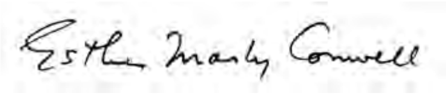
Esther Marly Conwell

ESTHER M. CONWELL

1922–2014

Elected in 1980

"Contributions to the semiconductor device industry and pioneering integrated optics and organic conductors."

BY ELSA GARMIRE

ESTHER MARLEY CONWELL (ROTHBERG), a condensed matter theoretician, died November 16, 2014, at the age of 92, ending a distinguished 62-year career investigating fundamental properties of new electrically conductive materials.

Dr. Conwell received wide recognition for her work in semiconductors, highly conducting quasi-one-dimensional organic crystals, conducting polymers, and DNA. She was honored with the National Medal of Science (2009), election to both the National Academy of Sciences (1990) and the National Academy of Engineering, and selection by *Discover* magazine as one of the Top 50 Women of Science (2002). In 1997 she became the only woman ever chosen to receive the Edison Medal of the Institute of Electrical and Electronics Engineers (IEEE), the institute's oldest medal (111 years), awarded for a career of meritorious achievement in electrical science, electrical engineering, or the electrical arts. She was honored "for fundamental contributions to transport theory in semiconductor and organic conductors, and their application to the semiconductor, electronic copying and printing industries."

Conwell's introduction to research was her 1943 master's thesis from the University of Rochester, deriving the scattering of electrons by impurities in germanium from first principles. Working alone on a suggestion from Victor Weisskopf, she produced what became universally known as the Conwell-Weisskopf formula. During her PhD studies at the University of Chicago she calculated, also from first principles, the energy levels of the H-minus ion for astrophysicist Subrahmanyan Chandrasekhar and graduated in 1951.

She interned for a year at Bell Laboratories, where she wrote a review paper for William Shockley that explained the basic properties of semiconductors. As she said in an interview, "That article was really many people's introduction to semiconductors." This paper solidified her reputation as someone with a profound understanding of the complexity of electrons and holes in semiconductors.

In 1952 Conwell joined Sylvania Labs (which became GTE Labs in 1962), continuing theoretical analysis of germanium and silicon. She focused on carrier transport in both p- and n-type materials, lightly or heavily doped, in high and low electric fields and at various temperatures, always comparing her theoretical understanding with experimental results. In 1958 she compiled the known properties of Si and Ge in two influential review papers. Her research analyzed the mobility of hot carriers and conductivity at high fields; she also derived properties of thermoelectric semiconductors such as bismuth selenide (Bi_2Se_3).

When GTE took over, her focus shifted to research supporting telecommunications, adding gallium arsenide (GaAs) to her research portfolio. Her 1967 monograph *High Field Transport in Semiconductors* (Academic Press) was influential in the development of semiconductor electronics. She supported research toward devices: optical frequency shifting by the electrooptic effect in zinc selenide (ZnSe); parametric amplification and nonlinear mixing of ultrasonic waves in cadmium sulfide (CdS). Next she moved into integrated optics, with an elegant solution to optical waveguides formed by diffusion, a field in which I overlapped her technically and personally. All her papers have been heavily cited.

In 1972 she left GTE to join Xerox Webster Research Center in Rochester, New York, where she studied organic conductors and quickly became a leading force in quasi-one-dimensional crystalline conductors. She derived fundamental models for band transport in tetrathiafulvene (TTF) and tetracyanoquinodimethane (TCNQ), and calculated how the phonon frequency, mobility, and magnetic susceptibility depend on temperature and pressure. By 1981 she coedited a special volume devoted to one-dimensional organic conductors, adding metal-complex and polymeric materials into the mix. She then began to investigate polymers with parallel chains, such as polyacetylene, shown to be one-dimensional conductors.

She foresaw the synergism of theoretical and experimental physics with synthetic chemistry and developed a collaboration with the Chemistry Department at the University of Rochester. She calculated the 3D band structures from first principles and elucidated the role of localized excitons in PPV [poly(phenylene vinylene)] and polyanilines, focusing on photoinduced charge transfer.

In 1991 Conwell represented Xerox as associate director of the new NSF Center for Photoinduced Charge Transfer at the University of Rochester, opening up new research opportunities: Investigating electron-hole interactions in conductive polymers led to excitons, polarons, and polaron pairs, as well as interchain coupling in photoluminescence and contact injection into polymer light-emitting diodes.

In 1997 she wrote the seminal review "Excimer Formation and Luminescence in Conducting Polymers" (*Trends in Polymer Science* 5(7):218–222). The next year she retired from Xerox and moved to the university as a research professor. She continued to analyze high field effects, photogeneration of polaron pairs, and evolved into studying ladder polymers, whose unique geometry led her to investigate DNA. In 2000 she suggested that an injected electron or hole can form a polaron on a DNA stack. Further research showed that the polaron results from polarization of the surrounding water. She had journal papers out for review when she died.

Looking back in 2003, Conwell said, "My life is the story of women scientists making a place in the world." The year she received her PhD, only five other women in the United States received similar degrees. Her father, an immigrant to New York City from Eastern Europe, provided motivation: "He impressed on his three daughters that in order to have a future, to be able to get married, we had to have jobs and be able to earn money, and he would prefer that we be professionals."

Born May 23, 1922, she was naturally attracted to mathematics and an excellent student, and in 1938 at age 16 she entered Brooklyn College, where she majored in physics. "I was frequently the only woman in the class.... My idea was to be a high school physics teacher, because that was all that I had ever seen." Her mentor, Professor Bernhard Kurrelmeyer, however, suggested she apply to graduate school—he was married to a physics professor at Columbia and understood what women could do.

While her contributions to physics rival those of her male peers, she faced difficulties that they didn't and often had to work alone. In the summer of 1942 she was hired at Western Electric as "assistant engineer," but "there was no such payroll classification for women as 'assistant engineer,' and I would have to be 'an engineer's assistant.' And it's obvious what that did to my salary.... There was no legislation at that time." It was difficult to find an advisor in graduate school, partly because World War II called away most of them, including her MS advisor. She worked out her PhD thesis alone since she had married and was living in New York. "Having a PhD from the University of Chicago, any guy would figure on getting a nice professorship at a good university," said Conwell. "But in physics in the early 1950s, there was no such thing for women and no such thing for me." She would spend most of her time in industry.

During her Bell Laboratories internship, she felt very conspicuous as a woman and lacked a sense of security or confidence. Fortunately Bill Shockley was impressed with her work and found her the job at Sylvania. One advantage she pointed out: "It was not long after the invention of the transistor and a marvellous time for research." She expressed satisfaction with her treatment at Sylvania, working with younger theoreticians who did the calculations, but she admitted that

"I did not get my share of invited papers, and that was due to being a woman.… I felt many times that I should have gotten an invited paper, but I didn't. But I also didn't know how to work the machinery. As a woman, I was not properly socialized.… We're not given a reason to have the same kind of self-confidence that some of the men do." At Sylvania she began encouraging young women to become scientists and mentored Mildred Dresselhaus as an undergraduate intern.

After unexpected termination when GTE downsized, Dresselhaus invited her to MIT to fill a temporary chair, from which she found her position at Xerox, where again she was comfortable. Conwell felt that "women had been treated better in industry than in academia.… I guess talented women seem to be getting more what they deserve in industry. They're promoted.… On the subject of women in academia, I would say I have never gotten a reasonable offer of a job from a university, and I've had a good reputation for some time. I'm a member of both academies, for instance. So that says something, that I spent my life in industry."

Conwell provided an excellent role model for women in physics. She lived a balanced life with her writer husband Abraham Rothberg, whom she met at Brooklyn College and married in 1944, and pursued her passion for ballet, enjoying its beauty, discipline, and order. She mentored young women all her life and was recognized for her dedication with the Dreyfus Foundation's Senior Scientist Mentor Program Award (2005) and the American Chemical Society Award for Encouraging Women into Careers in the Chemical Sciences (2008). As she said, "Although it's not nirvana yet, women have come a long way in my working lifetime, and it gives me hope."

Her son, Lewis Rothberg, is a tenured professor of chemistry and physics at the University of Rochester. He remembers that his father "made substantial sacrifices of his own career and ambitions to help his wife." He adds that his father, a distinguished author intimately involved in the publishing business, left New York in 1972 to move to Rochester so that Esther could accept a job at Xerox. "His advice, encouragement, and support were an integral part of her success.” Abraham Rothberg died in 2011.

According to Dresselhaus, “Esther was right there at a very exciting time in semiconductor research. Her work is the basis, the very fundamentals, of what we study today.… Esther is a true role model for what it means to stay vital as a scientist and as a woman. There is no denying that when Esther and I were first beginning, we faced many difficulties and obstacles as women scientists. But that climate is changing, and I’m proud of the role we’ve played.”

As a highly successful and influential woman in physics and chemistry, Conwell inspired countless young women worldwide to pursue and grow in scientific and engineering careers.