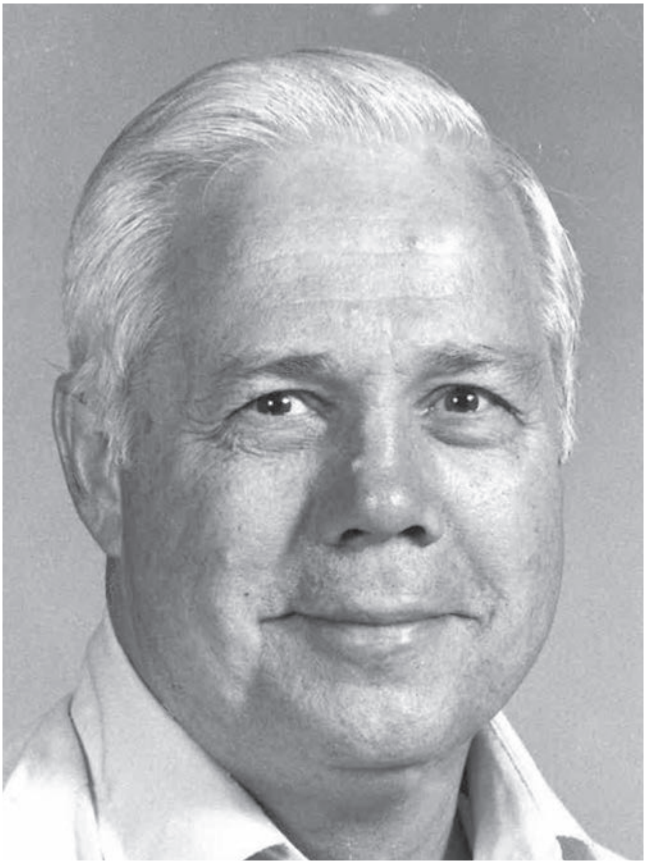

WALTER L. BROWN

1924–2017

Elected in 1986

"For discovery of semiconductor surface channels crucial in field effect transistors, and for contributions to ion beam uses in semiconductor diagnostics and processing."

BY LEONARD C. FELDMAN AND LOUIS J. LANZEROTTI

WALTER LYONS BROWN, a scientific and technical force of extraordinary ability and breadth, passed away October 29, 2017, at age 93. He possessed an uncanny ability to create meaningful science and technology and mentor next-generation scientists.

WLB (pronounced Wilby), as he was called by many, was born October 11, 1924, in Charlottesville, Virginia, the son of Frederick and Maude Brown. Youth activities included active involvement with the Boy Scouts, earning the rank of Eagle Scout. During his career at Bell Laboratories he sponsored scout troops and explorer posts and always kept the scouting flag in his office.

His father was a physics professor at the University of Virginia, and Walter was "working in the lab" at the age of 10. This environment provided him with some of his first exposures to physics. An innovative illustration of gravity and acceleration using an air gun and a falling stuffed monkey was a highlight in his memory.

Walter graduated from Lane High School in Charlottesville in 1942 after spending two years as a "senior" because of a change in the school structure. This was shortly after the December 7, 1941, Japanese attack on Pearl Harbor. Already at this point in life, Walter was convinced that physics was for him. He initially enrolled at Davidson College until, after a year and a half, he joined a Navy V-12 program designed for an accelerated educational matriculation and study program involving three semesters/year to finish early to become an ensign.

The Navy was a central experience for Walter, with assignments in various Navy organizations like the War Plans Office, where he was a "gofer," and finally the Office of Naval Research and exposure to a real laboratory at the forefront of science. The Navy experience included an educational stint at Duke University, where he completed his undergraduate degree in physics.

In 1942 Walter met Lucie Oakes, a student at Duke, when their paths crossed in the railroad station in Greensboro, North Carolina, as both were traveling home for Christmas. They were married June 14, 1946, after Lucie graduated from Duke.

Walter was discharged from the Navy in August 1946, with many memories and experiences, and headed to graduate school. With a recommendation from Walter Nielsen, chair of Duke's Department of Physics, he was accepted at Harvard for his graduate studies in physics. He and Lucie set up life in Boston. During the "lecture" phase of graduate school both Walter and Lucie worked as home caretakers for a prominent Boston family in exchange for "free" lodging. The young couple and their host family were an excellent match. For some time Lucie was also a companion to the mother of the president of Harvard.

When the research phase of graduate school began Walter and Lucie moved to different lodgings with better access to the lab—an early indication of what we were all to learn of his absolute dedication to research! Walter worked under the direction of Edward Purcell, a 1952 Nobel Laureate for his work on nuclear magnetic resonance (NMR). Walter noted that Purcell was also an excellent teacher—a characteristic that was clearly transferred to WLB.

Walter's thesis addressed the binding energy of the deuteron. He used NMR to calibrate the magnetic field of a specially constructed spectrograph to establish a better value for the absolute energy of an internal conversion electron from radium, often used as a calibration reference. In this work he calibrated the measurement using the high-resolution electron energy capabilities of a magnetic spectrometer—an instrument characteristically machined by Walter.

He earned an AM (1947) and PhD (1951), both in physics, from Harvard. A visit to Bell Laboratories with its stimulating atmosphere and high quality lured him and on December 1, 1950, he embarked on what resulted in a 51-year career at the "Labs."

Walter was a superb experimental physicist, with deep insights into physics, and his expansive character cultivated new science and young scientists. These qualities were exercised superbly at Bell Labs. His earliest work there was in the Contact Physics Department and then the Transistor Physics Department as part of the exciting efforts to produce the newly invented transistor. Daily interactions with William Shockley, Walter Brattain, and John Bardeen and a host of other scientific luminaries created an excitement and stimulation for Walter that lasted throughout his career. He noted that his early Bell work, observing the field effect on the surface conductance in germanium, might have been his most important scientific contribution. This early semiconductor science led to exploration of the effects of energetic particle bombardment, which was to strongly influence the remainder of his career.

In 1959 Walter was promoted to head the newly organized semiconductor physics department, designed by then Bell Labs research vice president (and later president) William O. Baker. Walter chose "Radiation Physics" as the title of his department; as he dryly noted, you could explore any field of physics with that title. As a department head Walter was able to exercise his strength not only as a physicist but also as a science leader creating new research areas, cultivating young scientists, and reinforcing the spirit and attributes that made Bell Labs so distinctive—collaboration, excellent science, and a hotbed of ideas and invention.

Experience with semiconductors and with particle beams stimulated entirely new directions, some far from the Bell Labs mainstream. This was the characteristic Brown/Bell philosophy: if it was exciting science and technology, "we" should be involved. For Walter this took the form of establishing nuclear physics at Bell.

In the 1960s nuclear physicists were leading the frontiers in electronics, radiation detection, and the online use of computers—all areas close to Bell Labs interests. To enable the nuclear enterprise Walter engineered one of the earliest and most substantial university-industry collaborations via the establishment of a joint, state-of-the-art Tandem 8 MV accelerator located at Rutgers University in New Brunswick and used by Bell Labs scientists and Rutgers academics.

As it turned out Walter's foresight paid off in very unexpected ways. In 1960 Bell entered the communications space race to develop a broadband satellite communications system, Telstar. A major concern—the effect of the Van Allen radiation belts on solid state electronics—was a perfect challenge for WLB.

Relatively little was known about the distribution and time dependence of the radiation levels at the low Earth orbit in which the AT&T Telstar 1 spacecraft would fly when the design and construction of this first active communication satellite was begun. This aspect of the "race for space" required solid science, made abundant use of Walter's background, and required entirely new areas of investigation and management.

Semiconductor detectors had been invented at Bell Labs by Kenneth G. McKay shortly after the invention of the transistor, and were being used in the nuclear physics research being done in Walter's department. As such, Walter and his colleague G.L. (Laurie) Miller (originally at Brookhaven National Laboratory and then a member of Walter's department) proposed that Telstar carry a series of solid state detectors to measure the fluxes, types, and energy spectra of the particles that would be encountered by Telstar.

The day before the launch of Telstar on July 10, 1962, the United States detonated a high-altitude nuclear bomb called Starfish Prime. Thus the launched Telstar encountered much larger radiation intensities than expected from the natural background, and these high intensities of radiation ultimately limited Telstar's lifetime in orbit, causing its failure in

February 1963. Nevertheless, Telstar was a tremendous communications success. Walter's detectors returned outstandingly high-quality data on the trapped radiation produced by Starfish Prime; he was invited to make many presentations on his results and published numerous research papers.

Based on the cutting-edge research led by Walter on radiation measurements on Telstar 1 and Telstar 2, he and his department colleagues developed more sophisticated space-based instrumentation. They built on experiences in the Bell Labs nuclear physics program to develop thin, larger-area silicon solid-state detectors that could be stacked in arrays for better identification of the trapped radiation and better characterization of their energy spectra.

Walter played a significant role in the harried atmosphere of space science—commuting among different labs and locations, testing and designing, calibrating, managing large groups, and even being the "midnight phantom foamer" to minimize launch vibration effects on the flight instruments.

He and his colleagues flew ever more complex instruments on the Explorer 15 and 26 NASA Earth-orbiting satellites, the geosynchronous orbit Application Technology Satellites (ATS) 1 and 3, and two interplanetary spacecraft IMP-4 and IMP-5. The instruments on the ATS were important to characterize the radiation environment at the geosynchronous altitude where future communication and weather satellites would reside for the next decades.

In order to understand the data obtained from his space experiments, Walter and his department colleagues used electron accelerators at Bell Labs and the Bell-Rutgers Tandem accelerator. The Rutgers-based facility played an essential role in calibrating the radiation instruments carried on the two Voyager spacecraft to the outer giant planets, into the solar system beyond, and ultimately into the local interstellar medium.

Walter recognized the relevance to Bell System communications of geophysical-type research that was initiated by his Telstar activities. As such, he encouraged and supported a wide range of geophysical research over the years. This included his support for ground-based research using sophisticated magnetometer instruments in the Antarctic and northern Canada, in the monitoring of anomalous currents induced by geomagnetic storms in Bell System cables across the Atlantic and Pacific, and in other space-based programs such as Galileo to Jupiter and Ulysses over the poles of the Sun to obtain better understanding of solar disturbances that could affect Earth's space radiation environment.

Walter was always open to new ideas and new ways of thinking. Triggered by a question posed across the stimulating Bell Labs lunch table some weeks before the encounter of *Voyager 1* with Jupiter in 1979, he quickly set up an experiment with his 2.0 MeV Van de Graaf to determine the sputtering rates by protons of water ice that might occur on the surfaces of the icy moons of Jupiter from the intense fluxes of electrons and protons trapped in the planet's radiation belts. This experiment revealed the new concept of electronic sputtering, which occurs at much higher rates than by the conventional nuclear sputtering regime. The laboratory results were used with the radiation data obtained by the two Voyagers to assess the implications for modifications of the surfaces of Jupiter's moons.

This laboratory research by Walter, his department colleagues, and the many visitors (US and international) that the research attracted, continued on and off for about a decade. Walter and his colleagues studied not only sputtering but also eventually the formation of molecules, such as formaldehyde, that could be produced by the impact of low-energy protons on ice mixtures such as water and ammonia. These studies had implications for the discoloration of icy bodies such as interplanetary grains and the surfaces of grains and comets. The research by WLB and his colleagues was unique at the time, and they were invited to give national and international presentations and papers. Walter noted that the ice research had quite important implications and overlaps for understanding of particle impacts on, and erosion of, resists and insulators in semiconductor research and manufacturing.

Charged particles and semiconductors remained an important theme in Walter's scientific repertoire. Significant new interest stemmed from the semiconductor industry and the use of ion beams to propagate Moore's law. Experience from the nuclear physics program fit nicely into this new application of ion beams.

Walter's department became an international leader in the broader and more fundamental field of "particle-solid" interactions. It was Bell Labs' style and Walter's as well to explore basic interactions and thus be in a superb position to help guide Bell into the era of silicon processing with ion implantation. The idea was to use energetic ion beams to "implant" the dopants into a silicon device. Implantation had some wonderful advantages in terms of precise control of the dopant number for more precise manufacturing, and enabled the "self-aligned" process that allowed the device scaling that exists today.

At first blush, implantation also had some formidable challenges, possible showstoppers. Central was the question of the damage created by the incident ion beams and the final atomic sites of the implanted species. Walter led the effort at Bell to establish a laboratory with prototype implantation and energetic ion beam analysis (Rutherford backscattering/channeling; RBS) to explore these questions.

RBS required a substantial facility: a ~2 MeV accelerator and an extraordinary range of accessories for controlled experiments. Not only was Walter a leader in understanding the science, but his innate ability at engineering led to unique equipment designs, some of which are still used today.

MeV ion beam analysis combined with channeling proved just the correct tool to measure the ion beam damage, to explore recovery of the damage, to find the critical lattice sites of implanted species, and to understand the numerous thin film structures and interfaces associated with Si processing. The field grew internationally and at Bell. At one time, there were three MeV energy accelerators in the research area, two more for use in the development area, and numerous users from all over the Labs.

Two aspects of this WLB-led development bear special note. Accelerator time was at a premium. Monthly scheduling meetings would apportion the time on the machines, typically in 4- or 8-hour slots. The machines often ran through the night for "urgent" and unexpected needs. The scheduling meetings run by WLB were a specialty where he would gently, and then more penetratingly, grill the requester—why did they need the time, how were they to analyze the results of their accelerator run…. Attendees needed to be prepared to be on the receiving end of this grilling. As with all WLB interactions, it was a learning experience.

A second aspect of the "particle solids" program led by Walter deserves mention. Although a new field for Bell Labs, ion beam–solid interactions had been a long and deeply explored specialty at several European universities, particularly in Denmark. Following in the footsteps of Niels Bohr, the University of Aarhus in Denmark established an excellent program in the field, on both the experimental and theory side. There was benefit to both Bell and Aarhus for a personnel exchange: Bell Labs scientists experienced the deep theoretical analyses at Aarhus, Aarhus scientists learned of new applications at Bell. Under Walter's leadership a personnel exchange program took shape in which over time at least five Bell scientists spent a year in Aarhus and a similar number of Aarhusians came to Murray Hill. In retrospect, it was extraordinary—a private laboratory participating in such an academic exchange program. It was an example of WLB management at its best: seeking, implementing, and managing a program to achieve the highest levels of science.

Charged particles and semiconductors remained an important theme in Walter's scientific interest over the decades. The early space-related research evolved to important Bell programs in astrophysics, geoscience, and plasma physics. Studies of particle-solid interactions led to Bell Labs leadership in ion implantation, a process that contributed importantly to the silicon revolution.

Walter's contributions were personal, in the laboratory at all hours, and professional, with the creation of a rich science and applications environment that expanded the horizons of all who interacted with him. He was awarded considerable recognition for his contributions to science and technology. He received the Arthur von Hippel Award from the Materials Research Society, and was elected to both the National Academy of Sciences and the National Academy of Engineering.

After retirement from Bell, he accepted a position as an adjunct professor at Lehigh University, where he mentored students in materials research.

Throughout his research career Walter was first and foremost devoted to his family and his faith. Walter and Lucie were dedicated to their children—Stephen (Michelle) Brown, Stuart (Peggy) Brown, Virginia (Donald) Mayer-Brown, and Keith (Natalie) Brown—nine grandchildren, and eight great-grandchildren. He taught Sunday school for over 40 years and until recently constructed houses with Habitat for Humanity. Lucie passed away July 7, 2018.

Members of Walter's Bell Labs department are thankful to have been a part of his life and his excitement in science and engineering. In a laboratory like Bell, with its Nobel Prizes and extraordinary technical accomplishments, it was superb individuals like Walter, with his scientific expertise and extraordinary management skills, who epitomized the spirit and excellence of the institution and its people.