NATIONAL ACADEMY OF SCIENCES

HOMER DUPRE HAGSTRUM
1915–1994

A Biographical Memoir by

PHILIP W. ANDERSON AND
THEODORE H. GEBALLE

Any opinions expressed in this memoir are those of the authors and do not necessarily reflect the views of the National Academy of Sciences.

Biographical Memoirs, VOLUME 83

PUBLISHED 2003 BY
THE NATIONAL ACADEMIES PRESS
WASHINGTON, D.C.

Photo by Fabian Bachrach

Homer D. Hagstrum

HOMER DUPRE HAGSTRUM

March 11, 1915–September 7, 1994

BY PHILIP W. ANDERSON AND
THEODORE H. GEBALLE

HOMER HAGSTRUM WAS BORN in St. Paul, Minnesota. His father, Andrew, had emigrated there from Värmland, Sweden, as a 22-year-old with his older brother, Nels, in 1889. His mother, Sadie Gertrude Fryckberg, was born in St. Paul in 1883, the youngest daughter of a family that had also migrated from Sweden. Homer was the second of four boys who reached maturity. The home environment was built upon strict Swedish Covenant practices, with a strong emphasis on education. Drinking, dancing, card playing, and movies were considered sinful.

Homer continued to live at home throughout his graduate years at the University of Minnesota, and did not see a movie until he was 25 years old and ready to go forth into the world. His going to see "Captains Courageous" actually caused his mother to break down and weep. She had gone from high school to work when her father died and was determined that her sons should obtain as much education as they could absorb. His father, with only an elementary school experience in Sweden, became the owner with his brother of a successful men's clothing store, Hagstrum Brothers, in St. Paul. The oldest son, Jean, although groomed to become a minister, later became a distinguished professor of English at Northwestern University in Evanston, Illinois, and sometime head of the National Endowment for the Humanities. The youngest two brothers, Vincent and Paul, became executives in the mercantile world. Homer and Jean had the unusual distinction of being awarded honorary degrees together from their alma mater, the University of Minnesota, during the commencement day of 1986.

Homer roller-skated to a local elementary school, where he attended an alpha class that covered two years' work in one year. In middle school he skipped half of his eighth-grade class. Homer later felt that being much younger than his classmates was a distinct social handicap. At home he showed a strong mechanical aptitude, with a workshop and darkroom in the basement and a crystal radio set in the attic. The high school Homer attended, Minnehaha Academy, was a private religious school in Minneapolis. He had begun questioning his family's religious doctrine early on, and in high school became engaged in science. He was fortunate to have an excellent science teacher, Henry Schoultz, who profoundly influenced his life. Even as a freshman Homer stayed after school and worked in Henry's laboratory.

In his senior year Homer and Henry built a 6-inch reflecting telescope, which remained at the school for many years. At home Homer built an "observatory," a portable wooden structure, to perch on the apex of the roof of his house. Homer sat up observing with star charts and flashlight for years afterwards. A photograph shows Homer sitting on the steep roof with one of his telescopes in hand. His early interest in science, astronomy, and mathematics, and in working with his hands, never diminished and gave him great pleasure for the rest of his life. In later years he arranged vacations so he could observe solar eclipses even when they were in faraway places, such as Africa—where he camped in the desert with his son, Jonathan—and South America.

Homer entered the University of Minnesota as an electrical engineering student, obtaining his B.S.E.E. in 1935 summa cum laude and also his B.A. in 1936. While at the university he developed a lifelong love of classical music and delighted later on in relating how he had learned about music while "ushering under Ormandy and Metropolis." Homer found physics to be his natural home and went on to graduate school, completing his M.S. in 1939 and his Ph.D. in physics and mathematics in 1940. He became the last graduate student of John Tate, who is well known, in addition to his own scientific achievements, for being the longtime editor of *Physical Review.* Tate was the second major influence in Homer's scientific life. His first two papers, published with Tate in 1941, were concerned with the ionization and dissociation of molecules by electron impact, and with the thermal activation of the oxygen molecule.

Homer left Minnesota in 1940 to join Bell Telephone Laboratories where he remained for 45 years, his entire professional career. Bell Labs was then at its West Street location in downtown Manhattan, and Homer found an apartment nearby. He had time after work to go out with friends, discovering opera, ballet, ballroom dancing—which he took up with enthusiasm—and skiing. It was at a ski resort on the slopes of the Berkshires in Massachusetts that he met Bonnie Cairns from Woodstock, Illinois, who was interested in art and sculpture. In contrast with the 25 years it took him to leave his first home, it took only six months before he and Bonnie were married in 1948. On a trip to Europe in 1955 Homer found a decrepit armillary sphere on the floor of an antique shop in Florence, Italy. Bonnie pitched in her half of the travel funds to produce the 60 dollars needed to buy it. Homer undertook the study of armillaries upon returning home and repaired and reconstructed the instrument, which dated from the sixteenth century. It became one of his and the family's most prized possessions.

After the war Homer and Bonnie moved to Summit, New Jersey, near Murray Hill, where the research effort of Bell Labs was relocated. They had two children, Melissa and Jonathan, and raised them in a comfortable suburban setting. The children completed graduate school, each obtaining a Ph.D.: Jonathan's in geology and Melissa's in anthropology.

A large number of physicists and other scientists had come from all over the world to join Bell Labs. Because of far-flung origins and the absence of local family and old friends, strong new ties were cemented. The Hagstrums' close friends included Joyce and Phil Anderson, John and Maggie Galt, Ted and Sissy Geballe, Bruce and Joan Hannay, David and June Thomas, Peter and Cathy Wolff, and of course, many others. The group met throughout the year, celebrating major holidays, going on outings with children, and on forays to Manhattan for symphonies and plays—off and on Broadway. After a few drinks Homer loved to recite German poetry and sing Swedish hymns. He enjoyed a good winter hike in the Great Swamp, and ice-skating with his and other children. Later in life he especially loved hiking in high alpine terrains with beautiful nighttime skies. He became a pillar of the Unitarian Church, whose minister Jake Trapp was the father of Bernd Matthias's wife, Joan.

Homer was devoted to his family. He actively encouraged Bonnie to develop her own talent as a sculptor and to travel to northern Italy to study and work in the local marble. Bonnie's work in stone is highly regarded. Some was shown in an exhibition at the National Academy of Sciences in the spring of 1991. In contrast to the Bible camp where Homer spent his youthful summers, his children went to camps with an outdoor orientation. Upon returning one summer from a camp in New Mexico, Jonathan brought home a wild bull snake for a pet. Initially the snake escaped regularly from its terrarium and roamed the house at will. Homer, in particular, was fascinated by the snake's mode of locomotion and would bring it out to show guests, usually to their great dismay. Jonathan later flew the snake back to its natural habitat.

Homer's professional life was spent at only two institutions—the University of Minnesota, where he was educated, and Bell Labs, where he did his pioneering research. His thesis was a characteristically careful and definitive investigation of the ionization and dissociation of molecules by electron impact and on the thermal activation of the oxygen molecule. His first two publications resulting from this work were published (naturally in *Physical Review*) with Tate in 1941. Homer went straight to Bell Labs in 1940 and joined the physical electronics group under Jim Fisk. That group was responsible for developing and, at first, manufacturing the "strapped" microwave magnetron that became the core element in the Allies' radar superiority during the war. One of the first dozen the English made was delivered to the United States by the famous Tizard mission of September 1940, and within a month Bell Labs had undertaken the responsibility of producing them. In the whole battle of the black boxes this and the early warning radar were most responsible for turning back the Germans in the crucial early battles on which England's survival depended—in the case of the magnetron the Battle of the Atlantic of 1941. Fisk, Hagstrum, and Paul Hartman described the work in a postwar paper in the *Bell System Technical Journal* (1946). Others who were involved include J. R. Pierce, J. C. Slater, J. P. Molnar, and A. H. White. In later years Homer enjoyed telling stories about his trip to England with John Pierce during the war in connection with this work and about the games with "fly-powered airplanes" the group invented to relieve the pressure of their work. He remained close friends with Ad White and Julius Molnar.

In 1946, with wartime priorities no longer dictating research, Homer returned to the study of dissociation by electron impact measuring the dissociation energies of important molecules such as nitrogen, oxygen, carbon dioxide, and nitric oxide (1951). The success of the experiments required ever improving the advanced vacuum techniques. Homer and H. W. Weinhart published a calibrated leak made from a porcelain rod (1950), but in fact his real contribution was in setting, and then breaking again and again in the course of the years, records for vacuum pressure and other measures of cleanliness (1976,1).

In the early 1950s Homer turned his attention to the interaction of ions with metal surfaces (1960). His first paper was on electron ejection from Mo by He^{+}, He^{++}, and He_2^{++} (1956). Homer recognized that this process could be turned into a new kind of spectroscopy: ionization neutralization spectroscopy (INS). This required new instrumentation, new experimental protocols, and new theory, all of which Homer took on and succeeded in arriving at workable solutions. This led to his first paper, in 1953, on the instrumentation and experimental procedure. The theory of the neutralization process at the solid surface turns out to be a complicated two-electron quantum problem. As the slow ion approaches the surface some of the large neutralization energy (i.e., the negative of the ionization energy of the atom) goes to emitting an electron from the surface while the second electron falls into the ion. The spectroscopic information is contained in the kinetic energy distribution of the electron emitted from the surface. Homer considered two related paths (1954, 1961), the first being a direct Auger following the theory of S. S. Shekhter (*J. Exp. Theor. Phys.* [U.S.S.R.] 7[1937]:750) and the second being more complex, involving resonance neutralization followed by Auger de-excitation (H. S. W. Massey, *Proc. Camb. Philos. Soc.* 26[1930]:386).

Many of Homer's wartime associates who were still at Bell had been tapped for higher administration, mostly on the technical side. During the immediate postwar years he continued to work in the physical electronics group, which did research mostly related to vacuum tubes. But this group was also mined for administrative talent, in view of the expectation that heated cathodes and vacuum technology would soon be superseded by solid-state devices. From this group came, for instance, Molnar, K. G. McKay, John Hornbeck, and its head, Addison White, as higher-level managers; several eventually went on to have very distinguished careers in management.

Homer, along with Conyers Herring, represented to the next generation such as ourselves the possibility of a second fruitful track within the expanding Bell Labs, a career staying within the cutting edge of fundamental science without succumbing either to the blandishments of academia or the technical management route. But in 1954 the Bell administrators recognized that surface physics was becoming an ever more important frontier in science and in technology. New and improved methods for characterizing surfaces were needed in semiconductor physics and technology, as well as in heterogeneous catalysis and biology. One of the first interdisciplinary research departments with expertise in physics, chemistry, and metallurgy—but focused on a single subfield, surface physics—was organized with Homer as department head. Sidney Millman, his perceptive laboratory director, undertook to relieve Homer of the most burdensome administrative duties in order to free his research time. Within a few years there were other interdisciplinary departments such as biophysics.

Homer recognized that INS had potentially more surface sensitivity than the more widely used sensitive soft X-ray scattering (SXS) and photoemission spectroscopies (PES). But more accurate INS data were required. It took Homer five years of sustained research to design and construct a new apparatus that pioneered by incorporating a low-energy electron-diffraction insert for being able to investigate the surface symmetry and reconstruction. In the course of this work he introduced the concept of a turret within which the sample could be maneuvered to allow a number of different probes or coatings to be applied to the same surface, a methodology that was widely applied. The apparatus for INS and the procedures for the data analysis are described by Homer in a comprehensive article (1966,1). He was awarded the Medard W. Welch Award by the American Vacuum Society in 1974. In 1976 he was elected to the National Academy of Sciences and was awarded the Davisson-Germer Prize by the American Physical Society.

With a minimum number of assumptions the relative probability that an electron at a given band energy in the solid will be involved in the neutralization process—the transition probability—is calculated. It depends upon the initial and final state densities and upon the transition matrix elements and final state interactions much as in PES. It depends upon wave functions outside the surface and is thus more surface sensitive than the other spectroscopies. It is also amenable to studies of surfaces containing foreign atoms. In a series of investigations with Y. Takeishi (1965), G. E. Becker (1966, 1973), E. G. McRae (1976), and T. Sakurai (1976, 1979) that continued until his last working day at Bell, Homer kept taking data. He and his collaborators studied pure well-characterized surfaces of the metals Fe, Co. Ni, Ag, Cu, W, and Mo and the semiconductors Si, Ge, and GaAs. The studies of these surfaces with adsorbed oxide, sulfides and other chalcogenides, and hydrides were made, as well as with alkali metals. Among many other results of interest was the observation of band narrowing at the surface for Cu and Ni, the first observation of surface resonances in adsorbed atoms and of the kinetics of adsorption. At the time of his retirement he was making the first measurements of magnetic resonant states in adsorbed atoms, though this work was not completed.

Homer was that rare type of scientist who enjoyed working on all aspects of a carefully thought out research program, from his initial idea to the design and construction of the needed apparatus, to the taking of data and then modifying the theory when necessary to obtain a detailed understanding. In the golden age of research at Bell Labs at that time it was possible for Homer to take five years from his research to build the apparatus. Even though he succeeded in establishing INS as a valued spectroscopy, it has not become a standard laboratory practice. The confluence of new developments rendered INS of less value than Homer had envisioned. In particular, a spectacular array of new scanning tunneling probes has come into being following Hans Rohrer and Gerd Binnig's revolutionary demonstration of scanning tunneling microscopy in 1984. There the electron tunneling is by means of wave functions that extend from the surface much as in INS. In all other respects the tunneling tip, which can be accurately controlled in all three dimensions, is much superior to the moving ion. INS has been made obsolete after only two short decades of existence. If there is a lesson to be learned, it is that science moves ahead on many fronts and the most admirable achievements are not necessarily the most enduring.

Homer kept taking data right up until the day he retired from Bell. He planned to be engaged in analysis in the years ahead. Unfortunately, about that time Homer suffered a series of small strokes that damaged his short-term memory and impaired his ability to concentrate. Nothing that has transpired detracts from Homer's achievements. While INS will not be remembered as a milestone of twentieth-century physics, Homer Hagstrum will be remembered as a pioneer who created many of the ideas and techniques of modern surface physics.

SELECTED BIBLIOGRAPHY

1941

With J. T. Tate. Ionization and dissociation of diatomic molecules by electron impact. *Phys. Rev.* 59:354.

With J. T. Tate. On the thermal activation of the oxygen molecule. *Phys. Rev.* 59:509.

1946

With J. B. Fisk and P. L. Hartman. The magnetron as a generator of centimeter waves. *Bell Syst. Tech. J.* 25:167.

1950

With H. W. Weinhart. A new porcelain rod leak. *Rev. Sci. Instrum.* 21:394.

1951

Ionization by electron impact in CO, N_2, NO, and O_2. *Rev. Mod. Phys.* 23:185.

1953

Instrumentation and experimental procedure for studies of electron ejection by ions and ionization by electron impact. *Rev. Sci. Instrum.* 23:1122.

1954

Theory of Auger ejection of electrons from metals by ions. *Phys. Rev.* 96:336.

1956

Electron ejection from metals by ions. *Bell Labs Rec.* 34(2):63.

1960

With C. D'Amico. Production and demonstration of atomically clean metal surfaces. *J. Appl. Phys.* 31:715.

1961

Theory of Auger neutralization of ions at the surface of a diamond-type semiconductor. *Phys. Rev.* 122:83.

1965

With Y. Takeishi. Effect of electron-electron interaction on the kinetic-energy distribution of electrons ejected from solids by slow ions. *Phys. Rev.* 137:A304.

With Y. Takeishi. Auger-type electron ejection from the (111) face of Ni by slow He^+, Ne^+, and Ar^+ ions. *Phys. Rev.* 137:A641.

1966

Ion-neutralization spectroscopy of solids and solid surfaces. *Phys. Rev.* 150:495.

With G. E. Becker. Ion-neutralization spectroscopy of copper and nickel. *Phys. Rev. Lett.* 16:230.

1967

With G. E. Becker. Ion-neutralization spectroscopy of copper and nickel. *Phys. Rev.* 159:572.

1971

With G. E. Becker. The interrelation of physics and mathematics in ion neutralization spectroscopy. *Phys. Rev. B* 4:4187-4202.

1973

With G. E. Becker. Folding and nonfolding electron distributions in ion neutralization spectroscopy and evidence for an electronic superlattice at the Si(111)7 surface. *Phys. Rev. B* 8:1592-1603.

With G. E. Becker. Resonance, Auger, and autoionization processes involving $He^+(2s)$ and He^{++} near solid surfaces. *Phys. Rev. B* 8:107.

1975

With K. C. Pandey and T. Sakurai. Si(111):SiH_3—A simple new surface phase. *Phys. Rev. Lett.* 35:1728-31.

1976

With E. G. McRae. Surface structure experimental methods. In *Treatise on Solid State Chemistry,* vol. 6A, ed. N. B. Hannay, pp. 57-163. New York: Plenum.

With T. Sakurai. Interplay of the monohydride phase and a newly discovered dihydride phase in chemi-sorption of H and Si(100)2x1. *Phys. Rev. B* 14:1593.

1979

With T. Sakurai. Study of clean and CO-covered Ge(111) surfaces by UPS and INS. *Phys. Rev. B* 20:2423.