Profile of Susan N. Coppersmith

Physics ranges from the practical to the abstruse. Susan Coppersmith, a theoretical physicist at the University of Wisconsin, Madison, has applied her talents across this span, from modeling the assembly of mollusk shells to programming quantum computers. Coppersmith was elected to the National Academy of Sciences in 2009, and in her Inaugural Article she describes and models the surprising intersecting lines and folds that appear in compressed monolayers of gold nanoparticles (1).

Coppersmith grew up in Johnstown, PA. Her father was a lawyer and her mother, a housewife and piano teacher. "Not many people in Johnstown went to college," she says. To her, it seemed that most people's ambition was simply to move away.

Coppersmith's schooling required a lot of perseverance; sexism and a lack of appreciation for scientific curiosity were significant obstacles. "I remember in high school a teacher said to me, 'You might be smart for Johnstown, but that doesn't mean anything,'" says Coppersmith. Still, high school science sparked her curiosity. "I was in science class and I asked a question and the teacher said, 'Oh, that's quantum mechanics, that's too hard for you.' I knew I had to go to college if I wanted to learn what quantum mechanics was," she adds.

After graduating from the Massachusetts Institute of Technology in 1978 with a degree in physics, Coppersmith spent a year as a Churchill Scholar at Cambridge University in England studying applied mathematics. At Cambridge University she met her future husband, Robert Blank, who is now on the faculty at the University of Wisconsin-Madison medical school.

Coppersmith enrolled in graduate school at Cornell University (Ithaca, NY) to study physics. "I had trouble at Cornell. I couldn't find an advisor. Fortunately, because I had a scholarship from Bell Telephone Laboratories' Graduate Research Program for Women, which aimed to help women in STEM disciplines, I was able to do my PhD thesis at Bell Labs," she recalls. "Bill Brinkman, who was an executive at Bell Labs for many years and is now at the Department of Energy, helped work it out. I remained a student at Cornell, and David Mermin was willing to take a chance on being a long-distance official faculty advisor. It didn't involve a lot of work, but he still had to go to bat for me. My actual thesis advisor was Daniel Fisher, who was a Bell employee then and who is at Stanford now."

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Although Coppersmith's degree is from Cornell, her PhD work was done at Bell Laboratories in Murray Hill, NJ, on the intersection of condensed matter physics and nonlinear dynamics. Her graduate work was carried out shortly after Mitchell Feigenbaum, a mathematical physicist now at the Rockefeller University, had developed his mathematical description of the period-doubling route to chaos. Feigenbaum's discovery was a key moment for chaos theory, as he found a simple universal relationship called "period doubling" that shows how an ordered system decays into chaos. The discovery made many difficult scientific problems open to analysis. "Universality is a big idea that came out of the theory of phase transitions, examples of which are transitions between a solid and a liquid and between a magnet and an unmagnetized material," Coppersmith explains. Universality means that sometimes knowledge of the microscopic details of a system isn't necessary to make certain quantitative statements about the system. Feigenbaum demonstrated this principle for dynamic systems, which are prescribed using simple dynamic rules. "I was working on a model that could be interpreted as both a condensed matter system and as a dynamical system, and understanding the relationship between the properties relevant to its behavior as a dynamical system and to its behavior as a condensed matter system. It turned out the interpretations were slightly different and there were interesting things to work out." (2)

In the dozen years after finishing her PhD in 1983, Coppersmith held positions at Brookhaven National Laboratories, Bell Laboratories, and Princeton University. She started working on the nonlinear dynamics of some condensed matter systems, and studying how these systems behave when they are subjected to very strong driving. "Peter Littlewood and I collaborated to try to understand how the effects of nonlinear dynamics are manifest in some nonlinear conductors, which I feel laid the groundwork for a lot of interesting work by many people," Coppersmith says (3). "I worked in that area for about four years after my PhD, but then in 1987 high-temperature superconductivity was discovered and I worked on that, along with a few thousand of my closest friends. I didn't do it for very long, though, because I wasn't having much of an impact."

Her work on dynamic systems led her to study disordered materials, such as glasses and magnets. "It is typical to study materials by looking at their lowest energy states, but many disordered materials never make it to their lowest energy state on human time scales, so if you want to know what they are doing you have to think about the dynamics and how they were formed," she explains. "We tried to develop new theoretical approaches for understanding their behavior." (4)

In 1995 she joined the faculty at the University of Chicago and formed fruitful collaborations there. One collaboration was with Sidney Nagel and Tom Witten, studying how forces propagate in granular materials. Granular materials include everything from sand on a beach to the explosives in a bomb. Coppersmith et al. found that the statistics of the measured forces in granular materials were fundamentally different from the statistics of the forces in elastic materials. The model they developed provided a widely applied theoretical framework for the study of granular materials (5).

Thanks to these accomplishments, Coppersmith was named a Fellow of the American Physical Society, the American Association for the Advancement of Science, and the American Academy of Arts and Sciences. The University of Wisconsin-Madison awarded her a Kellett midcareer award in 2007, and named her a Wisconsin Alumni Research Foundation professor in 2010 and a Vilas professor in 2011.

This is a Profile of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 824.

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Coppersmith's interests and research areas have evolved over the years. Granular materials, dynamical systems, statistical mechanics, magnets, quantum magnets, and quantum computing have all occupied her research plans. "There are many questions that I think are interesting, but often I don't have an angle on how to make progress towards answering them. But once in a while an idea crystallizes and there is something specific to develop."

Her Inaugural Article reflects several aspects of her career, she says. "It addresses some old questions from early in my career, and it's a collaboration with people at Chicago where I was in the middle of my career. The work is also a collaboration with experimentalists, which I feel is characteristic of my scientific style."

In her Inaugural Article, Coppersmith attempts to understand patterns that arise in a thin layer of nanoparticles. Starting with a monolayer of nanoparticles on the surface of water and compressing it, thin regions of trilayer (three layers of nanoparticles) form interesting and increasingly complicated patterns as the compression increases. "The formation of the lines of trilayer is not surprising, because they enable the system to put all the nanoparticles into a smaller area," she says. "The surprising thing is that the lines of trilayer in the pattern intersect a lot." Instead of seeing the nanoparticles fold like an accordion, many line intersections create ever more complicated line patterns and hexagonal tubes.

The paper builds on work from the 1980s that shows that in thermal equilibrium the intersecting lines enable the system to raise its entropy. A similar model developed by Villain for atoms on a graphite substrate showed that in thermal equilibrium the intersections can be favored because they raise the entropy of the system (6). The only major complication here compared with the system that Villain studied is that the nanoparticles tend to get stuck and the patterns seen in the experiment are frozen. "However, it appears that there is enough time before the configuration freezes for entropy to act, so that you get intersections even in a frozen pattern," Coppersmith says. She adds that in the 1980s, "We didn't actually figure out what the equilibrium state was, but now we have better computers, and we've been able to develop a more efficient algorithm that enables us to address the question."

The assembly of biomaterials has also intrigued Coppersmith since she moved to the University of Wisconsin in 2001. Her departmental colleague, physicist Pupa Gilbert, figured out how to use an X-ray technique called XANES, typically used to study metals, on biominerals. "In XANES spectroscopy, you shine X-rays on a sample and measure the electrons that come out," Coppersmith says. "The technique has nanometer spatial resolution because you can measure the electrons that come out very accurately and determine where on the sample they came from." The technique had been limited to studying metals because in an insulating sample a lot of positive charge builds up on the surface. The electrons are deflected by those charges, making it difficult to determine where they came from. "Pupa figured out how to coat insulating samples with a very thin layer of metal that did not corrupt the spectra but was also thick enough to solve the charging problem." (7)

One of the first biominerals Gilbert and Coppersmith studied is red abalone nacre, or mother-of-pearl, the shiny, strong material on the interior of many mollusk shells. "Pupa acquired XANES spectra of abalone nacre and found significant contrast within the layers that we weren't expecting," Coppersmith says. "Some of the theoretical work that we did aimed to figure out the source of the contrast, which turned out to be variations in the orientations of the crystal tablets. Other parts of the theory aimed to explain why the pattern of contrast was different in different parts of the shell," Coppersmith says. Their experiments showed that the orientations are highly disordered at the beginning of the growth and the order increases as the material is deposited. "We showed that the evolution of the contrast patterns could be understood using a very simple model in which different crystal facets grow at different rates. It was very nice to be able to show that a complicated-looking pattern can arise from very simple physics." (8)

Another of Coppersmith's major research interests since arriving in Wisconsin has been quantum computing. She is a member of a collaboration led by University of Wisconsin-Madison physicist Mark Eriksson, which is working to build and program a quantum computer made from quantum dots fabricated in semiconductor heterostructures of silicon and silicon-germanium (9). Coppersmith has also been working to develop new quantum algorithms based on the properties of interacting quantum particles (10).

The quantum-dot quantum computer being developed at Wisconsin uses the spin of a single electron as its fundamental entity, instead of using the charges of many electrons, as today's computers do. The goal is to enable the implementation of potentially more efficient and powerful algorithms than those currently available. "Quantum coherence is very delicate, and the experiments are very sophisticated. Everything involves measuring individual electrons, and it's very easy to ruin an experiment completely by touching the equipment. As a theorist, I definitely try not to touch anything," she says.

Coppersmith says that in the next several years the feasibility of building a large-scale quantum computer might become clear. "It may be the first time in my career that my relatives have some understanding of why the research that I am doing could be important, because they see how classic computers have changed their lives and they sense the exciting possibilities if the power of computers could be revolutionized," she notes. "I am very excited about this project right now."

Philip Downey, *Freelance Science Writer*

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