



William Oliver Baker

1915–2005

BIOGRAPHICAL

Memoirs

*A Biographical Memoir by
Louis Brus*

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NATIONAL ACADEMY OF SCIENCES

WILLIAM OLIVER BAKER

July 15, 1915–October 31, 2005

Elected to the NAS, 1961

Physical chemist William O. Baker led scientific research at AT&T's Bell Laboratories during the period, post-World War II, of its legendary achievements: semiconductor materials science, silicon transistors, solar cells, software-controlled electronic switching, digital communication based on information theory, the Unix operating system, satellite communication, optical communication involving semiconductor lasers and glass fibers, and wireless cellular technology. This massive R&D effort by the Bell system—the AT&T national telephone monopoly at the time—virtually created the digital-information age that has completely transformed our modern world.

Baker became Bell Labs' vice president for research in 1955 and its president in 1973. Believing deeply in the value of research in a technology organization, over time he convinced AT&T to expand research, both in size and in scope, to a broader range of sciences underlying telecommunications. Baker said: "Research must 'look away' from everyday pressures of the ongoing development and engineering enterprise toward the vistas opened by new knowledge and technique."¹



B. O. Baker

By Louis Brus

By the 1970s the research area had grown to about 1,300 people; Bell Labs as a whole then had about 25,000. The research effort was enormously productive. As of 2012, nine scientists have won Nobel Prizes for research performed inside Bell Labs during Baker's leadership and immediately following his age-related mandatory retirement in 1980: Charles H. Townes for laser physics, Philip W. Anderson for solid-state theory, Arno Penzias and Robert W. Wilson for the cosmic radiation background, Steven Chu for optical trapping, Horst L. Stormer and Daniel C. Tsui for the fractional quantum Hall effect, and George E. Smith and Willard S. Boyle for charge-coupled device (CCD) imaging.

The early years

Born July 15, 1915, and raised on a turkey farm on the eastern shore of Maryland, Baker grew up knowing the meaning of hard work. He was the only child of Harold and Helen May (Stokes) Baker. The family had lived in New York City for generations before buying the farm in 1913 and his parents remained intellectually curious and read widely, though neither had gone to college. Young Baker was much influenced by, and very close to, his mother—an exceptional woman who was known nationally for her pioneering work in scientific turkey husbandry. She wrote two books on this subject. Baker attended a one-room schoolhouse until high school and became a standout undergraduate at tiny Washington College in Chestertown, Maryland, just 10 miles from the farm.

While his intention was always to pursue a career in science, he also had a deep interest in the humanities. Baker received a classical liberal arts education at Washington College, with only a modest exposure to science even though his major was chemistry. In his senior year he was editor of the student newspaper and president of the debating society. He was also president of his fraternity. He played the lead role Hamlet in a student production of Shakespeare's tragedy. His 1935 senior yearbook says "His interests range from the nesting habits of birds to the philosophy of the Greeks, from colonial architecture to the amino acids." Baker never lost this fascination with all aspects of culture, human nature, and the world around him.

Baker focused on science when he entered the chemistry Ph.D. program at Princeton in the fall of 1935. It was an exciting time, as new physical methods and new quantum-mechanical chemical-bonding ideas, especially those of Linus Pauling, were then coming into molecular science. Science graduate students all lived together in one residential college; Baker became close friends there with Conyers Herring, then a theoretical solid-state physics student with Eugene Wigner and later a career researcher at Bell Labs. Solid-state physics was to become critical to Bell Labs in the 1950s; however, in the 1930s the electronic properties of solids were a poorly understood and minor area of physics. Baker took graduate courses both in chemistry and physics. He studied quantum mechanics with Henry Eyring and electromagnetism with J. van Vleck, who was visiting from Harvard. He attended astrophysics lectures given by Henry Norris Russell; and he worked briefly in the nuclear physics lab of G. P. Harnwell. In a 1985 interview, Baker vividly described how exciting it had been to hear Niels Bohr's famous January 1939 colloquium reporting the discovery of nuclear fission.²

His Ph.D. thesis advisor was Charles P. Smyth, an expert in dielectrics who had worked briefly with Peter Debye in Europe. In his thesis Baker inferred molecular motions from observation of phase transitions and hysteresis in the dielectric and optical properties of organic van der Waals crystals. He synthesized and purified samples, and took measurements with a capacitance bridge and vacuum-tube AC amplifier. Extensive purification by repeated recrystallization was essential to eliminate impurities. Baker received the premier fellowships available in the department, and later in life Smyth said that Baker had been his brightest student. In 1939, at age 24, Baker earned his Ph.D. *summa cum laude* in chemistry. This was a remarkable achievement after entering Princeton with a comparatively weak scientific background.



Baker adjusts an optical polarimeter in Bell Labs circa 1945.

Baker's broad cultural and scientific interests served him well in everything he undertook in life.

A rising star at Bell Labs

In 1939 Baker joined Bell Labs in New Jersey as Vice President Mervin Kelley began to form an embryonic research unit inside this communications-technology organization. Around this time, at the beginning of World War II, Kelley also recruited Claude Shannon, William Shockley, and Charles Townes. Baker joined a chemistry group, closely coupled to engineering and manufacturing, that focused on materials in the Bell system. Calvin Fuller, an expert on X-ray polymer characterization, was Baker's supervisor and mentor. The group had a vision that materials need not just be taken from nature but could be scientifically designed for optimal properties.

Fuller and Baker were influenced by the emerging understanding of polymers as covalently bonded macromolecules. This idea, originally proposed by Hermann Staudinger in Zürich, was strongly supported by Wallace Carothers' pioneering synthesis of nylon at Du Pont in 1935. Baker physically characterized a series of solubilized short linear polymers of known composition and length, to test the basic ideas and predictions of Staudinger and of Paul Flory. He also correlated macroscopic mechanical and dielectric

properties with microscopic structure in a wide range of crystalline polymers. At Princeton as a Ph.D. student, and at Bell Labs before 1943, Baker worked full-time in the laboratory. He was quite productive, publishing 11 papers in the *Journal of the American Chemical Society* and the *Journal of Chemical Physics*.

Everyone at Bell Labs worked on military technology during the war. For his part, young Baker played an essential role in the massive American effort to create copolymer synthetic rubber from butadiene and styrene feedstocks. He assumed responsibility for, and led laboratory work in, basic polymer-characterization science and polymer testing for quality control. This crash program—with the U.S. rubber industry effectively nationalized—was quite successful; production reached 700,000 tons per year in 1945.

During this research Baker discovered that emulsion polymerization created a previously unrecognized polymer structure, which he named “microgel”—a three-dimensional single-polymer macromolecule, of typical size 100 nm, somewhat cross-linked and significantly swollen by solvent. In 1949 Baker summarized his microgel research. Later in life, when discussing more general themes, Baker often wrote in a literary metaphoric style, but in this technical article his style was direct and logical. His fundamental insight was that the copolymer macromolecule would be of the same size as the emulsion micelle in which the gelation reaction occurred. He made the proposal, later confirmed, that this size controls mechanical properties of the final vulcanized extruded rubber.

To characterize microgel molecules, Baker systematically studied solubility, diffusion, and sedimentation behavior in organic solvents, using classical chemical thermodynamic ideas. He found solvent conditions under which microgel macromolecules could be individually dissolved. It was understood at this time that the thermodynamic driving force for hydrocarbon polymer solubility is entropy gain. Baker analyzed his data to show that the observed entropy gain was what would be expected for cross-linked, but not linear, polymer molecules. The cross-linked model was also consistent with the magnitude of the diffusion constant and sedimentation velocity. Moreover, swollen solubilized microgels at high dilution could be directly detected and characterized in right-angle light scattering using methods developed by Debye, a consultant on this research. Primitive electron micrographs of dried microgels were also obtained.

Baker’s work on microgels, like other research outcomes that occurred repeatedly at Bell Labs, was a significant discovery motivated by a practical issue. This research on colloidal microgels also anticipated much modern research on colloidal nanocrystals, especially in

methodology. Today, microgel polymer architectures are widely known. Microgels often exhibit complex structural changes as a function of external stimuli, such as pH and flow shear, and are being explored for drug delivery.

After World War II, research started again in Bell Labs on telecommunications problems. Famously, the transistor was invented in 1947 by a Shockley-led team explicitly assembled to search for a possible solid-state device to replace vacuum tubes and mechanical relay switches. Shannon's revolutionary paper on information theory appeared in 1948—the same year that Baker was promoted to department head for polymer science.

The materials group focused on developing solid polyethylene as a sheathing to replace lead on outdoor telephone cables.³ Polyethylene, a saturated hydrocarbon without polar functional groups, in principle had excellent strength, chemical inertness, and lossless high-frequency dielectric response. The British first synthesized polyethylene by accident in the 1930s, and they used it to insulate radar cables during the war. Baker analyzed and solved the critical problem of polyethylene cracking under bending stress; he did so by relating uniaxial and biaxial stress-strain relationships, and mechanical failure, to polyethylene molecular weight. In particular, because higher-weight polyethylenes were found to reorient rather than crack under biaxial stress, significantly improved sheathing could be manufactured.

In addition, new polyethylene materials were systematically created, stabilized, and optimized for other AT&T applications, such as undersea cables and indoor wiring (which previously had paper insulation). Polyethylene created huge cost savings and improved performance in the Bell system. Baker once estimated that these savings were equal to the budget for all of research at Bell Labs for 10 years. This success with polyethylene was built on the fundamental research that the polymer and dielectric group had carried out since the 1930s. Today polyethylene is ubiquitous, used as a structural material and in packaging, in addition to electronics.



William O. Baker, approximately 1960. (Portrait by Augusta Berns.)

As the polyethylene program developed, Baker quickly rose in the Bell Labs hierarchy. By 1955, at age 40, he was in charge of all research there.

A guru, a gentleman, a patriot

Baker had a prodigious memory for people, facts, and ideas. He made a point to befriend everyone at Bell Labs, from the most creative and quirky scientist to the lowliest technician.

A man of style and grace, with a kind word and genuine concern for all, he did not naturally dominate a group or project his ego. He was reserved and did not often volunteer his opinions. Baker's speeches were inspirational and literary, often quoting English poetry, and reflective of his early interest in humanities at Washington College. He kept detailed records and handwritten notes, and his office was piled high with stacks of paper. Yet as a manager Baker was organized—he was quick to assess people, to understand breakthroughs, and to accurately extrapolate into the future. His colleagues had deep respect for his probing intelligence and acumen. Yet he preferred to work in the background so that others would get public credit. His goal was always that the results of research be used to benefit mankind; it was this aspect that made Bell Labs' research area different from a university.

Baker's great gift was his understanding of how to organize, encourage, and lead people, especially ambitious scientists, so as to bring out their best. Even though he had hundreds of Ph.D.s in his organization, he read papers by individual scientists. Often he would drop by the researcher's lab unannounced, discuss the results for a few minutes, and encourage further work.

Baker did everything he could to support young scientists working full-time in research, and he made a tremendous effort to find and recruit the most creative recent Ph.D.s. Baker believed that great discoveries are made by individual scientists working in a stimulating environment. He once said, "The ideas of scientific discovery come one at a time from one person and one mind at a time. Sometimes two or three can aid each other."⁴ A stimulating Bell Labs research culture was built on free and spontaneous discussion across the entire organization; and this often led to new insights and interdisciplinary research.

There was stable long-term funding, and it was not necessary to write proposals. Rather, a young scientist needed only to convince his or her managers that the science was really interesting and that there was some possibility the research might ultimately influence the

Bell system. Often just a short discussion was sufficient. The managers themselves were scientists of accomplishment, promoted from within the research ranks, who understood telecommunications. Once when a young scientist asked where the money for a new idea could be found, Baker told him to “worry about and champion the right ideas; let others worry about budget support.” Moreover, a young scientist had the “freedom to fail.” It was recognized that truly novel projects, in comparison with safer research sure to lead to publication, might well fall short despite heroic effort. If this occurred, a scientist could go on to other ideas, without prejudice to his or her career.

Baker’s great gift was his understanding of how to organize, encourage, and lead people, especially ambitious scientists, so as to bring out their best. Even though he had hundreds of Ph.D.s in his organization, he read papers by individual scientists. Often he would drop by the researcher’s lab unannounced, discuss the results for a few minutes, and encourage further work. As he said, “you ask the right questions to stimulate the creative ego and then bend over backwards not to claim credit.” The number-one rule for a Bell Labs manager was not to compete with those doing the research. The management structure and style developed at the Labs during this period have since been widely adopted elsewhere.

It is remarkable to realize that during Baker’s long career of doing and overseeing Bell Labs research, he also was devoting extensive time to national security. In the 1940s he was recruited to join a secret committee formed by President Truman to estimate when the Soviets would first have an atomic bomb, and he later became a trusted advisor to Presidents Eisenhower and Kennedy. In the 1950s Baker led efforts to define and establish new technology for intelligence gathering in the National Security Agency, an entity whose very existence was secret at the time. He also specifically developed the plan to establish the U.S. Defense Communications Agency, and he ensured that the intelligence community used the latest solid state and computer technology.

In times of crisis Baker went to Washington; in fact, during the 1962 Cuban missile crisis, he personally brought the news to President Kennedy that the Russian cargo ships had turned back. He served a total of 29 years, under five presidents, on the President’s Foreign Intelligence Advisory Board. But rather than take a full-time position in the government, he preferred to influence events behind the scenes while leading research at Bell Labs. Thus in his office at the Labs there was a secure telephone line to the White House. Of course, most of his national security work was quite secret, becoming known only after the Cold War ended.

Having lived through the dark days of World War II, Baker had become a patriot who invested his time, intellect, and wisdom to defend freedom and human rights, and to prevent nuclear catastrophe. In recognition of his pioneering and sustained contributions, today the intelligence community's principal award, given by the Intelligence and National Security Alliance, is named the William Oliver Baker Award.

Baker was also a champion of the importance of materials science, both in the Bell system and throughout the nation, as a critical aspect of virtually any technology. When he was young, materials science was not a scientific discipline; moreover, academic interdisciplinary research, especially between science and engineering departments, was rare. In 1958, as a member of President Eisenhower's Science Advisory Committee, Baker proposed, and the president approved, new federal funding for academic materials research and education. Drawing on his Bell Labs experience, Baker envisioned a "Materials Research Program" of university-based centers that combined science and engineering, provided central technical facilities, and enjoyed stable multiyear funding.

During the 1960s this new federal program, and its model for structuring academic research, prospered; in 1972 the Materials Research Program was transferred into the National Science Foundation. Over time the centers adopted a team approach: faculty formed interdisciplinary groups to work on specific problems. Today materials science as an academic discipline has grown enormously from these early beginnings, and the interdisciplinary center model has been adopted across all of science.

Improving the human condition

As he grew older Baker assumed the role of senior statesman. He revealed some of his core beliefs when he spoke on the relationship between science and society at the 1960 annual meeting of the American Association for the Advancement of Science. Baker believed that science has the power—transformative power—to aid humanity, and that scientists must fully engage society despite the imperfect nature of politics. "Scientists must carry forth to all the world the bright hope, the good fortune, that science does betoken for mankind," he said. "We can indeed negate the spreading cynicism and nihilism of our time. Both are alien to science and to research."⁴ But he also acknowledged the intrinsic limits of science. He said, "To state it baldly, scientifically there are limits on truth, there are limits on certainty, and there are limits on discovery itself." Science is based on experiment, and as such is necessarily incomplete, always evolving, and subject to unpredictable changes and, though rare, drastic revision. Still, said Baker, "the scientist has to tell the whole truth

as he knows it at that moment in time, and nothing less or different can be expected.” Baker quoted similar thoughts from Richard Feynman as well. Today we see echoes of this issue—the nature of scientific “truth”—in discussions on climate change.

Baker received a great many honorary degrees and awards, including the Priestley Medal—the highest honor bestowed by the American Chemical Society. He won the NSF Vannevar Bush Award for Lifelong Leadership in Science and Technology, the President’s National Security Medal, and the National Medal of Science. To honor Baker upon his retirement, Bell Labs endowed the National Academy of Sciences’ annual Award for Initiatives in Research, most appropriately, “to recognize innovative young scientists and to encourage research likely to lead toward new capabilities for human benefit.”

Baker was chairman of the Board of Trustees both for Rockefeller University and the Andrew Mellon Foundation. He maintained a lifelong relationship with Princeton University, serving for 22 years on the Board of Trustees, and receiving several honors, including a named professorship in the computer science department and an honorary Doctorate of Laws degree. Robert Goheen, who was Princeton’s President in the 1960s, warmly praised Baker’s service in academia, saying “On my part, I know of no layman who has contributed so much so fruitfully to higher education in America through the quality of his mind, dedication to educational improvement and reform, a well mastered fund of experience, and an uncommon quiet ability to help colleagues both grasp the essence of critical issues and base their decisions more on ascertainable fact than wishful thought.” In this statement we see something of how his peers viewed Baker’s analytical mind and reserved yet effective leadership, qualities that were valued at Bell Labs and elsewhere.

Baker served for 34 years on the Scientific Advisory Board of the Welch Foundation in Texas. The author was a young scientist in materials research at Bell Labs when Baker was president, and after he retired from the Labs it was my good fortune to work with him when he organized a Welch Conference on Nanochemistry in 1995. He was then 80 years old, and continuing to focus on the newest ideas in chemistry. Baker lived through the Great Depression as a student, and he had seen its effect on the family farm and on the country. As a result he developed the habits of dressing simply, driving old cars, and leading a quiet life without interest in luxury. Bird watching was a lifelong hobby. He kept his family life separate from his life at Bell Labs. He married Frances Burrill in 1941; they had one son, Joseph, who made a career in information technology.

Baker's life was exceedingly interesting and eventful. His education began in a one-room rural schoolhouse, and he rose to shape and lead a world-famous scientific institution. He was one of the most influential leaders of twentieth-century American science and technology. Late in life, as he was organizing his papers for donation to Princeton, friends often suggested that he write his autobiography. Baker steadfastly refused. He would reply, "You should tell the story of Bell Labs instead." In essence, Bell Labs was Baker's life.

It is tragic that Baker clearly anticipated, and lived to experience, the collapse of Bell Labs as the Bell system's monopoly was broken up. In 1974, when asked what would happen if the U.S. government were to win the antitrust suit against AT&T, Baker said, "Well, I think that Bell Laboratories as we know it now would just disappear." In retirement he watched this occur in slow motion, finally concluding in 2002 that "Bell Labs does not exist as an institution." The residual Bell Labs of today (now part of Alcatel-Lucent) does not do physical- science research. Nevertheless, some of the spirit and structure of Baker's Bell Labs is present in every modern university interdisciplinary center. In addition, the science and technology that Bell Labs created under Baker's leadership have markedly improved the human condition throughout the world. Together, these results of Baker's life's work are his legacy to mankind.

SOURCES

Ron Breslow, Ed Chandross, Venky Narayanamurti, Mark Rochkind, Frank Stillinger, A. Michael Noll, and Phil Anderson shared their memories with me. Noll has described Baker's life and achievements in detail on the William O. Baker website. A recent book by Jon Gertner, *The Idea Factory: Bell Labs and the Great Age of American Invention* (Penguin Press, 2012), tells the story of Bell Labs and describes its leading figures, including Baker. Another recent book, dedicated to Baker's memory, contains autobiographies of Bell Labs research scientists during his tenure. Edited by Noll and Michael Geselowitz, it is titled *Bell Labs Memoirs: Voices of Innovation* (IEEE History Center, 2011).

NOTES

1. Millman, S. (ed.). 1983. *A history of science and engineering in the Bell system. Vol. 4: Physical sciences 1925-1980*, p. xviii. Indianapolis: AT&T Technologies.
2. W. O. Baker, interview by M. Goldstein, and J. L. Sturchio, May 23, 1985 and June 18, 1985, Oral History Transcript #0013, Chemical Heritage Foundation, Philadelphia, PA.
3. Millman, S. (ed.). 1983. *A history of science and engineering in the Bell system. Vol. 4: Physical sciences 1925-1980*, chapter 14. Indianapolis: AT&T Technologies.
4. W. O. Baker's comments on: Weaver, W., C. P. Snow, T. M. Hesburg, and W. O. Baker. 1961. The moral un-neutrality of science. *Science* 133(3448):255-262.

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