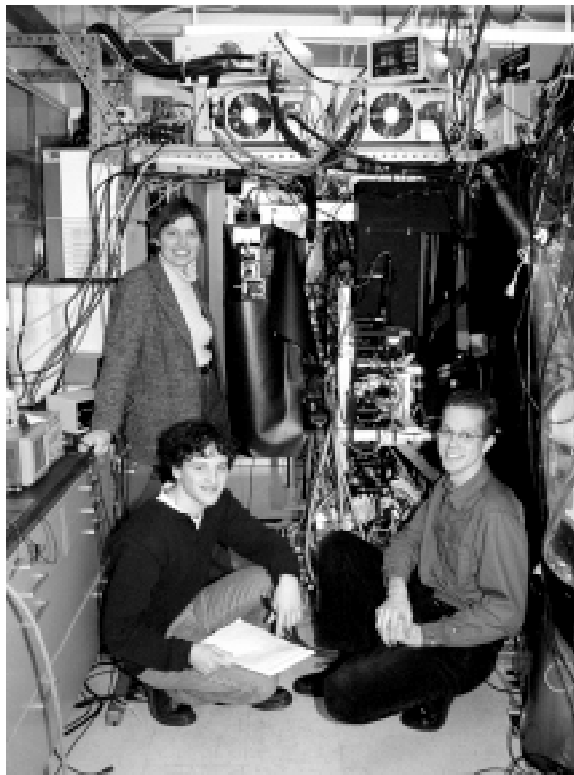
So now we have 2 to 10 million atoms in our atom cloud, cigar shaped, typically 100 to 300 microns long and maybe 10 to 30 microns wide. Then we send in the laser beam that will illuminate this atom cloud from the side. The atoms and the laser field will mix, entangle, and create a real entangled state for this system.

By choosing the right intensity and the right frequency for that coupling laser field, we can tune the optical properties of this mixed medium to do exactly what we want. With the right combination of cold atoms and that laser field with the right intensity and frequency, we send the light particles in along the long cigar direction of the cloud and then we simply measure how long it takes these light particles to go through our medium.

[Our measurements show that we] slow light down by a factor of 20 million. When you have a light pulse in vacuum—our light pulses are typically, say, two-and-a-half microseconds long in time—and if you stand from the side and look at it from space, that would be 750 meters long. And then when it goes inside our medium, it basically compresses by that same factor of 20 million, so it becomes a little, localized 40-micron long light pulse that

is moving through our condensate. So, we create a little piece of condensate moving through our bigger condensate, and it's moving very slowly—right now, 17 meters per second.

It's not because—and many people misunderstand this—it's not that we're creating a humongously big refractive index in our medium. Our refractive index, curiously enough, is actually 1. It's exactly the same as it is in vacuum. At resonance, it's 1. We use our light-pulse on resonance, so it's tuned to a resonance frequency in the atom. Our refractive index, and that's the important part, has a very steep variation. It varies very rapidly around resonance. If you go a little bit away from resonance, the refractive index will not be 1 any more. There will be a very steep variation as a function of frequency. That's what we're using. It's that steep variation of the refractive index that we set up in our medium.



Lene Hau and team at home in the lab

Q: What was your first significant scientific experience that made you want to go into science?

A: I always loved math and that was sort of my first exposure to something that could be related to physics. And I really liked that from first grade and onwards. And then we

started to have physics in junior high. That physics teaching, I would say, was pretty bad. But then I entered high school and that's a very special thing in Denmark. High school teachers have university degrees — they get Master's degrees. All of a sudden we got math, and in particular physics, taught at a very high level. In particular it was my encounter with the Bohr model that struck me as absolutely fascinating. Bohr, a Danish physicist, created a new way of thinking with a paper back in 1913 where he talked about how we should think about the atom as having discrete energy levels—not a continuum. He sort of kicked off this whole new way of thinking about the world in terms of quantum mechanics, a way to think differently about how atomic systems behave differently than our normal macroscopic world, and how we have to use quantum mechanics and these discrete energy levels

[when describing them]. That was just absolutely fascinating. And then, of course I chose to go into mathematics and physics.

In Denmark, at least at the time when I took my degree, you go to the university and you pick two topics [and that is all you study]. I picked mathematics and physics. And then you decide after approximately four years if you want to get a Master's in physics or a Master's in mathematics and whichever you don't choose you then have a Bachelor's in. I thought that I wanted to do mathematics until I had quantum mechanics. That changed my mind. Then, I wanted to do physics. And then I went on and got a Master's in physics.

Q: Do you have any advice for those starting out in science? In terms of people who are undergraduates now that want to get into experimental research, what are some good things to know?

A: I'm very, very curious. That's factor number one. And I also like competition, and I like to win. (laughter). But doing physics is not a 9-to-5 job. For example, when we were running this experiment we typically had 27 hour runs. You know, we line it up and tune it, and everything has to be just perfect, and then we go at it and go at it and go at it and maybe 27 hours later we think, "Okay, now we have what we need." Either it didn't work, or it worked and it's fantastic. We started the slow light project in the fall of '97. Of course, that was after we had spent years building up the laser cooling setup and the evaporative cooling setup.

Of course, when you have a plan, it doesn't work. Then you have to think, gee, why didn't it work? You've worked on this 27 hours, you figure out, hmm, it doesn't work. Something is wrong here. And you go home, and it's not like your brain starts to relax. It's with you all the time, and you think about it. You take a shower in the morning—showers are very good for having ideas for some reason—or you wake up in the middle of the night and, click, something just clicks and you realize something that maybe was wrong, or you have an idea. So it's with you all of the time, and so it's something that you really have to burn for. And it should be fun or you can't drive yourself to do this kind of stuff and work really hard. I've worked a hundred hours a week or something like that. You can't do that if you don't love it, so you really have to love it, and I think you have to be driven by curiosity.

Q: What are the rewards for this hard work? Do you remember the first time the experiment worked, and what that felt like?

A: Oh yeah! That was absolutely, totally fantastic, because we started to see our first sign that we had slowed the light down in the spring of '98. We started to see [that the light] was delayed a little bit...wow! And then, of course, you're afraid. Gee, what if somehow somebody moved the knob; it's an artifact. It could be all kinds of things. And then you want to do a test, for example, by turning that extra laser off, because if we turn that off the system gets totally opaque. We can't get any light, so that was certainly the first test we wanted to do to make sure that if we turn that off, that we would get no light. So, we're just sitting there, waiting for one minute, and [wondering], gee, are we going to see a pulse? Is it an artifact? And then it shows up, it's totally flat, there's no light. Then you just jump up in the air and run around yelling in the lab because it's totally exciting; that was actually really fantastic.

Q: Finally, I wanted to ask you also about the place of women in science. Has that changed, and has it ever been a factor in what you've done?

A: Why am I here as a woman? [I am] rather unusual, because, to begin with, you have few women in science, and the sort of hierarchy in terms of Ph.D.'s, Post-docs, researchers, you get fewer and fewer and fewer women for each step you take. And why am I here? I think if I should point to one single factor, it's the support of my parents. You know, women aren't often expected to go out and be successful in their careers, whereas, if they have a brother, the brother is supposed to go out and be successful. My parents had exactly the same expectation values for me and my brother. And my brother is very successful but in a totally different field—he's in advertising. I have a very close relationship with my brother, and I think we have some sort of—we have never really said, "Okay, we're competing"—but I think we have some really friendly competition. And he made some really great progress in his career, and I said, gee, wow, he's doing really well. Two weeks later, I got the condensate (laughter). So, I think parents' expectations for women, for their daughters, are really, really important. But also I was lucky growing up in elementary school. My teachers, my math teacher in particular, he was pushing me, and had expectations for me no different than he had for the guys. So that kind of thing early on, in terms of what you perceive you should expect from yourself, I think is really important.

The Origins of HIV

Contention surrounds the recent discovery of three simian viruses homologous to HIV

by Joanna Chan

Despite the intense investigation surrounding the AIDS epidemic, only recently have scientists identified the common subspecies of chimpanzee *Pan troglodytes troglodytes* as a likely candidate for the origin of Human Immunodeficiency Virus Type 1. Scientists have already identified the sooty mangabey *Cercocebus atys* as the primate reservoir of HIV-2, common in regions of Africa and Asia, but much contention has surrounded the possibility that chimpanzees spread HIV-1 to humans. While the lack of evidence has deterred scientists from drawing conclusions in the past, a team of investigators led by Dr. Beatrice Hahn of the University of Alabama at Birmingham recently published findings in the February 4 issue of *Nature* identifying *P. troglodytes troglodytes* as the primary reservoir for HIV-1 based on strong genetic and molecular evidence.

In a recent press release, Dr. Anthony S. Fauci, director of the National Institute of Allergy and Infectious Disease, commented on the significance of the finding by noting: “We now have chimpanzee isolates of Simian Immunodeficiency Virus [SIVcpz] that have been shown by careful molecular analysis to be closely related to HIV-1. This may allow us to . . . study infected chimpanzees in the wild to find out why these animals don’t get sick, information that may help us better protect humans from developing AIDS.” HIV-1 includes the subgroup M responsible for the global pandemic with present estimates of 35 million human carriers since its first transmission approximately 50 years ago. The other, less prevalent N and O varieties are endemic to western equatorial Africa and probably arose from two separate introductions of SIVcpz to the human population.

The results from the study performed by Hahn and her colleagues indicate that the DNA sequences of three chimpanzee viruses bear close relation to the sequence of HIV. According to molecular analysis, the chimpanzee viruses share as much genetic similarity to HIV-1 as they do to each other. This minor genetic change could have easily resulted from a mutation during virus transmission, allowing HIV to affect humans. The three chimpanzee viruses and HIV-1 share a common gene, called *vpu*, which is absent in the other monkey-infecting viruses that attack the immune system in the same way as AIDS. Hahn isolated the virus from two specimens taken from living animals and a third from a frozen sample extracted from a 26-year-old chimpanzee named Marilyn housed at a U.S. Air



Recent findings by Dr. Beatrice Hahn point to chimpanzees as the source of the HIV virus.

Force primate center in New Mexico. In all three cases, the chimpanzee carriers failed to express the symptoms of AIDS, suggesting that they may possess antibodies against the virus. Such antibodies could be isolated and adapted for human use, especially since chimpanzees are over 98 percent genetically identical to humans. Further study of the resistance of chimpanzees may help scientists to develop new HIV drugs and perhaps even a vaccine.

Although the research has received much press coverage, including an article featured in the *New York Times*, contention continues to surround the claim that chimpanzees are the source of HIV-1. In a telephone interview with JUS, Dr. Hahn cited the most common criticism put forth by skeptics that the samples thus far have not come from wild chimpanzee populations, and that confirmation by analysis of animals living in their natural habitat is required. Her response: “Stay tuned.” In terms of future studies, Dr. Hahn suggests, “First of all, we would like to look at the wild living chimpanzees and assess to what extent the virus is prevalent in their populations. Then, we would more rationally be able to address the risk of additional transmissions of SIVcpz to humans.” The possibility of any future study, however, is contingent upon the survival of the endangered chimpanzee. More than ever, the preservation of wild chimpanzee populations by enforcing anti-poaching laws is crucial, for these animals may hold the secrets to the cure for AIDS.

Cracking the Code

The race between the public and private sectors to sequence the human genome

by Elizabeth Kass

Ten years ago, the prospect of creating a complete database of the human genome seemed little more than the stuff of science fiction. No one would have believed that in 1999, as the world teetered on the brink of the new millennium, the scientific community would be on a threshold of its own, proudly entering an era where the dream of a universal genetic database is fast becoming a reality. Scientists have been hard at work for nearly a decade, attempting to realize this dream. At long last, the government-funded Human Genome Project is now entering its final phases in hopes that the complete sequence that forms the blueprint for all human beings may be available as early as 2003.

The Human Genome Project is a collaborative international program aiming to construct a detailed map localizing the estimated 50,000 to 100,000 genes in the human genome. In achieving this goal, researchers will be able to address at the source many of the biological questions that have remained unanswered simply because the proper tools were not available.

Although the idea behind the project actually came about in the mid 1980s, it officially began in the United States in 1990 under the sponsorship of the U.S. Department of Energy (DOE) and the National Institutes of Health (NIH). Initially, the target date for completion of the project was the year 2005. However, the proposed schedule was given a strong challenge in May of 1998 when Dr. J. Craig Venter of the Institute for Genomic Research in Rockville, Maryland. Venter announced that he was joining forces with the Perkin-Elmer company (a major manufacturer of DNA sequencing machines) to form Celera, a company whose goal was to finish sequencing the human genome by 2001, four years in advance of the government's initial target date for completion.

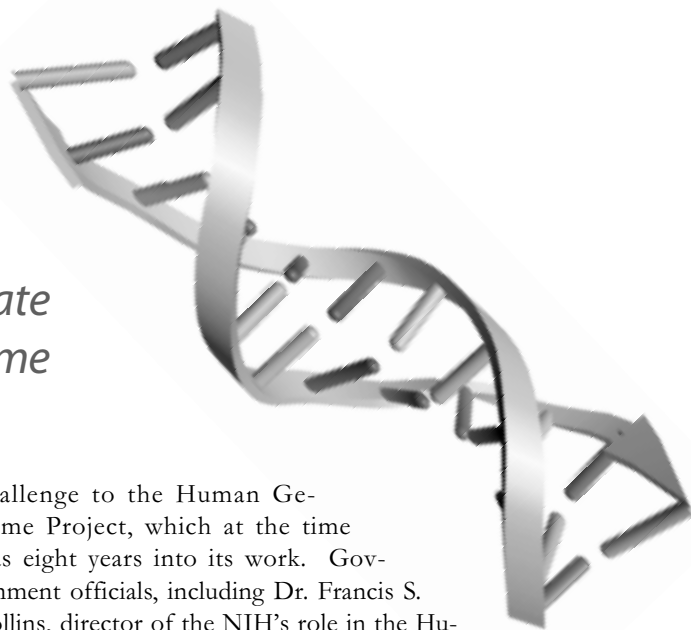
While a sense of skepticism prevailed among the academic science community as to the accuracy of Venter's methods, Venter's previous success in elucidating the genomes of bacteria meant that his claim posed a serious

challenge to the Human Genome Project, which at the time was eight years into its work. Government officials, including Dr. Francis S. Collins, director of the NIH's role in the Human Genome Project, were quick to defend the money that has been spent on the government effort and insist that the seemingly competitive public and private ventures should not be seen as a race.

Nevertheless since the advent of Celera, the goals of the government's program have been seriously updated. In the October 23, 1998 issue of *Science*, Dr. Collins and members of the DOE and NIH planning groups declared their new goals for the U.S. Human Genome Project: 1998-2003. According to the authors, the project had successfully completed all the major goals in its five year plan covering 1993-1998, allowing the projected date of completion to be moved up two years. In addition to the change in the completion date, the group also planned to have a "working draft" of the sequence completed by the end of 2001, about the same time Celera plans to finish its work.

By moving up the planned completion date for the human genome sequence, the National Human Genome Research Institute has clearly staked its claim on a project in which it has invested nearly three billion dollars. Celera, however, remains unfazed by the government's shift in strategy and is going ahead with its own goals. But will the challenge from the private sector compromise the original aim of the project to create an international databank of genetic information that can be harnessed to improve the lives of the general public?

For now, the outlook remains hopeful. Whichever group ultimately wins out, the complete human genome sequence is within reach. The next five years promise to revolutionize the study of the genetic mechanisms that provide the basis for human life, offering the potential to improve all of our lives.



The Face of Undergraduate Research

An interview with Kirk Doran, a college freshman researching protein folding

by Frank Farach

Although assembling proteins from their amino acid sequences may seem a far cry from playing with childhood building blocks, Kirk Doran believes that his research interests have been a part of him for as long as he can remember. Now a college freshman involved in protein folding research, Doran explains that his “interest in protein



Kirk Doran

folding stems from a more basic interest in creating and analyzing things.” On page 35 of this issue, Doran details his development of a computer algorithm to investigate one of the hottest problems in biophysical chemistry: how a protein’s specific three-dimensional structure arises from its constituent amino acids.

Doran’s research began in 1997 with an application to the Research Science Institute (RSI), an MIT-based organization that operates a summer research program for high school juniors and seniors. He indicated on his application that he would like to work on protein folding, and not only was he given his first choice research area, but he was also given the opportunity to work with a world-renowned expert on protein folding, Harvard Professor Eugene Shakhnovich.

Working in Shakhnovich’s laboratory, while time-consuming and intense, was very stimulating, due in part to the challenges and responsibilities he was given in the lab. “It was an inspiring thing, to be given the freedom to do something original and yet be part of a long-term research program,” said Doran. As the new face in the lab, he had to overcome barriers common to many students working in a lab for the first time. “It can be a little intimidating to work in an environment, indeed in the same room, with much more experienced researchers. As someone with essentially no experience, I guess I was at the bottom of the hierarchy.” However, there was at least one advantage to his inexperience: his errors were easily forgiven.

Doran worked all day, every day, for six weeks straight, and although he received excellent technical assistance at the lab, his ambitious research plan required that he write

some three thousand lines of C++ programming code. What kept him going? “Once you have been working on a computer program for so long, it becomes like an old friend. It’s something you’ve got to get fixed and working,” he explains.

Before approaching Shakhnovich with a proposal, he did extensive background research for his project. “Looking back, [doing background research] was the best thing I could have done. Protein folding is an area in which there is so much to do, you have to find your own niche,” he affirms. Indeed, protein folding is a broad and fast moving research field: a Medline® search of the words “protein folding” in scientific journals within the last year returned nearly 1,500 abstracts. Doran’s knack for computer programming and his interest in biophysics and chemistry made a computational approach to the protein folding conundrum look particularly appealing.

Doran is certainly no stranger to science research. He has presented research at the International Science and Engineering Fair, the Junior Science and Humanities Symposium, and the Intel (formerly Westinghouse) Science Talent Search, where he was one of forty finalists. Now a freshman at Harvard, Doran is concentrating on his classes, which he hopes will prepare him intellectually for further research. He aspires to pursue graduate studies in biophysics or to work as a research assistant following graduation. Doran says there are at least two career tracks that are not in his future: “I am not interested in medical or law school,” he said adamantly.

While not busy studying for classes, Doran likes to play and listen to music. He plays cello for a chamber music orchestra, enjoys playing piano, and is currently enrolled in a course on chamber music, where he is studying the works of his favorite composers, Beethoven, Bach, and Brahms. Currently a physics major, Doran is considering adding music as a secondary field so that he can pursue this passion.

Because doing research for the first time can seem a daunting undertaking, Doran left JUS with his own advice for high school and undergraduate students interested in pursuing research. “Find an area of research that you’re interested in and that will take a finite amount of time. Don’t make your research plan open-ended. You should do lots of background research on your area of interest before talking to a mentor.” Apparently, Doran has taken his own advice and has succeeded as a result.