BIOGRAPHICAL MEMOIRS

John Robert Schrieffer

May 31, 1931–July 27, 2019
Elected to the NAS, 1971

A Biographical Memoir by Daniel Arovas, Greg Boebinger, and Nick Bonesteel

Figure 1 John R. Schrieffer. *Photo courtesy of AIP Emilio Segré Visual Archives.*

John Robert ("Bob") Schrieffer was a towering figure in theoretical condensed matter physics. He is best known for his crucial contributions to the theory of superconductivity, a problem that vexed theorists who had searched for a microscopic theory of the phenomenon since its discovery in 1911. As a graduate student at the University of Illinois, and together with his advisor John Bardeen and postdoctoral researcher Leon Cooper, Schrieffer pioneered a revolutionary approach, now known as BCS (Bardeen-Cooper-Schrieffer) theory, that, upon its publication in 1957, was swiftly recognized as a seminal and definitive work.

Bob Schrieffer was born in Oak Park, Illinois, on May 31, 1931. Changes in his father's business entailed family moves to Manhasset, New York, in 1940, and then to Eustis, Florida, in 1947. There, he attended a small high school with very limited course offerings. He was encouraged to pursue self-study in mathematics and sciences, with some guidance from the principal and physics teacher. Schrieffer's interest in electronics was kindled in 1944 while babysitting at the home of a CBS radio announcer who happened to be an amateur radio operator. Looking to keep himself busy, he found and began to read a copy of *The Radio Amateur's Handbook*. He was subsequently tutored by his host and eventually began building radio equipment on his own. Inspired by two of his Manhasset neighbors, and by his passion for ham radio, Bob set his sights on studying electrical engineering at the Massachusetts Institute of Technology (MIT) and began his studies in 1949. Early on at MIT, however, he became captivated by physics and changed his major during his sophomore year. As a junior, he attended John C. Slater's lectures on atomic and molecular physics and found them to be pellucid and inspiring, so he approached Slater to supervise his bachelor's thesis. This was Schrieffer's first experience with an ongoing research effort. He was much impressed by the team effort and the esprit de corps among the undergraduates, Ph.D. students, and postdoctoral researchers in Slater's large group. Even so, he also yearned for an opportunity to express more individual creativity as he moved on to graduate studies, where he sought to work on more conceptual rather than computational problems.

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Initially, Schrieffer intended to study nuclear physics, inspired by Léon Rosenfeld's book on nuclear forces. In 1953, he received a Fulbright scholarship to England to study with Rosenfeld and Patrick M. S. Blackett, but fate intervened in the form of the Korean War and his father's failing health, and so Bob decided to remain in the United States. He applied to domestic graduate physics programs and was delighted by his acceptance letter from the University of Illinois. He knew of John Bardeen's work on the transistor and of the problem of superconductivity, and his acceptance letter offered him the possibility to immediately begin working with Bardeen. Initially, Schrieffer studied the problem of surface transport of electrons in semiconductors, as Bardeen was heavily engaged, along with David Pines, in understanding the electron-phonon problem. Schrieffer also performed experimental measurements in what was a fairly sizable laboratory that Bardeen himself maintained at the time. Sensing that Bardeen was gearing up for another major attack on superconductivity, Schrieffer selected it as a thesis topic in the late spring of 1955. Cooper would arrive in Urbana that fall.

In the early 1950s, work by Herbert Fröhlich and by Bardeen, based on perturbation theory, predicted a superconducting isotope effect, but the main phenomenon remained unexplained. Bardeen and Pines had extended Fröhlich's work to obtain an effective interaction in the many-electron domain, but still there were no available techniques to usefully address the many-body problem, as quantum field theory methods had not yet been ported from quantum electrodynamics to solid state physics. By the time BCS began their assault on the problem, Bardeen was convinced of two important aspects: first that the electronic spectrum must exhibit an energy gap, and second that the many-electron wavefunction must reflect a condensation in momentum space, with long-range phase coherence. A major advance was made when Cooper solved the problem of two electrons above a quiescent Fermi sea, taking into account the effective interaction mediated by phonons that results in a bound state. Schrieffer's focus then crystallized in finding a many-electron theory that could incorporate Cooper's bound pairs. His crucial inspiration came several months later, on a New York City subway while at an American Physical Society (APS) meeting, when he first scrawled on paper the iconic BCS wavefunction. A torrent of results soon followed and were validated by numerous experiments. The microscopic theory of superconductivity had been solved.[1] (It would take another several years to properly understand the thorny issue of gauge invariance in superconductors, thanks largely to the work of Yochiro Nambu and of Philip W. Anderson.) The significance of this achievement was recognized with the 1972 Nobel Prize in Physics, awarded to Bardeen, Cooper, and Schrieffer.

Following his Ph.D. years at Illinois, in the fall of 1957 Schrieffer went to the University of Birmingham in the United Kingdom and then to the Neils Bohr Institute in Copenhagen, Denmark, as a National Science Foundation postdoc. It was in Copenhagen that he met his future wife, Anne Grete Thomsen. Following a year as an assistant professor at the University of Chicago, Bob joined the faculty at the University of Illinois in 1959. In 1962, he moved to the University of Pennsylvania, where he remained until 1980, when he was recruited by the University of California, Santa Barbara. From 1984 through 1989, Schrieffer served as the second director of the university's Institute for Theoretical Physics (ITP). His presence both at the ITP and on the physics department faculty contributed greatly to Santa Barbara's rapid rise to prominence in the sciences and engineering. His last academic appointment, starting in 1992, was as Florida State University System Professor and chief scientist of the National High Magnetic Field Laboratory in Tallahassee, where he once again helped establish the scientific credentials of a major new endeavor.

Following the pathbreaking work of BCS, Schrieffer spent the next four decades working on problems at the forefront of condensed matter physics.[2] He made several important contributions to the theory of quantum many body systems in areas such as magnetism and surface science, and he continued to work on various aspects of superconductivity. In work that extended the BCS theory beyond its original domain, Schrieffer and collaborators showed that the electron-phonon interaction in lead and other strong-coupling superconductors could be treated within the Eliashberg formalism without assuming well-defined Landau quasiparticles—a key starting assumption of the standard BCS theory.[3] This analysis revealed that tunneling spectra gave direct evidence that superconductivity in these materials was the result of strong electron-phonon coupling, an observation echoed three decades later in work suggesting that ARPES line shapes in underdoped cuprate high-temperature superconductors will provide clues to the nature of the pairing glue in these systems.[4] In other influential work, Schrieffer and collaborators developed the theory of odd-gap superconductivity, an idea that has found a wide range of applications in the theory of superconductor-ferromagnetic junctions, topological superconductivity that supports Majorana zero modes, and other hybrid systems.[5]

On the more practical side, within a decade of the discovery of cuprate high-temperature superconductors, high-quality thin films were being used in passive radio frequency filters for cell phone communications. In a paper that evidenced his ongoing interest in technology, Schrieffer and colleagues articulated the limits on the Q and intermodulation of low-power high-temperature superconducting microstrip

resonators that arise from the intrinsic properties of the superconducting films.[6] Outside of traditional condensed matter, Schrieffer also contributed to the theory of collective excitations in nuclei.[7] In the field of magnetism, Schrieffer and Peter A. Wolff developed in 1966 the Schrieffer-Wolff transformation, which elucidated the relationship between the Anderson and Kondo Hamiltonians.[8]

Schrieffer's work on unconventional spin-charge quantum numbers of soliton-like excitations in condensed matter was highly influential, starting in 1979 with the celebrated SSH model (developed with Wu-Pei Su and Alan J. Heeger) of polyacetylene.[9] As fundamental particles, electrons concomitantly possess both charge and spin, and these attributes also pertained to elementary electronic states in solids, or so it was generally believed. But SSH found a remarkable mechanism for spin-charge separation, whereby these quasiparticles possessed charge but no spin, or spin but no charge—as if the fundamental particle of the electron had split into two pieces. Additional work by Schrieffer and collaborators explored the phenomena of fractionalization, elementary excitations in condensed matter that have fractional charge or spin and that may interpolate between Bose and Fermi statistics.[10] This body of work reified earlier field theoretic models of Roman Jackiw and Claudio Rebbi, Jon Magne Leinaas and Jan Myrheim, and Frank Wilczek, thus identifying for the first time actual materials, such as polyacetylene and fractional quantum Hall systems, in which fractionalization is manifested in low-energy excitations. (The notion that quasiparticles in fractional quantum states might possess fractional statistics was first conjectured by Bertrand I. Halperin.)

In addition to the Nobel Prize, Schrieffer was awarded the 1983 Presidential Medal of Science and served as APS president in 1996. He was a steady champion of and mentor to his younger colleagues and students. Because of illness, the last twenty years of his life were extremely difficult and indeed tragic. Throughout his struggles, Anne remained his devoted partner until her death in 2013.

Bob Schrieffer died on July 27, 2019, in Tallahassee, Florida. He was 88 years old. In addition to his brilliance and the twinkle in his eye when he would discuss physics, Bob's kindness and avuncular nature were well-known to his many students, colleagues, and friends, who were grateful to have benefited from both his genius and his humanity.

Acknowledgments

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