NATIONAL ACADEMY OF SCIENCES

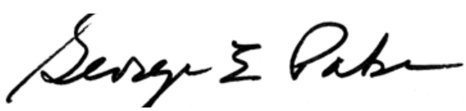
# GEORGE EDWARD PAKE
1924—2004

*A Biographical Memoir by*
CHARLES P. SLICHTER

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

*Biographical Memoir*

COPYRIGHT 2009
NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.



# GEORGE EDWARD PAKE

*April 1, 1924–March 4, 2004*

BY CHARLES P. SLICHTER

GEORGE PAKE WAS A brilliant scientist, a devoted teacher, a wise and strong academic leader, and an exceptional director of industrial research who brought to life a remarkable, highly creative industrial research laboratory. His accomplishments affect the lives of millions of people all over the world in numerous ways.

I met George in 1947 when we were graduate students doing our doctoral research with Edward Purcell. We maintained c lose scientific contact through the early 1960s and professional contact into the early 1970s, but our contacts became more sporadic as his enormous responsibilities at Xerox grew in scope and intensity. Nevertheless, any occasion on which I saw George was a delight. We picked up where we left off with no sense of intervening time. I feel especially fortunate since I saw close up his ability as a scientist, as a teacher, as someone who could bridge disciplines, and as someone others sought to be their leader.

George grew up in Kent, Ohio, where his father taught English at Kent State University. George loved baseball, remaining a fan all his life. He also learned to play the French horn, deriving great pleasure from it for many years. Pearl Harbor marked his senior year in high school. Interested in science or engineering, he was thrilled when he learned he had been awarded a Westinghouse Scholarship to attend Carnegie Tech. It paid full tuition, a stipend for living expenses, and a guarantee of summer jobs at Westinghouse. The program started on graduation from high school with a summer job at Westinghouse. There he met a young but slightly older scientist, Jacob Goldman (who called himself "Jack") who later played a central role in George's life. Goldman had just gotten his Ph.D. at the University of Pennsylvania.

At Carnegie Tech, George started as a major in mechanical engineering, specializing in aeronautics but soon switched to physics. The Physics Department had several outstanding scientists, including Otto Stern and his protégé Immanuel Estermann. Stern and Gerlach had done the famous atomic beam experiment that demonstrated spatial quantization. Another star was Frederick Seitz, who had done his thesis with Eugene Wigner just a few years earlier at Princeton, and whose book *The Modern Theory of Solids* (McGraw-Hill, 1940) basically defined the field of solid-state physics, from which in several years came the invention of the transistor. (Seitz, who had been Goldman's Ph.D. thesis adviser at the University of Pennsylvania, had just moved from there to Carnegie Tech).

In 1944-1945 Pake studied for a master's degree guided by Estermann. In 1944 the Nobel Prizes for 1943 and 1944 were announced. The 1943 prize went to Otto Stern for his contributions to the development of the atomic beam method of measuring magnetic properties of atoms and his measurement of the magnetic moment of the proton. The 1944 prize went to I. I. Rabi for his invention of the magnetic resonance method of measuring nuclear magnetism. (Although Stern together with Gerlach are perhaps most famous for using the atomic beam method to demonstrate spatial quantization of angular momentum, this is not mentioned in the citation for the Nobel Prize, which went only to Stern.) The celebration was an inspiring occasion for George, with I. I. Rabi, James Franck (Nobel laureate in physics from the University of Chicago), Ed Condon (associate director of research at the Westinghouse Laboratory), and J. H. Van Vleck (from Harvard) in attendance or as speakers. George was one of a small number of students invited to attend the celebration—a heady occasion. He did not realize that four years later his Ph.D. thesis would be based on the concept of magnetic resonance, would demonstrate spatial quantization, and would as a by-product measure the magnetic moment of the proton.

Having been kept from military service by a back problem from scoliosis, Pake went straight through Carnegie Tech in eight consecutive four-month trimesters, simultaneously getting both a bachelor's and a master's degree in April 1945. Normally he might then have gone to graduate school, but they were all shut down because of the war. Fred Seitz suggested that he get a war research job at Westinghouse and through Ed Condon got one for Pake working on microwave components for airborne radar. There again George saw Jack Goldman. In August 1945 the atom bomb was dropped, and the war came to a close.

Pake applied to graduate school at both Princeton and Harvard. With letters of recommendation from both Condon and Seitz and a superb record at Carnegie Tech, George had strong credentials. Seitz recommended Princeton where he had studied with Wigner but also recommended Harvard. George was admitted to both. Van Vleck was the chairman of the Harvard department. He wrote a warm handwritten letter, strongly urging Pake to come and offering a teaching assistantship. Princeton sent a stiff form letter admitting him. It is not surprising that George chose Harvard.

George entered graduate school at Harvard in February 1946, fortuitous timing since Purcell, Pound, and Torrey performed the first experiment on nuclear magnetic resonance (NMR) the previous December. George had intended to become a theorist, but hearing Purcell describe the first NMR experiment inspired him to ask Purcell to be his thesis adviser. Bob Pound had become a junior fellow at Harvard, and was doing NMR work across the hall from Purcell's lab. Purcell had taken on one student, Nicholaas Bloembergen, who had joined the research. So George Pake became Purcell's second student.

Bloembergen focused primarily on proton NMR in water and various other liquids. He had found that those NMR lines were very narrow and with Purcell and Pound had concluded that the rapid tumbling of the molecules in liquid were responsible for the sharpness of the NMR lines. Pake suggested that a test of this idea would be to look at the NMR spectrum of water molecules in a solid, where the motions would be absent. He was most familiar with water in the molecule $CuSO_4.5H_2O$ from freshman chemistry, but rejected it because the electron spin of the Cu atom made it a strong magnetic influence. Instead he settled on $CaSO_4.2H_2O$, gypsum, and undertook a study of the proton resonance of water of hydration in a single crystal. The proton spectrum was, as he had anticipated, much broader than lines in liquids but to his surprise he found that the absorption line was a doublet in contrast to the single lines of liquids. He soon showed that the doublet arose because each proton in the water molecule experienced a magnetic field arising from the other H atom. Since the proton has a spin 1/2, the orientations are quantized into two orientations, up or down, in the external laboratory magnetic field. Thus the field of the neighbor either aided or opposed the laboratory field. This was just like the famous atomic beam result of Stern and Gerlach that demonstrated spatial quantization for the first time. The splitting depended on how the crystal (and thus the water molecules it contained) was oriented in the field of his magnet. Pake showed that he could use NMR to measure the relative positions of the two protons (the spatial orientation of the water molecule) as well as the distance between the protons.

At that time George was studying quantum mechanics in the course of Julian Schwinger, and was thrilled to discover that he needed the material to get the correct interpretation of his experimental results. If one simply said that the role of quantum mechanics was that the neighbor spin could point either up or down, like the result of the Stern-Gerlach experiment, George predicted a magnetic field splitting, $\Delta H$, between the two absorption lines of the doublet of

$$\Delta H=\mu(3\cos^2\theta-1)/r^3$$

where $\mu$ is the nuclear magnetic moment, r the distance between the two protons, and $\theta$ the angle between the applied static magnetic field and the internuclear vector.

However, in quantum mechanics one must be careful if several different quantum states have the same energy. If we label the two protons in the water molecule as A and B, George noted that the state in which spin A is up and spin B is down has the same energy as the state in which spin A is down but spin B is up. The two states are “degenerate.” In a proper treatment one finds that the problem should be described in terms of the singlet and triplet states made up of a coherent superposition of the A up, B down and A down, and B up states. Using them Pake found that the correct formula was

$$\Delta H=(3/2)\mu(3\cos^2\theta-1)/r^3.$$

This was a triumph because without the factor of 3/2 he was getting a value for proton-proton distance that disagreed with the value deduced from gas spectra of the water molecule (Pake, 1948).

The need to use the triplet states is an example of coherent superposition in quantum mechanics. George's result is one of the first examples of the importance of quantum coherence in nuclear magnetic resonance. It is this property of spin systems that underlies the whole concept of quantum computers, a topic of enormous interest today, and is why many schemes to make a quantum computer utilize electron or nuclear spins. Moreover, the NMR dipolar splittings in solids are now at the forefront of the exciting field of biomedical science, for example, study of objects such as amyloid plaques suspected to play a role in such diseases as diabetes or Alzheimer's disease. Since the plaques are not crystals, their structure cannot be determined by the standard method, X rays. However, their structure can be found by advanced NMR methods that enable measurement of dipolar couplings while at the same time having narrow NMR lines like those of a liquid.

As mentioned above, I find it fascinating that in his thesis George demonstrated spatial quantization and measured the magnetic moment of the proton, the results that lay behind the Nobel Prize of Otto Stern that George helped celebrate at Carnegie Tech. I do not know whether George thought about his work in this manner.

Purcell reported George Pake's interesting result over lunch at the Harvard Faculty Club to his friend the physical chemist George Kistiakowsky. Kisty, as he was known to friends, became quite excited and suggested that he send his student, Herbert Gutowsky, over to Purcell to see whether Gutowsky and Pake could use NMR to determine the structure of the molecule diborane, $B_2H_6$. Although a molecule with a simple formula, its structure was unknown and was a matter of substantial interest as well as controversy.

Gutowsky had been studying the structure of molecules using infrared spectroscopy but in September 1947 he stopped that work to begin preparation of samples of diborane for study with Pake. In February 1948 Herb and George made their first NMR run on diborane. To have a solid they needed to freeze the diborane so they made a simple but crude apparatus for cooling the sample to low temperatures using liquid nitrogen in prodigious amounts. The spectrum was a featureless blob, without resolved lines such as Pake had seen for water. (I suspect that was because the protons of diborane had so many near-neighbors from other molecules, in contrast with the water molecules in gypsum in which each proton had only one near-neighbor from its own water molecule.)

Pake and Gutowsky quickly switched to study a number of other solids, seeking to get comparable spectra. Although they did not succeed in determining the spectrum of diborane, they did observe a variety of spectra of other molecules containing CH, $CH_2$, and $CH_3$ groups. In the process they found the characteristic NMR absorption line shapes of singles, pairs, and triples of protons and since they had made an apparatus that could cool samples to liquid nitrogen temperatures, they showed that at some temperatures NMR revealed the presence of molecular rotations in the solid phase.

This sequence of work done over a matter of a few months demonstrated that NMR might be a powerful tool to study the properties of solids. When Pake and Gutowsky got their Ph.D.s in June of 1948, Pake went to Washington University in St. Louis as an assistant professor of physics, and Gutowsky went to the University of Illinois in Champaign-Urbana as an instructor in the Department of Chemistry. Their detailed accounts of their joint activity can be found in two articles in the *Encyclopedia of Nuclear Magnetic Resonance* (Pake,1996; Gutowsky,1996).

Herb was hired because of his expertise in infrared methods to supervise the Chemistry Department's infrared facility but with the understanding that Gutowsky's research would be in nuclear magnetic resonance. With the help of an electrical engineering student, Herb assembled an NMR apparatus and launched a career studying chemistry by NMR. Gutowsky went on to be one of the most important figures in developing NMR as a major tool for chemistry. In my view, he more than anyone else was responsible for the realization by the chemistry community of the power of NMR. Evidence for the way the chemistry community valued Gutowsky's contributions to science was his election to the National Academy of Sciences in 1960. He was thus really Pake's first student and one can rightfully say that George Pake helped launch the use of NMR as a major tool for studies of chemistry, biology, and biomedicine.

Although the early workers made their own apparatus, their work stimulated the development of commercial apparatus by alert industrial companies such as Varian. At Stanford the close personal relationship among Felix Bloch, William Hansen, Russell Varian, and Ed Ginzton had led the newly formed company Varian Associates to begin carrying out NMR experiments. Indeed, many of Bloch's early students went to work at Varian (Martin Packard, James Arnold, and Weston Anderson). Those developments in turn made possible the explosion in NMR as a tool for chemical, biological, and biomedical research. The Varian HR-30, an instrument for NMR researchers, appeared in 1953. The Varian A-60, introduced in 1961, was their first model intended for routine use by organic chemists. I review some of this history in my paper (Slichter, 1998).

Pake cited the history of magnetic resonance as important in developing his understanding of how revolutionary technologies come to pass and how technological advances in turn feed scientific discovery in a fascinating article on the history of NMR for *Physics Today* (Pake, 1993). He traced the interplay between unplanned basic research and planned development. His deep understanding of this interplay and how to orchestrate it formed the foundation of his approach to management at the Xerox Palo Alto research lab.

At Washington University Pake set up a research program initially in NMR. In the first year he received two invitations to give invited talks at meetings of the American Physical Society. At the Chicago meeting in November 1948 he talked about the observations he and Herb had made of molecular motion in solids, and in March 1949 at Cleveland he talked about the work of his Ph.D. thesis. It was remarkable for such a young scientist to give an invited talk; usually, invited talks were presented by rather senior scientists. But for a brand-new Ph.D. recipient to give two in one year was quite spectacular.

There was no textbook about NMR, so at Washington University George wrote some notes for the benefit of his own students. In 1950 he published them in the *American Journal of Physics* (Pake, 1950). For many years these notes were the textbook throughout the world of students who were beginning NMR. His colleagues in St. Louis gave him a warm welcome. For lunch he frequently took a sandwich and a cup of coffee to the office of two brilliant theorists, Eugene Feenberg and Henry Primakoff. Feenberg gave some lectures on the quantum theory of angular momentum that George realized would be very useful for anyone working in magnetic resonance. So with Eugene Feenberg he wrote a book based on those lectures: *Notes on the Quantum Theory of Angular Momentum* (Feenberg and Pake, 1953).

George learned that the Chemistry Department was also strong. Primakoff mentioned one scientist in particular, Sam Weissman, and kept urging George to go meet him. Then one day Weissman showed up at George's office. Though a brilliant scientist, Weissman was modest, unassuming, warm, and blessed with a delightful sense of humor. He and George resonated with each other. Weissman's big interest was in free radicals, molecules with an odd number of electrons. Ordinarily such molecules are not stable but Weissman had made some that were stable. Weissman was excited because the odd electron should be detectable by means of electron spin resonance and urged George to undertake such studies. They enlisted the help of a new Ph.D., Jack Townsend, to help. In fact, over time George placed emphasis on studies of free radicals by both NMR and electron spin resonance.

In June 1949 I got my Ph.D. and was hired by the Physics Department of the University of Illinois in Urbana-Champaign as an instructor. I was strongly attracted by the fact that Fred Seitz was coming to Illinois. Although I knew very little solid-state physics, I knew about Seitz's monumental book *The Modern Theory of Solids* that gave a unified treatment of the entire field. I realized that Seitz was "Mr. Solid State Physics." I was also intimately acquainted with the work of Pake and of Gutowsky, and Pake on NMR in solids. I felt that there would be exciting things to do in the field of solid-state physics using magnetic resonance, and that I could learn a lot being around Seitz. Erwin Hahn, who had been a graduate student in physics at Illinois also got his Ph.D. that same June doing nuclear magnetic resonance. That summer he discovered spin echoes. For my first year at Illinois, Erwin stayed on as a postdoc. So George was in St Louis and Herb, Erwin, and I were in Champaign-Urbana, a three-hour drive away. This was a hotbed of magnetic resonance. We soon established a tradition of semiannual visits in which the magnetic resonance groups from Physics and Chemistry at Illinois went to Washington University for two days, or the Washington University physicists and chemists came to Champaign-Urbana.

George's colleagues quickly became aware that he possessed qualities of wisdom, judgment, fairness, integrity, modesty, warmth, and friendliness to an exceptional extent. Accordingly, in 1952 at age 28 he was made chairman of the Physics Department and was promoted to associate professor (a year later he was promoted to professor). He was launched on his career of administrative responsibilities because people wanted him to be their leader. George did not yearn for power. Others yearned to empower him.

In 1954-1955 George went to Stanford as a visiting professor ostensibly to take the place of Felix Bloch, who was on sabbatical. George had earlier turned down an offer to move to Stanford. He hired my able student, Dick Norberg, to take his place in his absence. Norberg was such a success that upon George's return, Dick was given a permanent position. For many years Norberg was head of the Washington University Physics Department. Then in 1956 George was lured to Stanford on a permanent basis to take the place of the Nobel Laureate Willis Lamb, who had just left for Oxford. During his time at Washington University and Stanford, George wrote a book about electron spin resonance, *Paramagnetic Resonance* (Pake, 1962). In 1973 with Tom Estle as coauthor he wrote a new edition titled *The Physical Principles of Electron Paramagnetic Resonance* (Pake and Estle, 1973).

Going to Stanford had freed George from the duties of department chairmanship but other aspects proved not as satisfactory. In 1962 he took a sabbatical leave from Stanford to go to the Physics Department of the University of Illinois. I was eager to persuade him to join our faculty. However, simultaneously Tom Elliott, the newly selected chancellor of

Washington University, wanted George to return to Washington University as provost and professor of physics. This would be a major career change since it involved giving up research and teaching. Elliott and Pake were well acquainted and admired each other, and George had real affection for Washington University, so George accepted.

While he was provost, Pake did many things. Fund raising was something he enjoyed when he believed deeply in the merits of the cause. From the Ford Foundation he obtained a $15 million challenge grant needing to be matched by $45 million. Washington University indeed raised $70 million. He undertook a major effort to enhance the Engineering School and strengthened the relationship between the famous Barnes Hospital and the Washington University Medical School.

From Computer Science Professor Jeremy Cox he learned of the possibility of recruiting a brilliant computer scientist at MIT, Wesley Clark, a pioneer in concepts of making computers smaller and easier to use, for the dedicated use of single researcher, rather than for multiple users based on time-sharing technology. Clark had developed his design of the computer with the application to biomedical research as its goal at Lincoln Laboratory, collaborating with Charles Molnar, a member of the group of MIT Professor Walter Rosenblith. This had created great interest at the National Institutes of Health, and led to a program in which 12 copies of Clark's computer "LINC" were distributed, following a competition, to different biomedical research groups at several universities to explore their use.

At that point the plans at MIT for follow-up collapsed, and Clark found himself looking for an institution at which to base his group for the next phases of the project. Cox, who had been working with the project, alerted Pake, who then flew to Boston to meet with Clark. Washington University had a computer center with a large computer shared by many users. It had a massive array of vacuum tubes generating prodigious amounts of heat and a very complex and cumbersome method of programming. The computer scientists kept pressing for even larger, more expensive computers. When Pake saw LINC, with its modest-size processor and memory, and a control console of LINC that could fit on a desk and be run by a single user, he was deeply impressed. Its designer, a computer scientist who wanted to make computers smaller and less expensive, was exciting. Pake wanted Clark.

Clark has described his meeting with George (Clark, 1988):

> He had heard of our situation from Professor Cox and "just happened" to be passing, visiting Cambridge, on his way to Woods Hole (he never got there). He had stopped so that we could, in his words, look him over. We were already well acquainted with Jerry Cox, an old friend even then . . . and had a high regard for his innovative work in biomedical computing at Washington University. For many of us, then, this extraordinary meeting with George Pake made an already very promising possibility irresistible.

Many from the Cambridge team uprooted and moved with Clark to Washington University.

Pake also worked to help Clark get funding from the Advanced Research Project Agency (ARPA), a funding arm of the Department of Defense. In the process George met a plainspoken but visionary ARPA manager, Bob Taylor, who managed much of the funding of computer research with little red tape. He knew most of the community of computer scientists. He visited Washington University, was very helpful, and impressed Pake greatly.

In 1965 George was appointed by Lyndon Johnson to his President's Science Advisory Committee for a four-year term. Pake served under Presidents Johnson and Nixon. He was also active on panels of the National Academy of Sciences and the National Science Foundation. In 1964 Fred Seitz, who had become the first full-time president of the National

Academy of Sciences, decided that the Academy needed to carry out some studies that looked at the opportunities that might be seized by future funding of science. He asked Pake to lead the first of the National Academy of Sciences studies of the status of fields of science as the chairman of the Physics Survey Committee, producing the so-called Pake Report.

The public division over the Vietnam War gradually increased in intensity, leading to turmoil and sit-ins on many university campuses. Finally, the strain on George of this and other aspects of the job, led him to step down from the provost's position in 1969 to return to the role of professor of physics. Then in November 1969 Jack Goldman called him and arranged a two-hour meeting at Lambert Airfield in St. Louis, where Jack had his Xerox Company jet land for this occasion. Since the time when George first knew Jack at Westinghouse, Goldman had been a physics faculty member at Carnegie Tech, then gone on to direct science research at Ford Motor Company. Now he was senior vice president for research at Xerox. He and George had served together on several advisory committees in Washington and elsewhere. Goldman proposed to George that he leave the academic world to head a new laboratory at Xerox in order to "bring Xerox into the digital age."

The timing was perfect, but Pake investigated the proposal carefully, meeting with top executives at Xerox, thinking through a concept of what such a lab might be, what would be realistic goals, etc. It looked exciting—a whole new set of challenges, an opportunity to create something new. Goldman reports that George said, "There is no such discipline as computer science and technology. The practitioners who are advancing this field come from all sorts of disciplines—mathematics, physics, philosophy, linguistics, anthropology, etc.; therefore, one steeped in the workings of an academic campus like Washington U can hope to move the field forward into new horizons." Goldman added, "And this was precisely how he went about organizing and staffing the new lab that was destined to become Xerox PARC and at the root of the remarkable success of that lab" (Goldman, 2004).

Around December 1969 George called Goldman and accepted the job. After thorough investigation of various possible sites, George and Jack settled on a site in Palo Alto, California, and on July 1, 1970, the doors opened on the Palo Alto Research Center, acquiring the name PARC. George led the lab from 1970 until 1978, then oversaw Xerox corporate research from 1978 to 1986.

George believed deeply that the key to a successful laboratory is the wise selection of its people. Then, to manage the laboratory he said,

> Little success is likely to come from showing researchers to a laboratory, describing in detail a desired technology or process not now existent, and commanding: "Invent!" The enterprise will go much better if some overall goals or needs are generally described and understood and if proposals for research are solicited from creative professionals. Managing the research then consists of adjusting the budgets for the program to give selective encouragement" (Pake, 1985).

An example of Pake's management style is given in the story of the origin of the laser printer. Gary Starkweather, the inventor of Xerox's laser printer, had been struggling in Rochester to get funding for his idea of using lasers in the printers. His boss, George White, called Pake in 1971, enthusiastic about the concept but unable to get the money to fund it from his superiors. He asked if Pake would take Starkweather so the idea could move forward. When he heard the description of the concept, George leapt for it. So Starkweather moved to PARC, where he brought the idea to completion. It is said that Xerox's laser printers easily paid for all of the costs incurred over the lifetime of PARC. After George's death, Starkweather said, "Getting to know George Pake was one of the great experiences of my life. . . PARC, as well as I, would not have been successful without George's capable leadership and guidance. I always admired his friendly and gentlemanly manner and will always remember him fondly" (PARC, 2004).

George originally planned to have three labs: the Computer Science Lab (CSL) to explore the fundamental principles of computer science; and the General Science Lab (GSL) to explore the sciences behind modern electronics and also to explore biophysics; the System Science Lab (SSL) to try to develop fundamental laws of computer science analogous to Newton's laws of physics. George did not himself know who the best people in the computer field were to hire for his goals at PARC. He started recruiting at the top computer science departments (Stanford, Carnegie-Mellon, MIT). But five years earlier, Bob Taylor had helped George in recruiting Wes Clark to Washington University. Taylor loved computer graphics and interactive computing. George realized that through his ARPA work, Taylor had come to know personally most of the best computer scientists in the country and was intimately familiar with the directions of their work. Taylor's formal educational background was a master's degree in psychology, and he had been an executive of research budgets, not a hands-on computer scientist. Impressed by Taylor's knowledge of promising directions for research as well as his knowledge of whom to hire, George sought his advice. In the discussions George decided to recruit Taylor as associate manager of the Computer Science Lab.

George and Taylor worked together to recruit computer scientists. One lead was a company in Berkeley, BCC (Berkeley Computer Company). Taylor proposed that they buy the company outright, but that turned out not to be necessary because the company's financial backers withdrew, closing the company's future. George and Bob drove over to Berkeley to visit the company. They met with the staff, George describing his plans, his management philosophy, and the resources he would commit. From this meeting they recruited some of the key people, including Butler Lampson and Charles Thacker.

Under Pake's leadership and philosophy of lab management PARC became a major architect of the information age, giving birth to such innovations as laser printing, the Ethernet, graphical user interface, client-server architecture, object-oriented programming, bit-mapped displays, and many other ideas that define modern computing. Some of the most prestigious honors in the world of computers have gone to scientists who made these advances. Among the awards are the ACM Turing Award to Butler Lampson in 1992 and Alan Kay in 2003 and the 2004 National Academy of Engineering Charles Stark Draper Prize to Butler Lampson, Alan Kay, Bob Taylor, and Charles Thacker for their work on PARC's Alto computer system. Kay, Lampson, Taylor, and Thacker were all elected to the National Academy of Engineering, and Lampson was also elected to the National Academy of Sciences. Pake gives a rather detailed account of this history in his IEEE article (Pake, 1985).

In 2004 Herve Gallaire, Xerox Innovation Group, and chief technology officer of Xerox wrote:

> George Pake was an extraordinary person, a compelling leader; above all, he understood research and researchers and was committed to create the space in which they would succeed. He was exceedingly successful in his approach. His impact and contributions to Xerox and PARC put him right at the top, with other great scientists like John Dessauer, as people who have a vision, go for it and achieve it only to set up the next goals. His influence on the management of research in the US has also been considerable (PARC, 2004).

George was elected to the National Academy of Sciences in 1976. In that year he was also elected vice president of the American Physical Society; he became its president the following year. In 1983 the American Physical Society established the George E. Pake Prize in his honor: “To recognize and encourage outstanding work by physicists combining original research accomplishments with leadership in the management of research or development in industry.” In 1987 President Ronald Reagan awarded Pake the National Medal of Science. After retiring from Xerox in 1986, George founded the Institute for Research in Learning.

In his freshman year in high school George represented his school in several state competitions. His teammate was a shy newcomer to his class, Marjorie Semon, whose father, Waldo Semon, was a star chemical engineer at B. F. Goodrich. He was the inventor of polyvinyl chloride. George won second place in the district, but Marjorie won first place, to George’s chagrin. Beaten by a girl, how mortified he felt. Five years later, in 1945, they became engaged to each other just before George entered Harvard. They married on May 31, 1947, on the first possible date after George finished his spring semester exams at Harvard and Marjorie finished her teaching duties for the year. They had four children: Warren, Bruce, Cathie, and Steve.

I AM VERY GRATEFUL TO Cathie and to Warren, Bruce, and Steve as well, for providing me with material about their parents that greatly enriched my detailed knowledge of their wonderful family. I also thank Jack Goldman, Charlie Duke, Wes Clark, and Butler Lampson for the information and perspectives they supplied, and Andrew Szanton, Mark Conradi, Dick Norberg, and Celia Elliott for their help.

REFERENCES

Clark, W. A. 1988. The LINC was early and small. In *A History of Personal Workstations,* ed. A. Goldberg, pp. 347-394. New York: ACM Press.

Feenberg, E., and G. E. Pake. 1953. *Notes on the Quantum Theory of Angular Momentum.* Cambridge, Mass.: Addison-Wesley.

Goldman, J. E. 2004. Remarks by Jacob E. ("Jack") Goldman at the memorial service for Pake at Washington University, May1, 2004 (kindly sent to me by Dr. Goldman).

Gutowsky, H. S. 1996. The coupling of chemical and nuclear magnetic phenomena. In *Encyclopedia of Nuclear Magnetic Resonance,* eds. D. M. Grant and R. K. Harris, pp. 360-368. Chichester, Eng.: John Wiley.

Pake, G. E. 1993. Nuclear magnetic resonance in bulk matter. *Physics Today,* Volume 46, Issue 10, pp.46-50

Pake, G. E. 1948**.** Nuclear resonance absorption in hydrated crystals: Fine structure of the proton line. *J. Chem. Phys.*16:327-332.

Pake, G. E. 1950. Fundamentals of nuclear magnetic resonance absorption. I. *Am. J. Phys.*18:162-170. Fundamentals of nuclear magnetic resonance absorption. II. *Am. J. Phys.* 18:473-486.

Pake, G. E. 1962. *Paramagnetic Resonance.* New York: W. A. Benjamin.

Pake, G. E. 1985. Research at Xerox PARC: A founder's assessment. *IEEE Spectrum* Oct.:54-61.

Pake, G. E. 1996. A graduate student and young faculty physicist wanders into NMR. In *Encyclopedia of Nuclear Magnetic Resonance,* eds. D. M. Grant and R. K. Harris, pp. 526-530. Chichester, Eng.: John Wiley.

Pake, G. E., and T. L. Estle. 1973. *The Physical Principles of Electron Paramagnetic Resonance.* Reading, Mass.: W. A. Benjamin.

PARC. 2004. Press release at http://www.parc.com/about/pressroom/pake.

Slichter, C. P. 1998. The golden anniversary of nuclear magnetic resonance, NMR—fifty years of surprises *Proc. Am. Phil. Soc.* 142:533-556.

## SELECTED BIBLIOGRAPHY


1948

With H. S. Gutowsky. Nuclear magnetism in studies of molecular structure and rotation in solids: Ammonium salts. *J. Chem. Phys.* 16:1164-1165.

With E. M. Purcell. Line shapes in nuclear paramagnetism. *Phys. Rev.* 74:1184-1188.

1949

With E. M. Purcell. Erratum: Line shapes in nuclear paramagnetism. *Phys. Rev.* 75:534.

With H. S. Gutowsky, G. B. Kistiakowsky, and E. M. Purcell. Structural investigations by means of nuclear magnetism. I. Rigid crystal lattices. *J. Chem. Phys.* 17:972-981.

1950

With H. S. Gutowsky. Structural investigations by means of nuclear magnetism. II. Hindered rotation in solids. *J. Chem. Phys.* 18:162-170.

With N. A. Schuster. The electric quadrupole moment of $^{6}$Li. *Phys. Rev.* 81:157-158.

1951

With N. A. Schuster. The spin of $^{6}$Be. *Phys. Rev.* 81:886-887.

1952

With J. Townsend and S. I. Weissman. Hyperfine structure in the paramagnetic resonance of the ion $(SO_3)_2NO^-$. *Phys. Rev.* 85:682.

1953

With J. Townsend and S. I. Weissman. Hyperfine structure in the paramagnetic resonance of the ion $(SO_3)_2NO^-$. *Phys. Rev.* 89:606.

With S. I. Weissman, J. Townsend, and D. E. Paul. Hyperfine splittings in the paramagnetic resonances of free radicals. *J. Chem. Phys.* 21:2227-2228.

1954

With H. S. Gutowsky and R. Bersohn Structural investigations by means of nuclear magnetism. III. Ammonium halides. *J. Chem. Phys. 22:643-650.*

1957

With C. W. Wilson III. Nuclear magnetic relaxation in polytetra-fluoroethylene and polyethylene. *J. Chem. Phys.* 27(1):115-122.

1960

With M. E. Anderson and T. R. Tuttle Jr. Proton resonance in diphenyl picryl hydrazyl. *J. Chem. Phys.*33(5):1581-1583.

1961

Can four-year colleges prepare physics majors for graduate work in physics? *Am. J. Phys.* 29(10):678-684.

1983

Long-range research investments for a semiconductor systems future. In *1983 IEEE International Solid-State Circuits Conference. Digest of Technical Papers,* pp. 52-53.