Norman M. Kroll

1922–2004

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
Joseph Kroll, Julius Kuti,
and Mal Ruderman

NATIONAL ACADEMY OF SCIENCES

NORMAN MYLES **KROLL**

April 6, 1922–August 8, 2004

Elected to the NAS, 1974

Photograph courtesy Robert Palmer, BNL.

By Joseph Kroll, Julius Kuti and Mal Ruderman

Norman M. Kroll was one of the pioneers of the field of quantum electrodynamics and a brilliant theoretical physicist with deep physical insight and broad scientific interests. His career began at Columbia University, where he and Willis Lamb published the first relativistic calculation of the Lamb Shift. He established himself as one of the pioneers in the field of quantum electrodynamics, and he rose quickly to the rank of full professor. Kroll was one of the founding faculty members of the Department of Physics at the University of California, San Diego, arriving in 1962 as a professor of physics after 20 years at Columbia University. He spent 40 years at UCSD, conducting research on electrodynamics, atomic physics, particle physics, free electron lasers, and the design of subatomic particle accelerators. In addition, he made numerous contributions to the development of UCSD as one of the nation's leading research universities and served twice as chair of UCSD's Department of Physics. A member of the National Academy of Sciences and the American Academy of Arts and Sciences and a fellow of the American Physical Society, he was regarded by his colleagues as one of the physics department's most distinguished faculty members.

Norman Kroll was born in Tulsa, Oklahoma on April 6, 1922. His father, Cornelius (Neil) Kroll, was a graduate of Columbia College and trained as an electrical engineer. His mother, Grace (Gracie) Kroll (nee Aaronson) was a homemaker. His father did not practice electrical engineering and was a business man and worked in the oil refinery business. His father's brother, Leon Kroll, was a well-known American artist. Kroll had an older sister, Vivian Altfeld, who was an actress and a younger brother, Lionel, who was a business man who drove a taxi in San Francisco at the end of his life.

Kroll grew up in a large extended family. His parents met in New York City, introduced because of the friendship between Neil's older brother, Leon, and Gracie's older sisters, who met Leon over their shared interest in painting. Gracie's family was close knit, and

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for many years Norman's family lived in close proximity to her sisters' families, her parents, and, for a time, her brother's family as well. The Aaronson siblings had children ranging widely in age; however, four cousins—Arline Deitch, Roy Travis, Howard (Buddy) Finston and Norman—were within a year in age. Something must have happened to that cohort, because they all had academic careers and all stayed active in their careers well past normal retirement age—these four were the only ones of all of the siblings in that extended family who went into academia, although others had artistic careers. Arline, like Norman, was a scientist, specializing in cytology, first in New York City and then at the University of California, Davis. Howard became a business professor as well as a labor arbitrator and Dean of the business school at the University of New Mexico. Roy Travis also had scientific leanings, but his early experiments with chemistry were more explosive than his cousin Norman's, and an explosion that singed his eyebrows dampened his enthusiasm for the subject. Norman and Roy had a shared interest in opera and chamber music, an interest that led Roy to a long career as a composer and music professor at the University of California, Los Angeles. He and Norman were close friends who saw each other several times a year throughout their lives.

Before the age of ten, Kroll had begun reading his father's technical books on building radios and had assembled a large chemistry laboratory. He would purchase chemicals from companies in Tulsa located about five miles from his home (he walked there by himself) using money he earned by mowing the lawn.

Kroll graduated from San Jacinto High School in Houston, Texas in 1938. He wanted to attend Columbia College in New York, where, perhaps not coincidentally, the Columbia Physics Department was housed in Pupin Hall, named after Michael Pupin, the famous applied physicist who was one of Norman's father's electrical engineering teachers. Norman's parents apparently promised him that he could attend Columbia for college, and then forced him instead to attend Rice University in Houston, which was closer to home and less expensive. Possibly they also aimed to encourage him in the direction of science and engineering, rather than the humanities. He attended Rice from 1938 to 1940 and then transferred to Columbia as a junior—after reminding his parents of their promise (which had come to include a requirement for academic success during his freshman year at Rice).

Once at Columbia, Norman loved the Colloquium—a three-hour weekly discussion group with fifteen of the most gifted students in the junior class, guided by Columbia's top humanities professors. Each week a different work (or works) of literature would be discussed (e.g., Goethe's *Faust*, Shakespeare's *Antony and Cleopatra*, etc.) Norman had a "salon" in his dorm on the top floor of Hartley Hall, where he would invite a whole coterie of friends to listen to and discuss classical music, played from phonograph records. They would also attend weekly concerts by many of the great music performers of the time, such as Arthur Schnabel (pianist and Beethoven specialist) and the Busch String Quartet. Norman had a very active social and musical life at Columbia.

It was only in the last semester of Kroll's two undergraduate years at Columbia that he decided on physics rather than music as a career. He received his bachelor degree (A.B.) in physics and mathematics in 1942. However, he always retained his enormous enjoyment of classical music and a devotion to the piano.

In 1942, the year of his Columbia College graduation, much of the Columbia physics community was deeply involved in activities to support the U.S. effort in World War II. Norman joined the Radiation Laboratory in Pupin where he worked on the design of magnetrons to be used for the generation of microwave power in radars. This experience had a crucial effect on his future life in physics in two ways. First, despite his relative lack of advanced undergraduate classwork, he was very successful in solving problems in which understanding and applying electromagnetic theory was essential. This theoretical work on magnetrons [1] later became the basis for part of Norman's Columbia Ph.D. physics dissertation. Applied theoretical physics of this kind remained important and rewarding for Norman all of his life. Second, inside the Columbia Radiation Laboratory, he shared an office with Willis Lamb.

Lamb subsequently performed his famous experiment measuring the tiny "Lamb-shift" contribution to the energy of an electron in a Hydrogen atom. Such a shift was a not-unexpected consequence of the generally accepted relativistic theory of quantum electrodynamics, but existing mathematical analysis techniques had not yielded a theoretical value for it. Soon after its measurement, there was an explosion of efforts to use the measurement as an exceptional test of quantum electrodynamics and, perhaps, to reveal new fundamental structures in the elementary particles of physics. Hans Bethe made a rough estimate of it, but the Kroll-Lamb calculation [2]—based upon clever use of the conventional formalism for quantum electrodynamics—was the first correct calculation. It was followed by others from Schwinger, Feynman, and French and Weisskopf, based on newly invented mathematical models and insights. Norman remained among the leaders in these new developments and was a partner in their application, first, to the electron's magnetic moment [3] and then to the polarization of a vacuum by a strong Coulomb field [4]. The calculation of the electron's magnetic moment by Karplus and Kroll [3] achieved higher-order precision than the original leading-order correction from Schwinger when expressed in terms of the fine structure constant. It was a considerable technical accomplishment and paved the way to ever-increasing accuracy of theoretical calculations of the muon's magnetic moment, providing a window of opportunity for new insights beyond the Standard Model of particle physics. Current versions of these calculations—now carried out to five loops in the fine structure constant—are still of great importance, and ever more precise measurements are still being carried out: the muon storage ring at Brookhaven National Laboratory in Long Island, New York, has been moved to Fermilab in Batavia, Illinois to continue the measurement of the muon $g - 2$.

During all of this activity, Norman was on the faculty of Columbia's Department of Physics (where his class lectures were considered by students to be among the very best). He was a National Research Council Postdoctoral Fellow at the Institute of Advanced Study (1948-49) and Cornell (1950), a Guggenheim Fellow at the Institute for Theoretical Physics, Copenhagen (1955) and a Guggenheim Fellow and Fullbright Scholar at the University of Rome (1955-1956). Many summers were spent at Brookhaven National Laboratory. He continued his applied research while working on many fundamental aspects of elementary particle physics. An example of the latter was his co-discovery of a "threshold theorem" giving the exact production rate of mesons in collisions of photons with nucleons for input parameters very close to those achievable in the laboratory [5]. Another example was his calculation [6] of internal pair production associated with the emission of high-energy gamma rays, which was used in Monte Carlo simulations of the Dalitz decays of π^0 mesons, an important background to electrons used as signals in particle physics experiments (this work is referenced, for example, in the paper announcing the experimental discovery of the charged weak intermediate vector boson $W^{\pm}$). An interesting personal story associated with this particular paper is that Kroll never met his co-author Walter Wada, who had submitted a similar calculation to the *Physical Review*. The journal encouraged Kroll and Wada to publish their work jointly.

While on the faculty at Columbia, Kroll resisted offers of an assistant professorship at Harvard University (1950), a staff position at Bell Labs (1953) and the Mary Amanda Wood Chair at the University of Pennsylvania (1954). Norman remained on the

Columbia faculty for 22 years until 1962 when he left to be among the first recruited into the Department of Physics of the newly founded University of California at San Diego (UCSD.) He was intrigued by the prospect of helping to build a new institution from scratch and with the idea of building from the top down. He liked the idea of being within walking distance of a beautiful beach and living in one of the world's best climates. Finally he was uncomfortable with the idea of bringing up a son (Joseph, born in 1961) in New York City. He was twice appointed Chair of the UCSD Department of Physics (1963–1965 and 1982–1987); during his second tenure he successfully recruited over twenty outstanding new faculty. He not only had an impact on the department, he contributed to the growth of the campus as a whole; for example, he played a major role on the Faculty Advisory Committee for the UCSD Chamber Music Series.

During his time at UCSD, he had several productive leaves that included the European Organization for Nuclear Research (CERN, 1965–1966) as an NSF Senior Postdoctoral Fellow, Princeton University and the Institute for Advanced Study (1967-1968) and three separate leaves at the Stanford Linear Accelerator Center (SLAC).

At UCSD, his research began to shift considerably. It moved from consideration of deep elementary particle questions [8, 9] toward more applied physics analyses. With Ken Watson, then a professor at the University of California, Berkeley, he wrote several articles [10] on the interaction of matter with strong electromagnetic fields produced, for example, by laser beams. Watson and Kroll also collaborated with Charles Cox, a professor at Scripps Institute of Oceanography, on the calculation of electromagnetic fluctuations induced by wind waves on the deep-sea floor [11]. Ken Watson remarked that Norman had a

> *very high sense of intellectual integrity, both in his personal and professional life. When we collaborated, it was always a useful lesson to me that I should habitually review my work once again for accuracy and objectivity.*

He spent almost a decade working on free electron lasers (FEL) [12]. John Madey, a pioneer in the development of FELs writes:

> *Norman Kroll and colleagues Marshall Rosenbluth and Phil Morton played a major role in the development of free electron lasers— following their first demonstration at Stanford in 1971 and 1972— principally as summarized in their publication [13].*

> *Norman brought to the field a creative mastery of classical mechanics combined with a fascination for the possibilities by which the kinetic energy of relativistic electrons could be converted to electromagnetic energy and the ability to work with others of widely varying backgrounds in the analysis of these devices and of their prospects for attainment of high average powers.*
>
> *These personal and professional traits made him a highly valued collaborator and colleague and a trusted advisor to the agencies who sponsored the large government-funded high-power FEL project of the 1980s and 90s.*

On one of his sabbatical leaves at SLAC, he co-proposed and developed the previously-ignored energy-loss mechanism for magnetic monopoles moving slowly through matter [14]. This mechanism was the basis of, or an important component of, the searches for magnetic monopoles using proportional tubes carried out by several different experimental collaborations, including the MACRO experiment in Grand Sasso, Italy.

Norman's work in particle physics during the UCSD years also has lasting value. Vector mesons have played a curious and very important role in the recent history of particle physics. The famous paper of Norman and collaborators [8] provides a novel theoretical framework for the explanation of the electromagnetic properties of vector mesons. The theoretical tools used in the paper remain in use beyond the particular application to vector mesons.

Kroll had many students who went on the successful academic careers including Eyvind Wichmann (Professor, University of California, Berkeley,) Robert Mills (of Yang-Mills fame, Professor at The Ohio State University,) and Toby Burnett (Professor, University of Washington).

In 1960 Norman became one of the first members of Jason. (Jason was founded by a group of academic physicists of Norman's generation to contribute to government-independent analyses of national problems where the work of physicists would be relevant.) Norman's interests and activities in applied physics flourished. He also became a world expert in the propagation of microwave radiation through the atmosphere and sound waves through the earth. Some of this Jason work had application to proposals for detection of distant underground nuclear explosions. Especially important was his pioneering work in the invention of the gas dynamic laser (1967) and development of free electron lasers (beginning around 1974). After 21 years as an active Jason member Norman resigned for two reasons. He thought that too much of his Jason work was classified, which limited wider discussion of it with others. Also, he felt that, after two decades, it was time for a change in direction of his applied physics research.

After his retirement from UCSD in 1991 he commuted weekly from his home in La Jolla to the Stanford Linear Accelerator Center. He spent a few days there each week designing room temperature accelerating structures, to be used mainly on possible power sources crucial for a proposed great new electron-positron linear collider. He led the theoretical effort that successfully addressed one of the most important degradations in luminosity, a crucial performance parameter of such a collider. During the decade before his final retirement (1991-2000), he contributed as an author or coauthor to over 80 research papers and reports on this subject (three particularly representative examples are provided in Ref. [15]) Someday this remarkable effort can be used by physicists of later generations to continue cutting-edge research on the nature and origin of the matter in our universe.

In the context of this work, he mentored many graduate students and post-doctoral researchers. One of whom, Professor Roger M. Jones—initially a postdoc, later a senior scientist at SLAC—is now Head of the Manchester Accelerator Group in the School of Physics and Astronomy at the University of Manchester and also Associate Director of the Cockcroft Institute of Science and Technology. In remembering working with Norman, Professor Jones wrote:

> *Something that has never left me is Norman's determination and dedication to get to the essence of the physics of any specific problem. Working with him late on into the night at SLAC was nothing unusual, and was a pleasurable experience as we usually made major inroads into the basic physics underlying the coupling of ultra-relativistic beams with complex electromagnetic fields. He drew on his expertise in quantum theory to apply these techniques to the over-coupled beam-wave interaction in microwave cavities to yield tractable analytical solutions which pure computation alone was unable to provide. His modest, and yet penetrating insight into physics will always be remembered. As to the work on linear collider during the NLC times, his crucial participation in the development of the Damped Detuned Structure (DDS) allowed rapid*

> *predictions as to the beam-excited higher-order modes, and it is now a major alternate design for CLIC. His dedication to physics, insight and generosity will always be remembered.*

Norman once expressed his goal as understanding all of physics, applied as well as fundamental. He was remarkably successful in realizing that ambition. In a letter written in 1995 to a long-lost college friend, Ralph Alan Dale, Kroll wrote:

> *I feel that I have been part of a heroic intellectual enterprise, one from which I have derived (and continue to derive) great emotional satisfaction, excitement, and continuous stimulation and involvement. And to think—you get paid for it (quite comfortably, actually)! Really can one ask for anything more?*

Kroll died in La Jolla on Sunday, August 8, 2004 after a brief illness. He was 82 years old. He was survived by his wife of almost sixty years (Sally Ruth Kroll, nee Sharlot), who died in 2009, four children (Linda Ruth, Cynthia Anne, Heather Roma and Ira Joseph) and nine grandchildren. In his letter to Ralph Dale–mentioned previously–he wrote:

> *It would be impossible to overestimate the importance of Sally in all of this. The most important, best, and luckiest happening in my life has been meeting her and having the good sense to ask her to marry me.*

Kroll was also very proud of his children's achievements: Linda Kroll has a Ph.D. in education from the University of California, Berkeley (1985) and is a professor of education at Mills College, Oakland, CA. Cynthia Kroll has a Ph.D. in city and regional planning from the University of California, Berkeley (1981) and has worked as a Senior Regional Economist for the University of California and is now the Chief Economist for Associated Bay Area Governments in Oakland, CA. Heather Kroll has an M.D. from the University of Washington (1994) and works as a physiatrist in a private practice she co-owns. Joseph Kroll has a Ph.D. in experimental particle physics from Harvard University (1989) and is a professor of physics at the University of Pennsylvania and a Fellow of the American Physical Society.

Norman's outstanding research and our fond memories of him will endure.

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