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A Different Light

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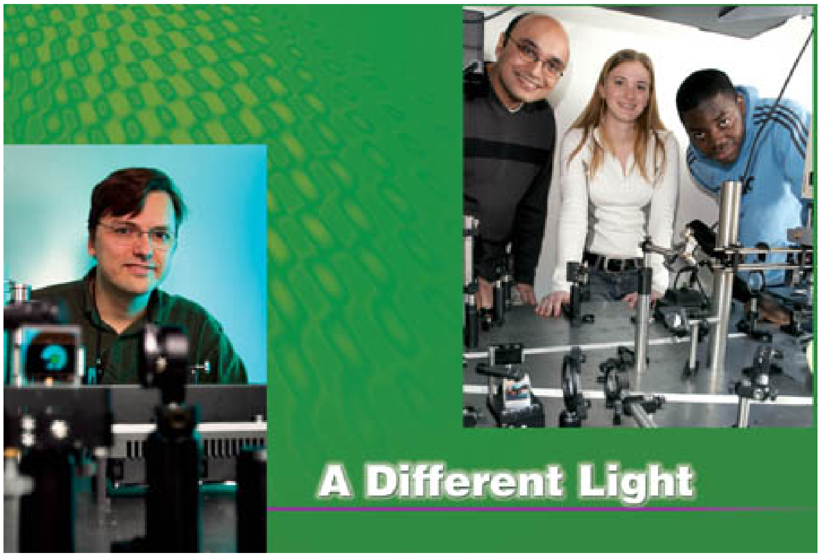
Physics professor Gabriel Spalding and his students use lasers and holographs to move matter in the microscopic world.



By Tim Obermiller

Call it an *extreme* visual metaphor. Physics students used a hose borrowed from the local fire department to blast a stream of water straight up into the air. Upon this stream, they levitated an assortment of objects, from plastic Easter eggs to bowling balls.

This curious demonstration was orchestrated by Gabriel Spalding, an associate physics professor at Illinois Wesleyan, to make a point about the nature of light and its ability to move matter.

Spalding used the stream-of-water analogy to get across a concept that seems strange to most of us. You can't budge a tennis ball with a flashlight beam, so how can light have force? In fact, light can move and levitate objects, just like the water from the fire hose. It just so happens that the objects it can propel are very, very small.

In the microscopic world of molecules and cells, where much of science's most important work is done, the idea of using light to manipulate matter has captured the imaginations of physicists, biologists, and chemists around the world. Spalding has worked with many of these scientists, as well as students at IWU, in the emerging field of optical micromanipulation. Their goal is to transform the raw power that light yields in the microscopic world into a sophisticated "optical toolkit," as Spalding describes it, useful in the most intricate and delicate kinds of research.

With tools from this kit, researchers are learning how to use light to "localize, guide, spin, and even optically organize matter on length scales that are of enormous technological importance," according to Spalding.

A measure of the growing interest in this field can be seen in the number of abstracts Spalding has received for an upcoming conference on optical micro-manipulation that will convene in Denver this August. Spalding and Kishan Dholakia from St. Andrews University in Scotland are chairing the first-of-its-kind conference. More than 100 abstracts have been submitted so far, Spalding says, from researchers in Asia, Australia, and Europe, as well as North America. He's currently seeking travel funding for IWU students involved in this research, so they can attend as well.

Spalding hopes the conference will emphasize a mood of congeniality in the midst of what the journal *Nature Materials* has described as a "global scientific race" to invent technologies that may "revolutionize the fields of chemistry and biotechnology in the same way that the silicon microchip has revolutionized electronics."

When the stakes are running that high, scientists can begin to regard their colleagues more as competitors. However, Spalding believes this hasn't and won't be the focus of most of the researchers he knows, whom he says are driven not by a desire for fame or promotion, but by scientific curiosity, pure and simple.

For his part, Spalding says he entered the field for a very practical reason: to provide his students with a subject that they could comfortably dig into and get productive results.

Spalding earned a Ph.D. in applied physics at Harvard University, where his thesis was on high-temperature superconductors. When he joined IWU's faculty in 1996, he decided not to pursue his Ph.D. research. The background in quantum mechanics that it required was beyond the grasp of most beginning undergraduates, he explains, and he wanted a lab project that could involve students in "their first semester, their first year of college."

Spalding's group uses a complex optical array (shown above). The green line is an illustration of the laser beam's path — the actual beam is not visible except at high

Was it hard to leave behind his previous work?

intensity.

"Well, I *love* superconductivity. Absolutely love it. I think it's beautiful. So, yes, it was difficult. But the world is full of fascinating things, so it was time to look around and find something that seemed right."

To find the right project, Spalding talked to his students. Several had done off-campus internships. He asked them if that research was worth continuing at IWU. Most said yes, including Nathan Mueggenburg '98, who had interned at the University of Chicago for a group working with optical tweezers.

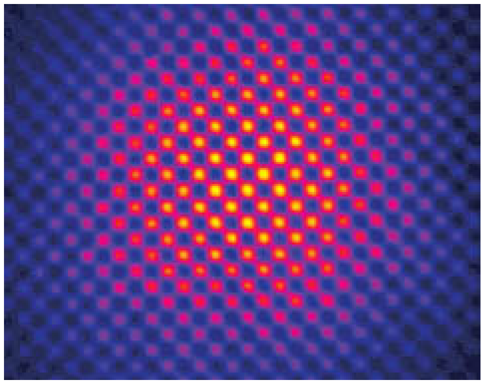
In 1986, Arthur Ashkin invented the first optical tweezers at AT&T Bell Labs by using tightly focused laser beams to trap and hold individual cells. (Ashkin, who is now retired, accepted Spalding's invitation to speak about his pioneering work at the Denver conference.) "Right away," Spalding says of Ashkin, "he recognized that this technology had enormous potential."

Early on, optical tweezers helped do important science. The 2001 Nobel Prize in physics, for example, was awarded to researchers who used technologies that sprang from Ashkin's early work to create the first Bose-Einstein condensates — the so-called fifth state of matter — in the lab. As he learned more about optical tweezers and their potential, Spalding found the student project he'd been looking for.

University of Chicago physicist David Grier invited Spalding and his IWU students Matthew Dearing '00 and Steven Sheets '01 to help with ongoing optical micromanipulation studies there. From that work emerged a paper, published in *Review of Scientific Instruments* in 2001, that made physicists worldwide take notice.

"The paper was about how to design your own computer generated holographic optical tweezers," says Spalding. Although the idea of using holograms with optical tweezers had been around a few years, previous attempts used only commercially preexistent holograms. Instead, Spalding and his colleagues described how to make holograms specifically for optical tweezer research. "We explained how to calculate it, how to generate it. It was a full recipe, and that had a lot of impact," says Spalding. "It empowered other groups to go and do things."

Those groups should have much to keep them busy in the coming years. Using holograms hugely increases potential applications of optical tweezers, says Spalding. That's because of the extra information about light waves that holograms contain. Regular photos pick up only the amplitude of those waves. But light waves also carry what scientists call the phase, which holds information about "time lags" due to, for example, the different distances traveled by the light striking different parts of an object. By incorporating phase information, a hologram can depict an object in three dimensions.



An optical lattice *(Image provided by Gabe Spalding).*

The holograms that Spalding and his students make in their lab don’t depict actual objects. Instead, they are mathematically designed on computers and implemented using a liquid crystal display similar to those found on computer laptops. With these complex, custom-made holograms, researchers can do once-impossible tasks such as manipulating hundreds of particles with a single light source. Holograms can also be programmed to “animate” matter. Like living movies, these holographic sequences can organize particles into precise patterns of motion choreographed by researchers. The science has been compared to *Star Trek’s* holodeck, but on a microscopic scale.

Collaborating with researchers at other universities, Spalding and his students gained expertise not only in creating computer-generated holograms but also in analyzing data produced by holographic optical tweezers. That experience earned Spalding invitations to work on several research projects when he took a sabbatical during the 2002-03 school year. One seemed like an especially good match: the Optical Trapping Group at the University of St. Andrews in Scotland.

A stumbling block was St. Andrews’ faraway location. Spalding had applied for travel grants which were eventually approved, but not before he and his family (wife Brenda and son Cooper) had to make a final decision to move to Scotland. “We were going to have to sell our house, because we weren’t sure we would have the money to do it, and my wife insisted that we go there, anyway,” Spalding says with a laugh. It’s funny only in retrospect — at the time he felt “terrified” but was convinced when Brenda told him, “This is the right thing. You said this is the best place for you to go, you should go there.”

The oldest university in Scotland, St. Andrews is located about 50 miles from Edinburgh. The Spaldings settled nine miles away, near the rustic town of Crail along the North Sea. The charming location held appeal, but even more attractive to Spalding was the science being done at the university. He particularly admired the optical trapping group’s expertise in creating “novel types of light beams.” For his part, Spalding brought to Scotland a working knowledge of calculating holograms and devices known as spatial light modulators.

Kishan Dholakia says Spalding's contribution to the group "was absolutely key and central. Many experiments would not have happened without his input. And it's an ongoing relationship."

Above, Spalding's wife Brenda and son Cooper accompanied him to St. Andrews University in Scotland.

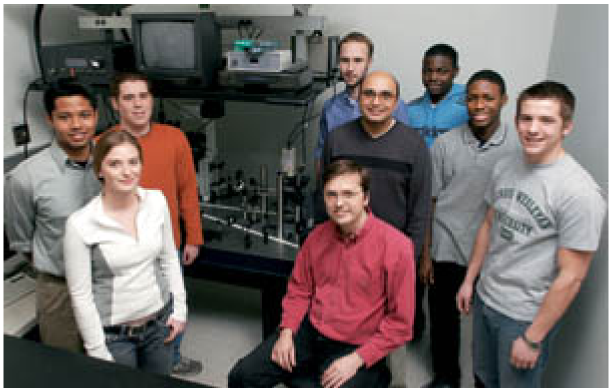
The collaboration's biggest success so far is the creation of an optical sorter: a grid of light beams that creates a powerful new way to separate cells and other microscopic particles. Instead of using a focused laser beam to hold or trap a particle, Spalding and his St. Andrews partners used many laser beams (holographically generated out of one input) to create a 3-D optical interference pattern called an "optical lattice," or grid. Microscopic protein capsules, which are used in drug delivery and biomedicine, were pumped through this lattice. By adjusting both the rate at which the particles flowed and the lattice's parameters, the St. Andrews group could perform size selection of the capsules with high throughput and 96 percent efficiency.

"We have found this system to be simpler, more sterile, and far less expensive than existing techniques for sorting microscopic materials," Spalding says. "It is also extremely accurate and has potential for biomedical and other commercial applications." For example, the St. Andrews group is trying to use optical sorters to distinguish between cancerous and non-cancerous cells. Such sorters could also help fulfill the long-held hope of developing "lab-on-a-chip" systems that would essentially compress an entire chemistry lab to the size of a Palm Pilot. "We're developing the pumps, the valves, the mixers, the sorters (for these lab-on-a-chip systems) — all done optically," Spalding says.

Key to the group's success in working with biological materials was Michael McDonald, a post-doctoral fellow at St. Andrews who "has an amazing knowledge of both optics and biology," says Spalding. "He was certainly the lead in putting this optical (sorting) system together."

Bringing together talented biologists, chemists, and physicists on such projects will open many new avenues of research, says Spalding. He hopes to recruit more biology and chemistry majors to collaborate with his physics students. Part of what makes this research so appealing, says Spalding, is that it combines so many different scientific areas. "The traditional disciplinary borders really don't apply. And we benefit enormously by just talking to one another and working together. So I'm really excited about doing those kinds of collaborations."

At the same time, he recognizes that "I'm not a biologist; I *can't* do the clinical things, I *can't* implement something at a hospital. But I can do something that I can hand off, not only to those people but to people wanting to do optical computing, people wanting to do things that will help get rid of the bottleneck on the Internet — there are direct applications of what we're doing to each of those things."



Participants in the Illinois Wesleyan optical micromanipulation research group include (from left): Prakrit Jena, Andrea Bulkley, Eric Macaulay, IWU Professor Gabriel Spalding (seated), Jason Forster (at rear), Professor Kishan Dholakia (visiting from St. Andrews University in Scotland), Debo Olaosebikan, Olukayode Karunwi, and Brian Simonds.

For his part, Spalding plans to remain involved in basic research, and leave development of specific applications to others. "I think of science and technology as like a tree. The applications are up at the leaves and the fruit — and to be really productive, I want to be working down at the level of making new roots." He points out that the St. Andrews group wasn't planning to make an optical sorter; they started out with much more general questions about three-dimensional optics. "It was just curiosity driven," he says, "and for me that's the fun of it."

It's an open approach to doing science that his students say they appreciate. "He doesn't tell you what to do, and that makes it exciting" says Andrea Bulkley, a physics student who set up an intricate optical-tweezers array in Spalding's lab. "He encourages you to let your curiosity guide you and soon you find yourself on some surprising paths."

Spalding says that he enjoys working with undergraduates in a liberal arts setting because their curiosity is fully intact and ready to be engaged. "To be honest, I probably learn as much from them as they do from me."

In finding new projects for him and his students to tackle, Spalding says his main criteria will continue to be: "Is it fun?" That may sound frivolous to some, he acknowledges. But given the results of their optical research so far, keeping it *light* seems like a scientific approach worth continuing in Professor Spalding's busy lab.