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FRANCIS E. LOW
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A Biographical Memoir by

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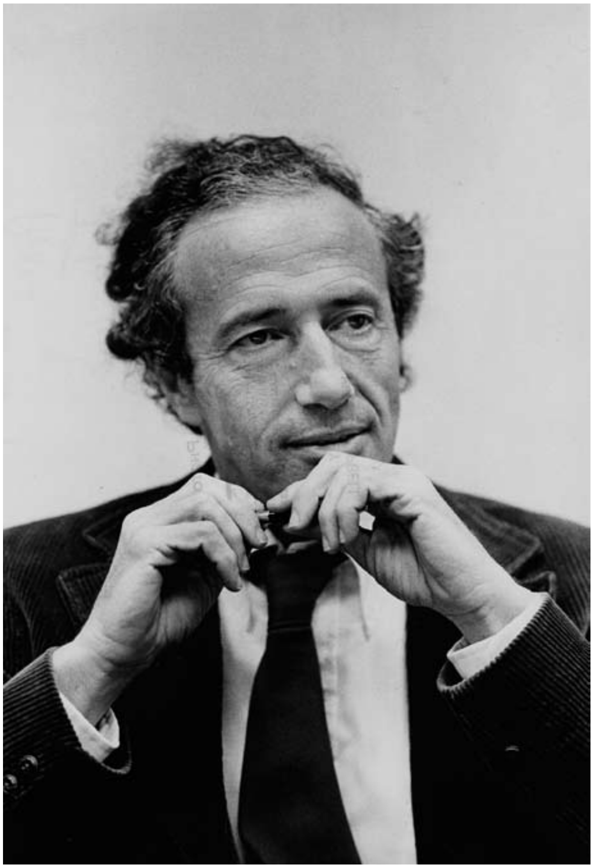
Biographical Memoir



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FRANCIS E. LOW

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BY DAVID KAISER AND MARC A. KASTNER

FRANCIS E. LOW, A MEMBER OF THE NATIONAL ACADEMY OF SCIENCES since 1967, died on February 16, 2007, in Haverford, Pennsylvania. His career exemplified the maturing of theoretical physics in the United States during the years after World War II. Low also experienced some of the new roles for physicists, from organized political engagement and consulting on national security issues to high-level university administration. One of Low's landmark articles helped to lay the groundwork for the renormalization-group approach in quantum field theory, a seminal technique in condensed-matter and particle physics. He also contributed influential approximation techniques for treating particle scattering.

EARLY YEARS

Low was an only child, who lived near Washington Square Park in Greenwich Village. His mother's parents were physicians and socialists. In fact, his grandfather helped found the Socialist Party of America. His mother also became a doctor. She made house calls at night in Greenwich Village until she turned 80, treating patients such as anthropologist Margaret Mead. Low's father was an engineer who was also a committed socialist and a close friend of his mother's father. His parents were introduced because of this close relationship.

Low's parents' home in the Village was always filled with interesting people—friends and patients—who were musicians, authors, politicians. Eleanor Roosevelt was also a friend and patient of Low's mother. Low's father died when Francis was only 21. Low's relationship with his mother was very close until her death.

EARLY CAREER

Low dreamed of studying physics even before he entered college. His interest had been sparked by reading Albert Einstein and Leopold Infeld's book, *The Evolution of Physics* (Einstein and Infeld, 1938). Years later Low recalled his excitement upon first seeing Maxwell's equations for electromagnetism and getting a taste for the beauty and structure of field theory.[1] Primed by Einstein's book, Low entered Harvard University as an undergraduate in 1939. He continued to focus on physics, in part because "this stuff was interesting," and in part because it seemed like the easiest course to follow. "I was less strong in fields where there was no discernable objective criterion for quality. So I would write what I thought was an excellent essay, and it would come back with a B– or C, whereas, if I was doing physics and I got an answer, if I thought it was right, it was generally right."[1] He remembered exciting lectures on mathematics from Saunders Mac Lane, along with classes on mathematical methods and theoretical physics from John Van Vleck, Edwin Kemble, and Wendell Furry.

Low had an added incentive to concentrate on physics at Harvard. September 1939 was a difficult time to enter college. War had just broken out in Europe, and Low was determined to complete his undergraduate studies as soon as possible, to have his degree in hand before wartime mobilization could interfere. Following along in physics, which he found both interesting and practicable, made the most sense. Having gone to high school at the International School in Geneva, Low had entered Harvard with a French baccalaureate degree and a strong Francophile inclination. From the start he had been an interventionist, arguing with fellow classmates that the United States should enter the war. He graduated with his physics degree in three years, and immediately volunteered for military service.

He volunteered more than once. His first stop was with the Army Air Force, until a minor surgical complication interfered six months into flight training. (After the war, Low completed training for a pilot's license and flew recreationally for many years.) Back home in Manhattan he bumped into Elliott Montroll, a physical chemist, who helped recruit Low to a special wartime project. At the age of 22 Low thus joined the world's largest laboratory effort: the top-secret Manhattan Project tasked to build an atomic bomb.

Low joined the gaseous diffusion effort in Oak Ridge, Tennessee. Uranium was combined with fluorine to form uranium hexafluoride, a nasty, corrosive gas. The fissionable uranium-235 atoms formed molecules that were ever so slightly lighter than those that included uranium-238 atoms—a mass difference of only 0.85 percent. Once brought to equilibrium, the molecules in the gas would each have the same average kinetic energy; thus the less massive molecules (containing uranium-235) would move with slightly greater average speed than the more massive molecules. If the gas were to be heated and passed through a porous membrane, the faster moving molecules after a short time would be just barely more likely to pass through to the other side than the more sluggish molecules. After one of these enrichment cycles, the concentration of the sought-after uranium-235 would be increased by only a factor of 1.0043, so the process was repeated thousands of times, each time taking the slightly enriched portion and passing it through another diffusion cycle (Rhodes, 1986). Low's job was to help with some of the arithmetic calculations behind this enrichment process.

Yet with only an undergraduate degree in hand, Low quickly grew frustrated, thinking that he "didn't know anything, and that I was pretty useless."[1] So he left Oak Ridge and volunteered yet again with the army. Sent to Camp Upton (now the site of Brookhaven National Laboratory on Long Island), Low was interviewed to find out where in the army he might make the best fit. When the recruiter learned that Low had done some calculations (though Low could not reveal what the calculations had been for), Low was assigned to be a "computer" with the Tenth Mountain Division (the Ski Troops). His job involved working with survey teams in the field to help aim artillery and maintain maps of their own and enemy locations. They were stationed in Italy during the Appenine and Po Valley campaigns.[1]

After the war, with assistance from the GI Bill, Low entered graduate school in Columbia University's Physics Department. Like his military service, even this was not quite as straightforward as it might appear. After having volunteered for the Army Air Force but before being called up, Low had been admitted to the graduate program at Princeton. Princeton at the time was strapped for teaching assistants, so the Physics Department chair, Henry DeWolf Smyth, asked Low to work as a teaching assistant while waiting for the call from the air force. Low thus worked in Princeton's Physics Department after graduating from college, leaving within the year to join the service when called. Upon returning from the war, he was told he had to reapply for admission to Princeton's graduate program, and then he was turned down.

He chose Columbia instead. Low began his graduate studies at a time when graduate enrollments in physics were doubling faster than any other academic field in the United States (Kaiser, 2002). He remembered the new bustle within the hallways and classrooms of Columbia's Physics Department. Whereas only two other students had taken Wendell Furry's course on electromagnetic theory with him at Harvard before the war, suddenly the classes at Columbia (as elsewhere) were overflowing with young physics students.[1]

Life in graduate school proved to be an interesting time, both inside and outside the classroom. During his graduate studies, Low married Natalie Sadigur, and they settled into an apartment together on West 29th Street. "The apartment was full of life," Low recounted in a brief autobiographical sketch in the mid-1960s. "On the floor above us lived a semiprofessional prostitute, who received many interesting phone calls on the pay phone, which we answered since it was just outside our door. Also just above us was a mother with two hysterical adolescent daughters." On one occasion, "we broke up a knife fight between them. Next to us we had a newlywed couple; she was frequently on the phone, talking to her mother, in tears because of the dismal environment in which she was living." Meanwhile, "below us lived Leo Dubensky, a violinist who was formerly with the Philharmonic. I had a Steinway upright [piano], which my mother had bought for me, in our apartment and Dubensky and I played sonatas together mornings while his and my [wives] were out supporting us." (Music remained important throughout Low's life. Colleagues remembered his great gift for performing Cole Porter songs on the piano. He even composed a musical play based on Mark Twain's book, *The Adventures of Huckleberry Finn.*) A few months after getting married, Low saw I. I. Rabi, at the time a recent Nobel laureate and one of the senior physicists in Columbia's department. "What's new?," Rabi asked. "I'm married," said Low. "Delusions of economic grandeur," came Rabi's quick reply.[2]

Rabi became a major influence on Low at Columbia, as did several visiting faculty members. Rabi had been busy after the war bringing in visitors to help train the suddenly large number of graduate students. He focused on bringing theoretical physicists in particular since historically theory had been less strongly represented in U.S. physics departments than experiment. Low recalled working with distinguished visiting faculty members, such as Hideki Yukawa, Aage Bohr, and Walter Heitler. Hans Bethe became especially influential. Low began his dissertation under Bethe's supervision.

Low worked on a topic near to the hearts of Rabi and Bethe: the hyperfine structure of deuterium. Rabi, together with John Nafe and Edward Nelson, had been conducting extremely sensitive experiments at Columbia since the close of the war to measure the energy levels within simple atoms. They used surplus electronics equipment from the wartime Radiation Laboratory at MIT, where Rabi had worked on radar along with thousands of other physicists and engineers. During the late 1940s, they used this equipment to probe the energy levels of hydrogen atoms to unprecedented accuracy. Both the proton and the electron in a hydrogen atom carry some intrinsic angular momentum or "spin." The spin of the proton can line up either in parallel with the electron's spin or antiparallel. The energy of the atom will be slightly different in the two cases, by just a fraction of a percent, precisely the kind of minute difference that Rabi and his experimentalist colleagues were just beginning to measure after the war. The difference in energy levels owing to the alignment of the proton's and electron's spins became known as the "hyperfine structure" of the atom's energy spectrum. Theoretical physicists such as Hans Bethe and Gregory Breit struggled to calculate the tiny energy difference using quantum electrodynamics, physicists' quantum-mechanical description of electromagnetic forces (Schweber, 1994).

The situation became even more complicated in the case of deuterium, an isotope of hydrogen with one proton and one neutron in its nucleus. Since the neutron also carries its own intrinsic angular momentum, the hyperfine structure of deuterium arose from the coupling between the combined spin of the nucleus and the spin of the electron. Low investigated whether motions of the proton and neutron within the nucleus could account for some of the discrepancies between the measured and predicted values of the deuterium hyperfine structure. He concluded in the end that the improvements in the theoretical value looked promising, but uncertainties in both theoretical and experimental parameters remained too large to know for certain (1950).

Certainty is rarely required in a dissertation. Having finished his thesis, Low left Columbia in 1950 to embark on postdoctoral work at the prestigious Institute for Advanced Study, in Princeton, New Jersey. His path following the Ph.D. illustrates some of the rapid changes taking place within American physics after the war. Before the war, Americans who were interested in theoretical physics needed to travel to Europe for postdoctoral training. Only in places like Cambridge, Copenhagen, Göttingen, or Zürich could Low's teachers—Kemble, Van Vleck, Rabi, and their generation—"learn the music, and not just the libretto" of research in physics, as Rabi famously put it (Rigden, 1987). After the war, these same physicists endeavored to build up domestic training grounds for young physicists. Low and his generation benefited enormously from those efforts (Schweber, 1986).

PRINCETON AND URBANA

One of the key centers for young theorists to complete postdoctoral work became the Institute for Advanced Study. Physicist J. Robert Oppenheimer assumed directorship of the institute in 1947, having achieved worldwide fame for his role as scientific director of the Manhattan Project's Los Alamos laboratory. Upon arriving at the wooded, picturesque institute, Oppenheimer stirred up controversy by increasing the number of young theoretical physicists in residence, at the expense of other fields. The institute quickly became a favored gathering place for young theorists, who circulated through what Oppenheimer called his "intellectual hotel" for two-year postdoctoral stays (Kaiser, 2005a).

Low recalled his time at the institute fondly. "It really was wonderful. I loved the Institute. I loved the Institute…It was a place where you went and you met your contemporaries, you saw where you were and who you were in the hierarchy. You were at the place where important things were going on."[1] In addition to benefiting from Oppenheimer's example, Low "met people who were special in my life." He befriended other young theorists, such as T. D. Lee, C. N. ("Frank") Yang, Abraham Pais, and Murray Gell-Mann. There was an informal social atmosphere among the postdocs but also some self-applied tension. "It was a tense place, and I would go into my office every day. The tension was, you couldn't imagine how likely an important advance was. And the fear was not being there when dynamite was uncovered or discovered."[1] While at the institute, Low began a collaboration with Gell-Mann that extended well into the 1950s.

Following their postdoctoral visits in Oppenheimer's "hotel," Low and Gell-Mann both headed for teaching jobs in the Midwest: Gell-Mann to the University of Chicago in 1951 and Low to the University of Illinois in Urbana in 1952. While still in close proximity, they completed a paper in 1954 on the short-distance behavior of quantum electrodynamics (1954). Though little appreciated at the time, their paper would become a classic and establish the basis for renormalization-group techniques in quantum field theory.

At the time that Gell-Mann and Low tackled the problem, the rudiments of quantum electrodynamics had been known for 30 years. For most of that period, however, the theory had suffered from a grave sickness. As soon as physicists tried to calculate basic physical processes beyond the simplest, bare-bones approximation—such as the probability for two electrons to repel each other—the theory produced infinities instead of finite answers. During the 1940s, young theorists such as Julian Schwinger, Richard Feynman, and Freeman Dyson (all working in the United States) and Sin-Itiro Tomonaga (working independently in Japan) found ways to evade the troubling infinities. The idea was to work with effective or "renormalized" quantities, rather than "bare" masses or charges. No one ever encountered a bare electron, all on its own. Rather, thanks to the Heisenberg uncertainty principle, particles would constantly pop into and out of existence, borrowing energy from the vacuum for brief periods of time. Some of these "virtual" particles would carry negative electric charge while others carried positive charge. Pairs of oppositely charged virtual particles would constantly surround any given electron. An observer would therefore measure the electron's charge as shielded or screened by the ever present sea of virtual particles. The effective charge of the system—electron plus cloud of virtual particles—remained finite. The program for systematically replacing infinite quantities with these compound, finite ones, was dubbed "renormalization" (Schweber, 1994).

In their 1954 work Gell-Mann and Low returned to the hard-won terrain of renormalization, examining still more closely the structure of the theoretical expressions for quantities such as the electron's mass and charge. They found that the value of these parameters varied with the distance scale at which they were being studied. An electron's charge when measured at a certain distance would not be the same as the charge when measured at a much closer distance. In particular, they found simple scaling relationships between the parameters at various distance scales (1954). Decades later the paper was recognized as having laid the crucial groundwork for the renormalization group and investigations into effective field theories, topics and tools that moved to the center of both particle theory and condensed-matter theory during the 1970s and 1980s (Brown, 1993). Indeed, Kenneth Wilson, in his Nobel Prize lecture in 1982, recalled that the Gell-Mann and Low paper provided critical inspiration for his work (Wilson, 1982). But that's not how the paper was greeted at the time. Low remembers that the paper "did not get great approval. One of my close friends, whose name I won't tell you, said, 'Francis, you could really be doing something interesting'" by working on more fashionable topics in particle physics, rather than the abstract electrodynamics work.[1]

While at Urbana in the early and mid-1950s, Low also struck up an active collaboration and friendship with Geoffrey Chew, and through Chew with Marvin ("Murph") Goldberger. Chew was a young colleague of Low's in Illinois, and Goldberger was working at Chicago; Chew and Goldberger had studied together both as graduate students and postdocs. Their varying styles of theorizing became complementary. Goldberger was fond of remarking that "the only rigor in theoretical physics is rigor mortis," as he casually broke from formal developments and followed what looked to be promising phenomenological routes (quoted in Schweber, 1989, p. 685). Chew meanwhile had mastered techniques for calculating scattering phenomena, including various approximation schemes, long before they had entered common use. Low contributed his strong command of quantum field theory and his general style of theorizing, which he later characterized as "minimalist, but not dirty."[1]

With these varying strengths the Midwest collaboration of Low, Chew, Goldberger, and Gell-Mann flourished for several years (Pickering, 1989). They produced a series of papers trying to make sense of the "zoo" of unexpected particles then being discovered in the new particle accelerators. Low worked especially closely with Chew. "We were very good collaborators," Low recalled. "Geoff had lots of ideas and initiative, and I had a more critical view. We worked very well together, and we made a good team".[1] Even after Low left Urbana for MIT in 1956 and Chew left Urbana for Berkeley in 1957, they continued to collaborate over summers. The Chew-Low model for treating nucleon-meson interactions in the limit that the nucleon remained static (1956) soon led to even more useful results, such as the Chew-Low extrapolation technique (1959). In this work Chew and Low demonstrated how to extract information on interesting yet experimentally inaccessible interactions from the data on more humdrum experimental systems. The case they analyzed concerned elastic pion-pion scattering, some properties of which could be extrapolated from the data on inelastic proton-pion interactions, by then increasingly routine. Many years later the Chew-Low technique was still guiding experimentalists who worked on similar scattering problems (Kaiser, 2005a).

POLITICAL ENGAGEMENTS

As he struck up his collaboration with Chew in Urbana, Low's attention also began to return to politics. Chew had organized the Urbana chapter of the Federation of American Scientists. Low, who had spent many late nights as an impassioned undergraduate arguing about foreign policy with classmates, joined the Urbana group. The FAS lobbied against some of the worst abuses of McCarthyism, which were affecting physicists across the country. Even before the infamous hearing that stripped Oppenheimer of his security clearance in 1954, younger physicists had routinely labored under increasingly intrusive background checks when applying for jobs or fellowships. Politicians feared that physicists, as guardians of the "atomic secret," required special scrutiny—even for the majority of physicists who did not work on military projects. Scores of young physicists found frustrating delays or denials when applying for passports for themselves, or for visas to host distinguished foreign visitors (Wang, 1999; Kaiser, 2005b).

Part of Chew's and Low's duties in the Urbana federation chapter focused on their neighbors. "One of the things we had to do was explain to the Illinois campus what the Fifth Amendment meant, and how one should listen to it."[1] They organized meetings on campus and hosted speakers. They also became a clearinghouse for other scientists' complaints about unfair passport treatment. Chew eventually testified before the U.S. Senate to bring these abuses to wider attention (Chew, 1956).

While working closely with Chew on both scientific and political questions, Low received an invitation from the Department of Physics at MIT to spend the academic year 1956-1957 in Cambridge as a visiting professor. It soon became an offer to stay at MIT permanently. Although he considered his new geographical distance from Chew to be a major loss, Low decided to stay at MIT.

Soon after moving to Cambridge, Low became involved with another kind of political activity. He joined the JASON group, organized under the auspices of the Institute for Defense Analyses, a private think tank with close ties to the military. The JASON group was founded in late 1959 with the help of Goldberger and Kenneth Watson, another young theorist who had completed his postdoctoral work at the Institute for Advanced Study during the late 1940s (Aaserud, 1995; Finkbeiner, 2006). Low recalled how he became involved. "Ken Watson was very devoted to getting this group together, mainly theoretical physicists. And Ken convinced me that there were things happening, very dangerous things, and that if we didn't solve some pressing physics problems, we, the United States, could be in real danger."[1] The group met for summer study sessions, then divvied up problems that each member would work on during the intervening academic year.

Nearly all of these issues were highly classified; Low's own clearance level had to be raised. They worked on topics such as the purported missile gap, which several politicians feared had opened up between American and Soviet nuclear capabilities. Fairly quickly, Low became disenchanted with the group, years before the Vietnam War-era protests brought the group into open controversy. Part of the problem, as Low looked back on it, was that he could not find anything useful to work on. "Classified experiments are very tough to work with," he explained. "If you want to test a model or theory, you need to produce a range of experiments and data which will cover the idea. You need to get a long range of continuous data," a point he had learned to appreciate from his work on the Chew-Low extrapolation technique. "It's difficult enough in particle physics. But when you get into classified experiments, it's just awful. With these classified experiments, you just have a point here, a point there. They go out to Eniwetok or Bikini"—islands in the South Pacific where the United States conducted tests of nuclear weapons during the 1950s—"and they say, 'There's a good point; here's another point.' It militates against effective analysis." In terms of scientific questions, therefore, he quickly lost interest. "It got to the point where when I saw a red

'Secret' stamp on a file, a feeling of boredom immediately came over me."[1]

Worse still, most of the problems were political problems, Low began to realize, and not necessarily scientific or technological ones. That realization led Low to question what role he and his physicist colleagues should be playing in the first place. "I felt that I really shouldn't be doing it," he recalled, "because it wasn't necessary. It was just using up money and making me and other people do things that didn't have to be done."[1] Low quietly left the group in frustration.

A few years later during the late 1960s and early 1970s, he experienced similar frustrations when trying to balance scientific and political matters. MIT physicist Herman Feshbach had helped to organize the Cambridge, Massachusetts-based Union of Concerned Scientists in 1969. Soon after founding the organization, Feshbach stepped down and Low succeeded him as chair. Once again Low found scientific or technological questions—such as how safe or clean nuclear power could be—tangled up with hard-set political positions. Even worse, Low and his colleagues' advice often received a cool reception from officials in Washington, D.C. He left the group after a short stay.

MIT LEADERSHIP

Low took an active role within MIT administration beginning in the late 1970s. His first step was to become director of MIT's Laboratory for Nuclear Science, a capacity in which he served from March 1979 until July 1980. The directorship proved to be but a short step into higher administration. When Paul Gray became president of MIT in 1980, he sought a scientist who could serve as provost, following a long line of engineers who had held the position. Gray approached Low, and Low accepted the offer. He served as MIT's provost from July 1980 until July 1985.

"In the large, it was very exciting to be at the center of this institution, and to see what was happening all around you," Low recalled. "In detail, however, it was rather painful. People would walk into your office every day with important concerns that you usually couldn't fulfill. Money was not as easy to come by as it had been before."[1] The generous federal funding that had been directed toward science and technology in the United States since World War II had slowed dramatically over the course of the 1970s, with détente and an economic recession. Federal spending for scientific research rose again during the 1980s (driven largely by national security concerns during the Reagan Administration), but budgets still remained tighter than the post-Sputnik boom years until well after Low's tenure as provost was done (Kevles, 1997).

Despite the difficult financial times Low did pursue two main initiatives. One was an attempt to strengthen the humanities program at MIT and boost undergraduate enrollments in those areas. "I thought it was very important for students to have peers pursuing other kinds of studies. In the end, though, I didn't actually accomplish much on this front."[1] The other initiative proved to be more successful: the launching of the new Whitehead Institute for Biomedical Research, which opened its doors in 1982. The Whitehead Institute was one of the first of its kind: a cutting-edge research facility for the life sciences funded primarily by private investment, which was independent of, but affiliated with, MIT (Durant, 2010). "It wasn't easy to get the terms acceptable to both the Whitehead's attorneys and to MIT's faculty," Low recalled. "But eventually we did, and that has proven to be very important."[1] New institutions like the Whitehead helped spur the rapid rise of biotechnology.

Other highlights of Low's long career at MIT include his teaching and interactions with students. Among his most prominent students include Alan Guth, now the Victor

F. Weisskopf Professor of Physics at MIT and one of the main inventors of inflationary cosmology, a model of the early universe infused with ideas from particle theory that remains the front-running cosmological theory today. Low also singled out string theorist William Weisberger, now a professor at SUNY Stony Brook; Mitchell Feigenbaum, one of the inventors of chaos theory and presently Toyota Professor of Mathematical Physics at Rockefeller University; Adrian Patrascioiu, an expert on quantum field theory, statistical mechanics, and dynamical systems who is now a professor at the University of Arizona; and Susan Coppersmith, now a professor at the University of Wisconsin at Madison, where she specializes in theoretical condensed-matter physics.[1]

Low retired from MIT in 1991, though he remained active in teaching for several more years. His wife of 56 years, Natalie Sadigur Low, died in 2003, after which Low moved from the Boston area to a retirement home in Haverford, Pennsylvania. Low died there on February 16, 2007, of heart failure at the age of 85. He is survived by two daughters (Margaret Low Smith and Julie Low), one son (Peter Low), and six grandchildren.

Francis Low's career highlights the sea change that physics and physicists have undergone during the past half century. A member of the first generation of American physicists to "grow up" amid the new institutional arrangements forged during World War II, Low and his peers embarked on home-grown training in theoretical physics, capped by domestic postdoctoral study. His research began with the new age of renormalizable quantum electrodynamics. Then along with his colleagues, he helped to sharpen those hard-won tools for use in other areas of nuclear and particle physics, such as the strong-force interactions—tools that would eventually undergird the standard model of particle physics. Along the way he saw the discipline enter the broader public sphere, becoming involved with political questions, both as a classified inside consultant with JASON, and as a concerned outside critic with the Federation of American Scientists and the Union of Concerned Scientists. He served as a research scientist and as a scientist-administrator, helping to direct the vast institutions of scientific research that sprang up in the wake of World War II. His scientific and administrative legacies continue to thrive.

NOTES

1. Interview of Francis E. Low by David Kaiser, April 11, 2001, Cambridge, Mass.
2. Francis Low, "Autobiography, ca. 1965," deposited in the History of Physics Manuscript Biography Collection of the Niels Bohr Library, American Institute of Physics, College Park, Md. On Rabi's career, see Rigden (1987).

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