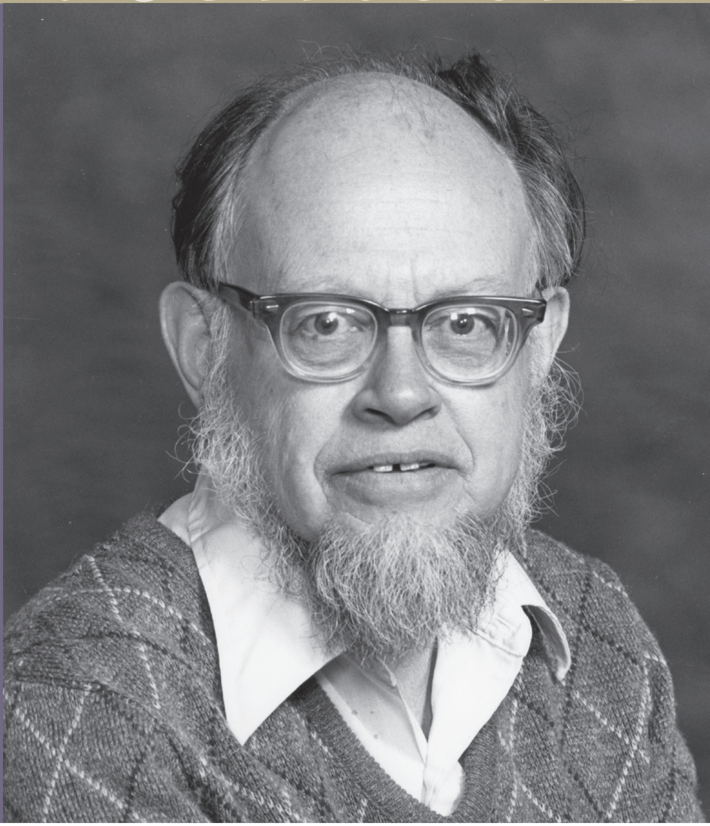
Lincoln Wolfenstein

1923–2015

BIOGRAPHICAL *Memoirs*



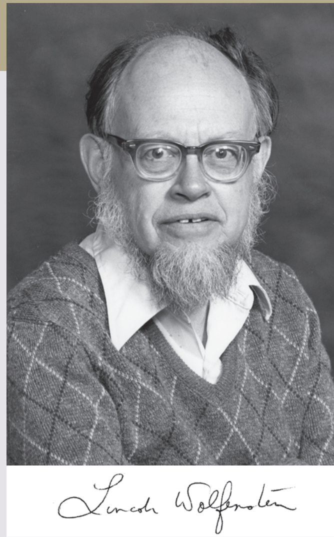
A Biographical Memoir by
Barry R. Holstein

NATIONAL ACADEMY OF SCIENCES

LINCOLN **WOLFENSTEIN**

February 10, 1923–March 27, 2015

Elected to the NAS, 1978



Photograph courtesy AIP Emilio Segrè Archives.

By Barry R. Holstein

The career of nuclear/particle physicist Lincoln Wolfenstein coincided with the golden age of particle physics, beginning around the time of the pion's discovery and ending a few years after the Higgs boson was discovered. His work was performed almost entirely in Pittsburgh, where he was a faculty member at Carnegie Mellon University. Lincoln had been a graduate student at the University of Chicago, where his teachers included two Nobel laureates—Enrico Fermi and Maria Goeppert-Mayer—and where some of his fellow students—T. D. Lee, Frank Yang, Owen Chamberlain, and Jack Steinberger—each went on to win the Nobel Prize.

Lincoln's own career in theoretical physics began with a series of influential papers involving the analysis of nucleon-nucleon scattering, which built on the work that he began for his Ph.D. thesis under the direction of Edward Teller. This effort was emblematic of Lincoln's work during his entire career[1] in that it was closely based on experiment, and he was often sought out for theoretical input by experimental colleagues.

Following the discovery of parity violation in 1957 by Chien-Shiung Wu et al., Lincoln directed his focus to the weak interaction, a decision that would have important consequences for the remainder of his professional life. After the discovery of *CP* violation in 1964, he became an expert in this area and formulated a model, the superweak interaction, that stimulated experimental work for several decades. Together with Manny Paschos, Lincoln developed an approach to measuring neutrino and antineutrino reactions, which proved very useful to experimental analysis as well. He also coined the idea of analyzing neutrino interactions with matter in terms of an effective index of refraction that, when augmented by input from Stanislav Mikheyev and Alexei Smirnov,

1 We are fortunate to have much of Lincoln Wolfenstein's history recorded in his own words, in an autobiographical article titled "The Strength of the Weak Interactions," that was published in 2004 in Volume 54 of *Annual Reviews of Nuclear and Particle Science*.

widened the understanding of low-energy neutrinos' propagation within the solar interior.

Lincoln was a Fellow of the American Physical Society and won its J. J. Sakurai prize for theoretical particle physics as well as the Bruno Pontecorvo prize awarded by the Joint Institute for Nuclear Research. He was elected to the National Academy of Sciences in 1978.

Throughout his career, Lincoln was a strong advocate of nuclear nonproliferation, for which he received an award from the Thomas Merton Center in Pittsburgh. He was a founder of the Pittsburgh chapters of SANE (Committee for a Sane Nuclear Policy) and the Union of Concerned Scientists, and he was a perennial presence in the letters and op-ed pages of the *Pittsburgh Post-Gazette*. Nonproliferation also figured in his teaching; over the years, he taught a series of courses that stressed opposition to nuclear weapons and included discussions of science-and-society issues.

Family was always very important to Lincoln. After his 1957 marriage to Wilma Miller Caplin, involving eventually the blending of their families into a total of five children, he aided her in supporting other such families in the Pittsburgh area. Lincoln and Wilma had nine grandchildren and two great-grandchildren. The couple's marriage lasted 58 years, ending only with their 2015 deaths—within 10 days of each other.

Personal history

Lincoln Wolfenstein was born and raised in Cleveland Heights, Ohio. His father Leo Wolfenstein, an ophthalmologist, was the son of a well-known Cleveland rabbi, Samuel Wolfenstein, who was superintendent of the city's Jewish Orphan Asylum. Lincoln's mother Anna Koppel Wolfenstein had been born in Warsaw, Poland, which at the time of her birth was part of Russia. Lincoln had three older siblings: a sister Martha, born in 1911, who became a well-known Manhattan psychologist and died in 1976; a brother Julius, born in 1915, who died in Cleveland at the age of 15; and a brother Samuel, born in 1922, who became a mathematician and died in 1985. Anna Wolfenstein passed away within a month of Lincoln's birth; he was raised by his sister Martha and his father's sister Laura Wolfenstein, who lived with the family, and also by an influential African-American housekeeper.

Following graduation from high school in Cleveland Heights—where a ninth-grade science teacher told him that he would never succeed in science because of a perceived lack of experimental ability—Lincoln followed his brother Samuel to the University of

Chicago. There, perhaps affected by the advice received from his science teacher, he was at first undecided between a physics and economics major. However, he reported, "After one course in economics, I chose physics," receiving his B.S in 1943 and M.S. in 1944. His masters' thesis was on the spatial distribution of cosmic rays and was carried out under the direction of Marcel Schein. (Lincoln wrote, "My main memory is that Schein kept trying to correct my spelling of 'spatial,' changing it to 'special.'")

After receiving his masters' degree, Lincoln undertook "war work," studying jet-engine airflow at a National Advisory Committee on Aeronautics (later renamed NASA) laboratory in Cleveland. At the end of the war, he was anxious to resume his study of physics and applied for graduate study. Clearly a very strong prospect—he was accepted by Harvard University, Columbia University, Cornell University, the University of Chicago, and the California Institute of Technology—Lincoln selected Chicago for graduate study. The postwar period there proved to be exciting, as his teachers included Fermi, Goeppart-Mayer, Teller, and Gregor Wentzel, while his fellow students included Owen Chamberlain, Richard Garwin, Marvin Goldberger, Tsung-Dao Lee, Marshall Rosenbluth, Jack Steinberger, Sam Treiman, and Frank Yang. Lincoln was awarded his Ph.D. in 1949, having written a thesis under Teller's direction on the subject of nuclear reactions involving polarized protons.

In 1944, Lincoln wed a Cleveland Heights classmate, Charlotte Anne Mahler, and in 1946 the marriage produced a daughter, Frances Anne, who died in California in 1997. However, the union did not last; the couple divorced in 1954. Meanwhile, another Cleveland resident, Wilma Miller, born January 12, 1919, had married Samuel M. Caplin in 1942. That marriage produced two children: Donna, born in 1948; and David, born in 1949. This union too did not survive, and after the couple divorced in the mid-1950s Wilma Caplin returned to Cleveland with her two young children.

She met Lincoln Wolfenstein shortly after her return and the couple married in 1957, settled in Pittsburgh, and had two children of their own—Leonard, born in 1960, and Mimi, born in 1964. The family purchased a Marlborough Avenue home in the Squirrel Hill neighborhood, from which Lincoln could walk the mile or so to his office at Carnegie Tech.

Wilma had earned a B.A. in psychology from the University of Chicago, and after her youngest two children were of school age she resumed her own education, earning a masters' degree in child development from the University of Pittsburgh. Because of her experience, Wilma developed a strong interest in helping other families of divorce.

Together with Gloria Clark, she founded Stepfamilies of Pittsburgh, and for many years held monthly support sessions for stepfamilies.

Professional history

In 1948, a year before he completed his Ph.D., Lincoln accepted an instructorship at the Carnegie Institute of Technology, and upon receiving the degree he became an assistant professor. He was to spend virtually his entire academic career at Carnegie Tech (which was renamed Carnegie Mellon University in 1966), rising through the ranks to associate professor (1956–60), professor (1960–1978), and University Professor (1978–2000). After becoming University Professor Emeritus in 2000, he continued to come into his office nearly every day (in what Boris Kayser called a "failed retirement"). In the early 1970s, Lincoln had received a professorship offer from Yale, but he turned it down. (His sister Martha disapproved of this action, saying that he had missed an opportunity to be at a "real university.")

Lincoln's research work underwent a slow evolution from strong-interaction physics to *CP* violation to neutrino interactions. In the early days of his career, when nucleon-nucleon scattering was a research focus of U.S. physics, he developed a formalism that enabled analysis of scattering wherein the initial nucleon is polarized and the final nucleon spin is detected. Because the initial-state polarization was produced in a scattering process while the analysis of the final-state spin involved a subsequent scattering, such reactions were designated "triple-scattering" and the quantities used to analyze them were called the Wolfenstein parameters.

In the early 1950s, Carnegie Tech built a 450 MeV synchrocyclotron, funded by the U.S. Atomic Energy Commission, in Saxonburg, PA, about 30 miles northeast of Pittsburgh, and Lincoln made weekly visits there regarding various aspects of his research—such as nucleon-nucleon scattering, pion interactions, and compound nuclear reactions—in strong-interaction physics. But a major change in the focus of his work occurred in 1957 when, while attending a high-energy physics conference (Rochester, NY) organized by Bob Marshak, Lincoln heard a presentation by Columbia's C. S. Wu. In it she announced her discovery of the violation of parity (*P*) in the beta decay of polarized ^{60}Co—a phenomenon that Lincoln's former Chicago classmates T. D. Lee and C. N. Yang had suggested the previous year and that led to their winning of the 1957 Nobel prize. This discovery was startling at the time because it implied that nature intrinsically distinguishes left from right. From that point on, nearly all of Lincoln's research was on symmetry or the weak interaction, which is responsible for beta decay.

Actually, Lincoln's initial encounters with the importance of symmetry happened earlier in his career. The first case occurred when a student, assigned to calculate the three-photon decay rate of the spin-singlet state of positronium (the bound state of electron and positron), found that result was identically zero. After studying this situation, Lincoln and postdoc Geoff Ravenhall realized that the null result was due to the charge-conjugation (*C*, or particle-antiparticle interchange) invariance of the electromagnetic interaction: the positronium singlet state is even under interchange of electron and positron, while the photon is its own antiparticle and is odd under *C*.

In a second case, Lincoln had used time-reversal (*T*) symmetry to demonstrate the validity of the identity $P = A$ for nucleon-nucleon scattering, where *P* is the polarization perpendicular to the scattering plane produced in a scattering reaction while *A* is the left-right asymmetry when a polarized nucleon undergoes scattering. These processes must be identical if nature is invariant under the reversal of time's arrow, because a film taken of the scattering of an initial-state polarized particle becomes the scattering into a final polarized state if the film is run backward.

After the physics world was stunned by the discovery of parity violation, it was widely believed that nature must be invariant under the product of *C* and *P*. However, when a second astonishing discovery was announced in 1964—that $C \times P$ also was violated—Lincoln immediately jumped into this problem, as did many others. Numerous models were proposed that attempted to explain this phenomenon. However, Lincoln came up with perhaps the simplest—the "superweak" interaction. It was known at the time that the hadronic currents that contributed to the weak interaction responsible for beta decay predominantly had the property $\Delta S = \Delta Q = 1$, meaning that if the strangeness quantum number of a hadron changes in such processes, the hadron charge change must be identical. Today we would say that this property is a consequence of the quark structure of the weak interaction, but in 1964 the idea of quarks was just beginning to be recognized, and Lincoln asked what would happen if there existed a very small piece of the weak current that had the opposite property—that is, $\Delta S = -\Delta Q = 1$. Were this to be the case, then when combined with the conventional weak current, a *tiny* effective Hamiltonian having $\Delta S = 2$ and $\Delta Q = 0$ would result. Because the violation of $C \times P$ had been discovered via studying the mixing between the particles K^0 (having $S = 1$) and $\bar{K}^0$ (having $S = -1$), then if Lincoln's *superweak* interaction was the explanation for the experimental finding of *CP* violation, this mixing would be the only observable consequence.

After a half century of study, it is now known that the superweak interaction is not responsible for the observed $C \times P$ violation, but during this period of discovery the hypothesis served as a useful motivation to experimentalists. The modern understanding is that the origin of $C \times P$ violation lies in the feature that the weak interaction involves the mixing among three families of quark currents. In this regard, while analyzing the structure of the matrix that described this mixing, Lincoln came up with a very useful parametrization that simplified its form and clearly revealed a hierarchical structure. The "Wolfenstein parametrization" has now become a standard way to represent the mixing matrix. He went on to study how to measure the elements of this matrix directly by the use of $C \times P$ violation in the decays of very heavy (bottom) quark particles, and he predicted that such effects would be large. Recent experiments have confirmed his prediction.

Following the 1972 discovery at the European Organization for Nuclear Research (CERN) that the weak interaction also involves "neutral" currents having $\Delta S = \Delta Q = 0$, Lincoln got deeply involved in studying the properties of neutrinos. At Aspen, CO, during the summer of 1972, he met Manny Paschos, and their discussions led to what is now called the Paschos-Wolfenstein relation—an expression that relates neutrino-induced and antineutrino-induced reactions both in neutral currents and charged currents—and is often used by experimentalists in analyzing neutrino data. A second neutrino paper that had enormous significance resulted from exploring the structure of a possible weak-neutral-current mixing matrix for neutrinos. In thinking about this problem, Lincoln realized that neutrino propagation through matter could be described in terms of an effective index of refraction, written in terms of the weak electron-neutrino scattering amplitude.

In an early version of this paper, Lincoln used this idea to explain both the experimental depletion of muon neutrinos after passing through Earth (seen at the Kamiokande neutrino detector in Japan) and the deficit in electron neutrinos coming from the sun (observed by the Ray Davis-John Bahcall experiment in South Dakota's Homestake Mine), but discussions with his former student Daniel Wyler convinced Lincoln that the analysis was incorrect. About seven years later, however, he received a letter from two Russian physicists, Stanislav Mikheyev and Alexei Smirnov, who showed how, for the case of varying solar-matter density, resonant enhancement was relevant for the solar neutrinos. This phenomenon has come to be called the MSW effect and is now understood to be the reason for the factor-of-three discrepancy between theory and experiment observed in the Davis-Bahcall experiments.

Lincoln was a cofounder of the Aspen Center for Physics, which came about as a result of discussions between him and others wishing to establish a venue where physicists from diverse locations could gather during the summer to discuss ideas. It turned out that the family of a graduate student, George Stranahan, who at that time was studying with Lincoln's colleague Dick Cutkosky, had a foundation that funded worthy projects. Stranahan suggested Aspen as a location, partly because it was a beautiful place and partly because of his friendship with Robert Craig, who was then the head of the Aspen Center for Humanistic Studies. In any case, the foundation provided funds that enabled the construction of Stranahan Hall, the first building of a complex that has become an important part of U.S. physics, and Lincoln was a frequent visitor.

Lincoln's teaching philosophy ran counter to what was central to the conventional instruction of physics—that is, lectures on the physical laws, accompanied by the assignment of numerous problems so as to nominally solidify understanding of the subject matter. He disdained this approach, stating, "I always think of Tom Kuhn's comment that science is taught in the schools like religion. If we teach our students that they must believe what we tell them or otherwise they will get a bad grade, then we cannot compete with the church, which tells them if they do not believe they will go to Hell." So Lincoln generally eschewed teaching introductory physics. Rather, he chose to instruct non-science students, or to conduct courses for science majors on science and society, or to educate students on nuclear weapons and their implications. He only occasionally taught an advanced graduate course on more traditional topics.

But over the years, Lincoln's down-to-earth approach to physics *research* provided an important grounding for the numerous graduate students and postdocs he supervised. Many of them have gone on to academic positions around the world, where Lincoln's influence is still felt and helps to enlighten the next generation. A partial list includes:

Gustavo C. Branco, Instituto Superior Tecnico, Lisbon, Portugal.

Darwin Chang, Ting-Hua University, Taiwan.

Cheng-Wei Chiang, National Central University, Taiwan.

John F. Donoghue, University of Massachusetts, Amherst

Barry R. Holstein, University of Massachusetts, Amherst

Luis Lavoura, Instituto Superior Tecnico, Lisbon, Portugal

Glenn K. Manacher, University of Illinois, Chicago

Palash B. Pal, Saha Institute of Nuclear Physics, Calcutta, India

D. Geoffrey Ravenhall, University of Illinois, Champaign-Urbana

Lahlit Sehgal, Technische Universität at, Aachen, Germany.

K. V. L. Sarma, Tata Institute of Fundamental Research, Calcutta, India Joao P. Silva, University of Lisbon, Portugal

Daniel Wyler, University of Zürich, Switzerland

…in addition to doing extensive scientific work, Lincoln communicated often to the physics community and the general public on a wide range of issues. Thus he was a prolific writer of letters to the *Pittsburgh Post-Gazette* and to *Physics Today.*

In his *Annual Reviews* article (see footnote on p. 1), Lincoln said, “I think I have learned as much from all my students as they have learned from me.” But as a former Wolfenstein student, I must respectfully disagree. Indeed, I learned not just the subject matter of physics but also what it was to be both a scientist and world citizen.

For example, in addition to doing extensive scientific work, Lincoln communicated often to the physics community and the general public on a wide range of issues. Thus he was a prolific writer of letters to the *Pittsburgh Post-Gazette* and to *Physics Today.* At the *Post-Gazette,* a staff writer assigned to author Lincoln’s obituary included quotes from some of his missives: “The lesson of these wars is ‘aggression equals disaster’” “The Bush administration’s motives for this war [in Iraq] don’t add up” and “Cut defense spending. Fund essentials.”

Regarding *Physics Today*, after Lincoln pointed out in a 1980 letter that the abortive attempted rescue of American hostages in Iran was undertaken without adequate planning by an ex-physicist (Secretary of Defense Harold Brown), the Department of Defense issued a detailed justification. In another case, a 1983 letter from Lincoln, which that strongly defended the American Physical Society’s stance to negotiate an arms-control agreement, elicited an angry rejoinder from then presidential science advisor George Keyworth.

Lincoln also penned longer articles for other venues. In a piece in the faculty magazine *Focus*, which he titled "The Yellow-Brick Wizards"—referring to the economists of Carnegie Mellon's highly regarded School of Management—Lincoln wrote:

> *One day while walking home through Schenley Park, I met one of the wisest of the Wizards … and asked what economists thought about issues such as pollution. He replied that these were 'externalities.'…If I understand that word, he meant they are external to the equations the Wizards use.…In my experience, when I leave an important term out of an equation, I get the wrong answer.*

In such ways, Lincoln showed his students and colleagues how they might conduct their own careers. He defined "true north" for living one's life, and though he is gone his example will continue to help us find our own way.

Even after his retirement in 2000, Lincoln remained a major presence in the Carnegie Mellon physics department. Any visitor to the particle/nuclear group would be ushered into his office for a grilling on his or her physics. In 2010, our University of Massachusetts group had the honor of Lincoln's participation in a meeting we held in Amherst, and he appeared to be as sharp as ever despite his 87 years. After this time our "wave functions" did not overlap until I learned from the CMU physics newsletter that he had moved to California to be closer to family. Indeed, in 2014, after 66 years in Pittsburgh, Lincoln and Wilma left their large home on Marlborough Avenue and relocated to a small apartment in Oakland, California. Unfortunately, he developed cancer shortly after this move, which led to his death on March 27, 2015, in Oakland. Wilma passed away 10 days later.

SELECTED BIBLIOGRAPHY

1945 Theoretical calculations on extensive atmospheric cosmic-ray showers. *Phys. Rev.* 67:238-247.

1948 With R. G. Sachs. Note on angular distributions in nuclear reactions. *Phys. Rev.* 73:528.

1951 Conservation of angular momentum in the statistical theory of nuclear reactions. *Phys. Rev.* 82:690-698.

1952 With J. Ashkin. Invariance conditions on the scattering amplitudes for spin ½ particles. *Phys. Rev.* 85:947-949.

With D. G. Ravenhall. Some consequences of invariance under charge conjugation. *Phys. Rev.* 88:279-282.

1956 Polarization of fast nucleons. *Ann. Rev. Nucl. Sci*. 6:43-76.

1958 Determination of the coupling constants in $\mu^- + p \rightarrow n + \nu_\mu$. *Nuovo Cim.* 7:706-711.

Virtual pion effects in μ-meson capture. *Nuovo Cim*. 8:882-887.

1964 Violation of *CP* invariance and the possibility of very weak interactions. *Phys. Rev. Lett.* 13:562-564.

1965 With T. D. Lee. Analysis of *CP*-noninvariant interactions and the K_1^0, K_2^0 system. *Phys. Rev. B* 138:1490-1496.

1966 Analysis of *CP* violation in possible experiments on K^0 decay. *Nuovo Cim.* 42:17-38.

1973 With E. A. Paschos. Tests for neutral currents in neutrino reactions. *Phys. Rev. D* 7:91-95.

1978 Neutrino oscillations in matter. *Phys. Rev. D* 17:2369-2382.

1980 A theoretical pattern for neutrino oscillation. *Nucl. Phys. B* 175:93-96.

1981 *CP* properties of Majorana neutrinos and double beta decay. *Phys. Lett. B* 107:77-79.

1982 With P. B. Pal. Radiative decays of massive neutrinos. *Phys. Rev. D* 25:766-773.

1983 Parametrization of the Kobayashi-Maskawa matrix. *Phys. Rev. Lett*. 51:1945-1947.

1984 *CP* violation in $B^0 - \overline{B}^0$ mixing. *Nucl. Phys. B* 246:45-51.

1985 $D^0 - \overline{D}^0$ mixing. *Phys. Lett. B* 164:170-172.

1987 With J. Liu. Spontaneous *CP* violation in the $SU(2)_L \times U(1)_Y$ model with two Higgs doublets. *Nucl. Phys. B* 289:1-22.

1988 With T. Altomari and J. D. Bjorken. *CP*-violating lepton asymmetry due to $B - \overline{B}$ mixing. *Phys. Rev. D* 37:1860-1864.

1991 Final-state interactions and *CP* violation in weak decays. *Phys. Rev. D* 43:151-156.

1994 With Y. L. Wu. Sources of *CP* violation in the two-Higgs-doublet model. *Phys. Rev. Lett.* 73:1762.

1999 With M. Suzuki. Final state interaction phase in *B* decays. *Phys. Rev. D* 60:074019.

2010 With J. P. Silva. *Exploring fundamental particles*. New York: CRC Press.