Biography of Karl Hess

Physicists have strived for centuries to understand the behavior of electrons, information crucial for explaining electricity and the physical properties of all materials. Although electrons are exponentially too small to see, researchers have developed a variety of techniques for simulating electronic nature and movement with computer models. A leader in this field is Karl Hess, professor of electrical and computer engineering at the University of Illinois, Urbana.

With his colleagues, Hess has developed numerous simulation tools for discerning the behavior of electrons in solids, semiconductor lasers, and other devices. His work has earned him many grants and accolades, including the rare dual election to both the National Academy of Engineering (2001) and the National Academy of Sciences (2003). In his Inaugural Article (1), published in this issue of PNAS, Hess and mathematician Walter Philipp discuss certain limitations of Bell's Theorem, a current cornerstone for quantum theory. The authors' conclusions suggest completely new interpretations of quantum mechanics and may help foster the development of quantum computers.

Combining Science and Technology

As a young boy in Vienna, Austria, Hess became fascinated with electricity. During his elementary years, he came across a book on 19th century inventions in his father's library. "I read the book intently, especially the section on electricity," he said. Hess continually tinkered with small electrical devices, building his first microphone at age 8.

A particularly engaging high school teacher encouraged Hess to focus on a career in applied physics. With this advice in mind, Hess studied physics and mathematics at the University of Vienna. He continued his education at the same university, pursuing a doctorate in applied physics under the mentorship of solid-state physicist Karlheinz Seeger. For his thesis, Hess investigated electronic transport in semiconductors, crystalline materials with conductivity between that of a metal and an insulator. The work was partly experimental and partly theoretical: by irradiating semiconductors with microwaves, thus exciting electrons, Hess developed theories on how the electrons interacted with each other and with the semiconductor's lattice structure (2).

After earning his doctoral degree in 1970, Hess worked as an assistant professor at the University of Vienna. A year later, he met University of Illinois professor John Bardeen, who was on a lecture tour throughout Europe. A giant of electrical engineering, Bardeen coinvented the transistor in 1947 and was a pioneer in the field of superconductivity: the complete disappearance of electrical resistance in some substances, especially at very low temperatures. When Bardeen offered Hess a favor in return for some translating work, Hess asked for help finding a postdoctoral fellowship in the United States.

Karl Hess.

Bardeen didn't let Hess down. After receiving a Fulbright scholarship in 1973, Hess left Vienna with his wife and two children to join Bardeen at the University of Illinois. Hess soon met Chih-Tang Sah, who was also at the University of Illinois and is coinventor of a technology known as complimentary metal oxide semiconductor (CMOS), now ubiquitous in chip technology. For the next 2 years, Hess and Sah combined their expertise to solve the Boltzmann transport equation, which describes electronic transport in transistors (3). "I was a little intimidated because I was surrounded by these famous people, Bardeen and Sah," said Hess. "But at the same time, I was also enormously excited because this was the place where they did what I liked most, combining science and technology."

In 1974, Hess moved back to Vienna with his family. For the next 3 years, he worked as an assistant professor and lecturer at the University of Vienna. However, he strove to retain connections to Illinois, communicating often with Bardeen and Sah. "My wife, Sylvia, liked it there, and so did my children, Ursula and Karl. We wanted to move back," Hess said. His persistence paid off; in 1977, the University of Illinois offered him a visiting associate professorship.

Supercomputers, Super Simulations

After Hess returned to Illinois, he worked to improve the efficiency of charge-coupled devices, semiconductor chips that record images in video cameras. However, craving more basic study, he soon teamed up with engineering professor Ben Streetman, now at the University of Texas at Austin, to investigate a broader class of semiconductor materials and devices. The two scientists developed the concept of "real space transfer" (4), which explains the performance of certain high-frequency transistors. Streetman also mentored Hess on the politics of American university life. His advice helped Hess land a tenured professorship of electrical and computer engineering at the University of Illinois in 1980, a position he still holds.

At about that time, Hess' expertise in semiconductor research caught the attention of the United States Naval Research Laboratory (NRL), which assigned him confidential military research. His work with NRL, as well as his consequent research for the Office of Naval Research and the Army Research Office, was invaluable in shaping his future research interests. Although unable to elaborate on the specifics, Hess said, "It gave me an overview of what was going on in semiconductor research in the United States."

In his nonclassified research, Hess sought a way to determine electrical properties, such as conduction, resistance, and radar or microwave absorption, in solids or semiconductors through computer simulation. Toward this end, he and his graduate students developed the full-band Monte Carlo method, a combination of the Boltzmann equation and quantum mechanics (5). Quantum theory dictates that electrons are both a particle and a wave; however, previous attempts to predict the path of electrons through a solid neglected the particle's wave-like nature, yielding imprecise results. Hess and his students used supercomputers to include electrons' wave structures into their calculations, creating simulation methods

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This is a Biography of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 1799.

that provided accurate predictions for electronic transport in semiconductors. Now a popular simulation technique used throughout electrical engineering, the full-band Monte Carlo method forms the base of several commercial software packages, such as IBM's DAMOCLES and Integrated Systems Engineering's DESSIS programs.

A chance opportunity prompted Hess to focus his engineering and computer simulation skills on optoelectronics, a branch of electronics that deals with devices for emitting, modulating, transmitting, and sensing light. When Hess's University of Illinois colleague Nick Holonyak, Jr., was unable to attend a 1984 meeting of high-level scientists interested in optics technologies, Hess went in his place. "I got the feeling [at the meeting] that the field of optoelectronics was in need of computer-aided design and simulation tools," he said. Over the next several years, Hess and his students developed a program to simulate quantum well laser diodes, tiny lasers found in bar-code scanners, CD players, and fiber-optic technology. Previous research had supplied a basic design for these lasers. However, engineers were faced with hours of laborious calculations to predict the effects of new design modifications, which frequently led to inaccurate results. To improve the accuracy and speed of these calculations, Hess's team created a new algorithm and incorporated it into software known as MINILASE (6, 7). The program accurately simulates quantum well laser design adjustments and cuts down calculation time.

Bell's Theorem, Revised

Hess credits the evolution of his current research interests to the influence of his work environment at the Beckman Institute for Advanced Science and Technology at the University of Illinois. In 1984, philanthropists Arnold and Mabel Beckman offered the University of Illinois a generous grant to build an interdisciplinary science center to combine physical and biological research interests. Hess chaired one of two faculty committees at Illinois that wrote a proposal for this center, and, in 1989, the Beckman Institute opened its doors with Hess serving as associate director. Since then, Hess's close involvement with life scientists has stimulated an interest in nanostructures and biomolecules. He has published several papers reflecting this new curiosity over the last decade (8–10). However, rather than pursue applications of nanostructures in the biological sciences, Hess became interested in applying nanoscience to quantum computing. Currently only a theoretical concept, quantum computation is based on the simultaneous interaction of its component devices, in contrast to standard computing machines that work their devices in sequence.

To construct a quantum computer, researchers must first understand the basis of quantum information, a topic closely related to the work of British physicist John Bell. Bell's famous 1964 Theorem (11), which sprang from a debate between Albert Einstein and Niels Bohr, appears to show that an event in one location could instantaneously affect a second, nonlocal event, a phenomenon sometimes referred to as "spooky action at a distance." In his Inaugural Article, found on page 1799, Hess and mathematician Walter Philipp argue that Bell's Theorem breaks down given certain parameters. This finding could influence current understanding of the flow of quantum information and might even lead to new interpretations of quantum mechanics. Hess acknowledges that this conclusion has already stirred a heated debate throughout the field of quantum physics; however, he is confident in his work and plans to build on these findings in future research.

"I've worked on this [Bell's Theorem research] more than anything else. For the last 4 years, I dream of it, I go to bed with it, and I wake up with it. It's close to driving me crazy, but I think I've come now to a conclusion about it," he said. "It might be my greatest contribution to science."

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Christen Brownlee, *Science Writer*

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