The Science of Small

On the nanoscale, tiny particles offer enormous potential to revolutionize the way we live.

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BY SHELBI THOMAS

Amanda Haes watched helplessly as dementia robbed her once strong and independent grandfather of his memory, personality, and autonomy. A chemistry graduate student at Northwestern University at the time, she coped by learning all she could about the disease.

At a lecture several years ago, Haes listened to doctors explain that they needed a better method of distinguishing whether a patient was suffering from dementia or Alzheimer's in order to tailor their approach for treating the disease. That's when Haes' mood changed from helpless to hopeful. Excitedly, she realized that perhaps she possessed an answer to this medical quandary—thanks to her work in the relatively new field of nanoscience.

Haes now serves as an associate chemistry professor and associate director of the UI's Nanoscience and Nanotechnology Institute (NNI), which helps faculty from areas such as chemistry, physics, biology, engineering, medicine, dentistry, pharmacy, and environmental science explore this new frontier.

Unknown until about 30 years ago, nanoscience and nanotechnology involve the creation and manipulation of particles almost at the atomic level. Atoms are the building blocks of every kind of matter in the universe, and nanoscience enables researchers to begin their own construction projects at the molecular levels. For a field that focuses on the incredibly small—a million nanoparticles can fit on the head of a pin—nanotechnology holds immense promise, with the potential to yield cheaper energy, faster computers, "greener" ways to protect the environment, and improved medical devices, procedures, and drugs.

Haes' research aims to see if silver or gold nanoparticles can be used to hunt down previously undetectable chemical biomarkers for diseases in patients' blood samples. These metals don't behave the same way on the nanolevel as they do in the everyday world, so Haes is developing nanoparticles that can interact with the molecules of chemicals associated with various diseases and then change color to indicate the chemicals' presence. In theory, such biomarker detectors could lead to earlier diagnosis and better treatment for people suffering from chronic conditions like dementia, cystic fibrosis, heart disease, and cancer.

Nanoscience's novel and experimental nature makes it controversial among people who fear its untested, long-term effects on human health and the environment (see sidebar). But, many experts endorse the sentiments of U.S. Senator Ron Wyden, who said at the first nanotechnology Senate hearings in 2002, "The nanotechnology revolution has the potential to change

America on a scale equal to, if not greater than, the computer revolution."

Although they sound futuristic, nanoparticles have always existed in nature and throughout human history. They're present in substances like sea spray and volcanic ash, in human hemoglobin and DNA. Roman and medieval artists didn't know nanoparticles existed, but they nonetheless managed to inadvertently produce them by applying heat and other methods to gold, silver, and copper—resulting in stained glass windows that glow and dichroic glass vessels that switch from opaque to translucent in the light.

Until the development of powerful electron microscopes in the 1980s, such nanoparticles remained invisible. When they gained access to this hidden universe, scientists must have felt like Alice tumbling down a rabbit hole into a strange, topsy-turvy realm where normal rules no longer apply.

The nano realm is sandwiched between the regular-sized universe that's ruled by Newtonian laws of physics and the atomic world governed by quantum mechanics. In this middle realm, size is critical. Depending on its size, the same material can exhibit different physical, chemical, mechanical, and optical properties—like color, melting point, electrical conductivity, and magnetic permeability. So, nanoparticles of gold can appear either red or purple and melt at different temperatures. (In an interview with the *Daily Iowan*, NNI founder and co-director **Vicki Grassian** once joked that Herky on the nanoscale would appear red instead of his usual golden hue.)

By adjusting the size and shape of particles, scientists can "fine-tune" materials, enhancing certain properties to meet distinct needs—as in Haes' experiments using nanometals to change color in response to certain chemicals associated with diseases. To bring out other properties, researchers can also build and customize unique structures like nanowires, nanotubes, and the comically named "buckyballs" (represented in the photo below). The discovery of these carbon molecules shaped like a soccer ball, which earned Rice University researchers the 1996 Nobel Prize in Chemistry, has been credited with creating the field of nanoscience.

Only a year after its opening in 2006, the NNI helped earn the UI's second-largest research grant ever—$33.8 million from the National Institutes of Health (NIH) to apply laboratory findings towards clinical practice and patient care. Since then, the institute has received tens of millions of dollars in grants from organizations like the NIH, the National Science Foundation (NSF), and the Environmental Protection Agency (EPA) to research the applications and implications of nanotechnology.

Thanks to an NSF grant, Haes is using the light-emitting properties of gold nanorods to monitor and enhance the delivery of anti-cancer drugs. Currently, such drugs that target tumors also harm healthy tissues. Haes uses gold nanorods to analyze the different enzymes in anti-cancer drugs to determine the most effective dosage of the medicine for a particular patient's metabolism, reducing the drugs' harsh side effects through this personalized approach. Her research into drug delivery and targeted therapy can similarly be applied to hormone, asthma, osteoporosis, cystic fibrosis, and Parkinson's disease treatments.

Meanwhile, UI assistant civil and environmental engineering professor **David Cwiertny** studies the

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Nano in Your Life

Nanotechnology isn't only confined to research laboratories. More than 1,500 consumer products made stronger, lighter, or otherwise more effective by the addition of nanomaterials are currently on the market—from sunscreens to computer chips, housing insulation to auto parts.

Silver nanoparticles provide antibacterial properties to keep socks smelling fresh and plastic-wrapped food from spoiling, while carbon nanotubes add strength to tennis rackets and bicycles. Among numerous other applications, manufacturers also use nanotechnology in air-purifiers, dental ceramics, and scratch-resistant eyeglasses.

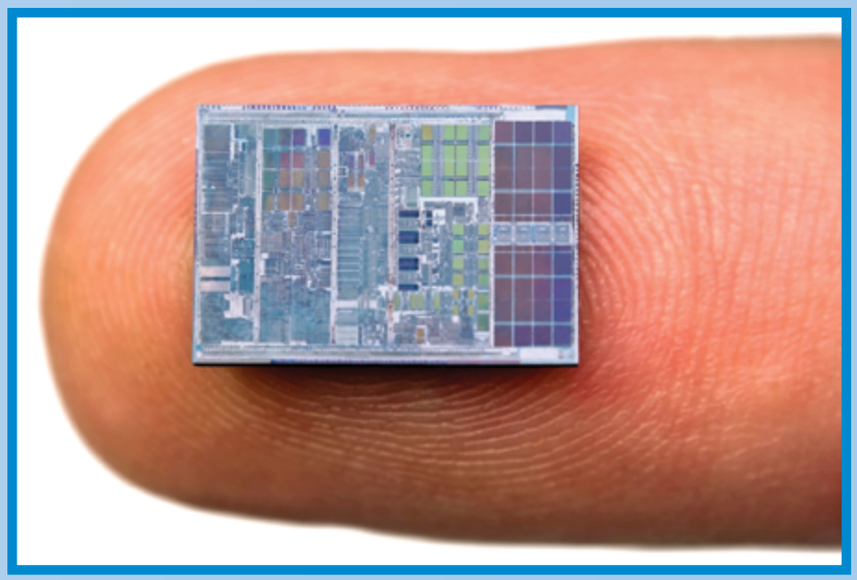
In fact, nanotechnology is big business, bringing in hundreds of billions of dollars in sales and employing some 150,000 U.S. workers. In response to this fast-emerging field, the U.S. Patent Office has registered more than 13,000 patents that include the word "nano," and, in 2000, the federal government launched the National Nanotechnology Initiative—now funded to the tune of $1.8 billion a year—to help scientists from various disciplines share and accelerate their research in this fast-growing field.

Though the Project on Emerging Nanotechnologies maintains a list of products that contain nanoparticles, the commercial use of nanotechnology is largely unregulated. At the UI's Nanoscience and Nanotechnology Institute (NNI), two programs—Nano Tox and Nano Enviro—focus on some of the issues that have made nanoscience controversial.

As nanotechnology is so new, critics fear that its miniscule particles present an enormous, undetermined threat to human health and the environment. Some experts say that nanoparticles could potentially penetrate through human skin, into organs, and even through the barrier that normally protects the brain from toxins in the bloodstream. And while some applications can help remediate contaminated soil and provide cheaper, more-efficient energy sources, little is known about nanoparticles' long-term effects on water supplies, aquatic life, and air quality.

This past November, the National Institute for Occupational Safety and Health (NIOSH) issued new recommendations for controlling worker exposures to engineered nanomaterials during their manufacture and industrial use. Meanwhile, research continues at the UI to ensure that nanoscience safely lives up to its promise.

As NNI co-director Vicki Grassian says, "Ultimately, any technology will only be of real value and use to society if the technology is nontoxic or free of a major environmental concern."



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potential of nanotechnology to improve water treatment and sustain the water supply. Through grants from the NSF, the EPA, and the U.S. Department of Agriculture, Cwiertny investigates the possible use of carbon nanotubes to improve ozone-based water treatment. In reaction to the ozone oxidant, the carbon nanotubes filter out contaminants more effectively than treating water with ozone or filtration alone.

Other UI scientists are working on ultrasensitive nanoparticles to detect, identify, and clean biological and chemical toxins in the air and water, as well as to create more energy-efficient fuel cells, batteries, and solar panels.

"Nanoscience will be foundational in solving some world problems, such as water quality, the environment, and health care," says Grassian. "We worry about sustainability these days, and with nanotechnology, we can make small things do big things with less material."

Many of nanoscience's much-hyped, big-picture possibilities are still in the research and development stage, years from practical applications. But, with nanotechnology set to affect all our lives and make a large impact on our economy, NNI professors are eager to educate people about its current uses and potential. "Ever since we started this institute, we wanted to do it all," says Grassian. "We always had not only research in mind, but also education and outreach."

The primary education and outreach occurs in UI classrooms. Through an NSF grant, NNI professors have developed lab experiments to introduce first-year chemistry students to the world of nanotechnology. For more advanced students, NNI co-director and chemistry professor **Sarah Larsen** runs an undergraduate research program through the NSF, where scholars across the country come to Iowa each summer for 10 weeks of interdisciplinary lab experience in nanoscience. Grassian takes pride in the fact that the NNI is led by women, still a rarity in the field of science. Only the second woman ever to be hired by the UI chemistry department (in January 1990) and the first to go through the full tenure process, Grassian says that the institute inspires female students.

The NNI also supports UI faculty through writing and receiving grants for equipment vital to research on the nanoscale, as well as through symposiums that help push intellectual discourse on nanoscience and technology. Grassian recently became inaugural editor of the Royal Society of Chemistry's *Environmental Science: Nano* journal to further promote research.

To open young people's minds to this marvelous miniature world, NNI professors give STEM (Science, Technology, Engineering, Mathematics) presentations at area schools or on the university campus. When Larsen recently asked a rambunctious group of middle-school students if they'd ever heard of nanoscience, none of them raised their hands. But, sitting around a table with water droppers and spoons coated in a substance called "Magic Sand," they were eager to find out. Larsen invited the 7th-graders to pour water onto the spoons—and then reveled in their amazement as the liquid simply beaded up and rolled off rather than soaking in.

She explained that the sand's surface properties had been altered at the atomic level by an invisible coating of nanoparticles that makes it hydrophobic. Such water-repelling nanoparticles are also found in stain-resistant or waterproof clothing—perhaps in some items that these children wore.

As the youngsters clamored to learn more about nanoscience's mysteries, Larsen marveled at their childlike wonder. To her, nanoscience may be a captivating, life-enhancing chemistry experiment involving molecules and microscopes. But to them, it's pure and simple magic.

More Nano

Nanoscience is such a complex, evolving field that this article can only offer an introduction. Learn more at these websites:

UI Nanoscience and Nanotechnology Institute (*http://nanotech.uiowa.edu*)

National Nanotechnology Initiative (*www.nano.gov*)

Museum of Science (*www.mos.org/nano*)

The Project on Emerging Nanotechnologies (*www.nanotechproject.org*)

"The Strange New World of Nano-science," a 17-minute video on YouTube from Cambridge University (*http://tinyurl.com/puvlzf8*)

Any comments about this article?
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