Norman F. Ramsey

1915–2011

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
Daniel Kleppner

NATIONAL ACADEMY OF SCIENCES

NORMAN FOSTER **RAMSEY**

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By Daniel Kleppner

Norman Ramsey was a towering figure in the world of physics during the second half of the 20th century. He was esteemed for his scientific accomplishments, his service as a statesman of science, his role as a teacher and mentor, and the friendships he shared with people of all ranks around the planet.

Norman was born into a military family in Washington, D.C. His father, Norman Foster Ramsey, Sr., had a distinguished career in the U.S. Army, enlisting in the infantry while underage and rising through the ranks to brigadier general. Norman's education was frequently interrupted when the family was ordered to new locations in the United States and abroad. Nevertheless, Norman revealed scholarly and leadership abilities early; at age 15 he graduated from the Fort Leavenworth, Kansas, high school as class president and at the top of his class. He had hoped to enter West Point or M.I.T. but was too young. Columbia University had no age restriction, and in 1931 Norman enrolled there as an engineering concentrator. A year later, he switched to his first love, mathematics. For his minor concentration he chose physics, a subject he had never heard of before Columbia.

In his senior year, Columbia awarded Norman a Kellett Fellowship, which normally supported studies at the University of Cambridge in the humanities. But the committee members were so impressed by Norman, who wanted to study physics there, that they awarded the fellowship to him anyway. He arrived in Cambridge in 1935 and for the next two years studied physics at the Cavendish Laboratory. He attended lectures by Ernest Rutherford, Paul Dirac, and J. J. Thomson, among others, and was tutored by Maurice Goldhaber, who later became a close friend and director of Brookhaven National Laboratory. In 1937 Norman returned to Columbia armed with two bachelor's degrees, a graduate teaching fellowship in physics, and enough formal training to permit him to move directly into doctoral research. His experience at Cambridge, particularly

Norman, Minnesota, 1926.

Rutherford's lectures, had kindled in Norman an enthusiasm for experimental physics, and he applied to work in I. I. Rabi's laboratory.

Rabi's group studied atomic nuclei using the molecular beam technique, in which streams of atoms or molecules are deflected by strong magnetic fields as they fly through a vacuum. Rabi initially discouraged Norman because he felt that the field was essentially exhausted. Norman persisted, however, and was permitted to join the group.

Graduate research with Rabi

Rabi had been seriously mistaken when he spoke to Norman about the limited future of molecular beam research. A few months later Rabi invented molecular beam magnetic resonance, precipitating a scientific explosion whose echoes still reverberate today. Rabi's resonance concept opened the way to fundamental quantum measurements and high-precision metrology, and it helped to spark nuclear magnetic measurements, atomic clocks, lasers, optical communications, and the global positioning system.

Applying the new resonance technique to study the proton and deuteron was high on the agenda of Rabi's group, but the lab's apparatus, which gave excellent results for nuclei in alkali-halide molecules, refused to yield data for hydrogen and deuterium. The quest was turned over to Norman, at the time the group's junior member, so that the others could pursue more productive research. Working alone at night, he got their apparatus to work and made the most important discovery yet to come from Rabi's lab—that the deuteron is not spherical. Within a year this discovery had stimulated 10 publications by theorists, including Hans Bethe, Eugene Wigner, and Gregory Breit. The discovery also launched Norman into a lifelong study of magnetic interactions in molecules.

Norman received the Ph.D. in 1940 and accepted a fellowship at the Carnegie Institution in Washington. He added particle physics to his research agenda and worked on neutron-proton scattering using Carnegie's 1 million electron-volt accelerator. That same year he married Elinor Jameson of Brooklyn, N.Y., and accepted a position at the University of Illinois at Urbana. The newlywed couple arrived at Urbana in mid-September, but war was breaking out and their plans abruptly changed.

The war years

During the summer and fall of 1940 Germany launched the Battle of Britain, the first battle fought by air. The British employed an early type of radar that turned out to be decisive in their effort. The American inventor/philanthropist Alfred Loomis recognized the significance of radar for the U. S. military and arranged for what became known as the Tizard mission to bring British radar technology—particularly the magnetron—to the United States. The mission arrived late in August. To avoid bureaucratic delay in developing radar, Loomis personally provided the funds for launching the U.S. radar effort. He selected MIT in Cambridge, Massachusetts, as its site and within days the MIT Radiation Laboratory was born.

In September 1940, Rabi moved to Cambridge to help organize the new effort and he immediately recruited Ramsey. Norman and Elinor had just arrived at the University of Illinois but in October, before they were fully unpacked, they moved to Cambridge. Norman expected the job to involve a three-month leave from Illinois, but they never returned.

Norman was made head of the group charged with developing 3 cm radar, and he and his colleagues made great advances; much of the microwave hardware one sees on radar installations today originated from that group. In the summer of 1941 he flew to England to share technology, and he discovered that the British had a decisive invention—a crystal diode detector for microwave radiation—that was vastly superior to the vacuum-tube triode detectors used in the United States. He carried home a handful of the crystal diodes in his coat pocket, and personally transferred the new technology to the Radiation Laboratory. In 1942 Norman was assigned to Washington, D.C., to advise the Secretary of War, Henry L. Stimson, on radar. Stimson was concerned that the Air Force, unlike the Navy and Army, did not recognize the value of radar to its mission. Norman was so successful in generating Air Force interest that he was ordered to advise in creating a budget for bringing radar to that branch. Such a massive transformation required many planes, radar sets, and ground installations. The budget, which he and a few others devised over one weekend, came to about $2 billion and was quickly approved.

In 1943 the Manhattan Project—to create an atomic weapon—was launched under the supervision of General Leslie Groves. Groves selected J. Robert Oppenheimer to direct the scientific effort, and the Los Alamos Laboratory was founded. Rabi was a close friend of Oppenheimer's and served as his informal advisor, particularly on issues of personnel. Evidently, Rabi recommended Norman to Oppenheimer because a somewhat unseemly tug-of-war ensued for Norman; it was between Groves and Stimson and between Oppenheimer and his counterpart under Stimson, Edward Bowles. The conflict was resolved by an unconventional arrangement: Norman would work for the Manhattan Project but continue to be an employee of the War Department. The understanding was that Norman would report to Stimson if he sensed trouble at Los Alamos. Norman later described how on a few occasions Oppenheimer prevailed in a disagreement with Groves by threatening to ask Norman to complain to Stimson.

Norman was put in charge of Project A, the so-called delivery group. As he described it, he was given responsibility "for design and procurement of components which were required to convert a nuclear explosion into a combat bomb; coordination with Air Force activities including the modification of suitable aircraft; supervision of field tests on bombs without active material, planning, and establishment of the necessary advance base where the final bombs would be assembled; assembly of active bombs and loading into aircraft; supervision of all tests and actions pertaining to the bomb while aboard the aircraft but prior to release; etc."[1] Norman's experience in procurement in Washington was evidently of some advantage. To the detailed list of required equipment he added an innocuous item: "one kit bomb assembly." This "kit" eventually included, among other things, several buildings, air conditioning, hoists, and a fleet of trucks.

Norman was on hand at the Trinity test site in order that final assembly of the bomb might benefit from the test, which was carried out early in the morning of July 16, 1945. Later that day he drove Rabi and Oppenheimer to Los Alamos (Rabi argued that Oppen-

1. Ramsey, N. F. (1945) *Report of project A*. Los Alamos National Laboratory Archives. Report unclassified July 17, 1979.

heimer was too jittery to drive), and the following morning Norman left for the Pacific island of Tinian, where the delivery group was waiting for him to supervise deployment.

Although Norman was ever ready with stories, he rarely talked about Los Alamos. In a 1962 oral interview, however, he described his experiences and views, particularly his profound aversion to bureaucracy, in some detail. The entire scientific community at Los Alamos appreciated the need for speed, as they were concerned that the Germans might develop a nuclear weapon first. But Norman and undoubtedly others were continually frustrated by bureaucratic delays. In that interview he commented, for example, on “the many dedicated and hardworking people without whom the war would have ended sooner.” In all the years I knew Norman, I never heard him speak unkindly of anyone. This jibe was about as cutting as he got.

Columbia and Brookhaven

Norman left Los Alamos in October 1945 and resumed his academic career by returning to Columbia, now as a tenured associate professor of physics. He set about building a molecular beam laboratory by salvaging apparatus that had been cannibalized during the war. The scientific cost of the war to Columbia’s physics department had been high. Enrico Fermi and Harold Urey left for the University of Chicago, attracted by Chicago’s Metallurgical Laboratory, which was soon to be transformed into the Argonne National Laboratory; other scientists had moved to the Oak Ridge National Laboratory and Los Alamos. Rabi and Norman decided that the highest priority for the physics department should be to gain access to a nuclear reactor, preferably nearby. They took their case to Vannevar Bush, head of the U.S. Office of Scientific Research and Development, who encouraged them, and in January 1946 they organized a meeting at Columbia with representatives from nearby universities and research laboratories.

Columbia’s ambitions were not unique; Harvard and MIT argued that they too needed access to such a facility, and other universities became interested as well. A second organizational meeting was held in March, now with participants from nine universities. The single seriously divisive issue was the location of the new laboratory. Because of its size, the site had to be at a former military base and each university had a favorite candidate that happened to be close by. A working group was appointed to settle on the location and Norman was asked to head it.

With a combination of relentless logic, patience, and good humor, Norman brought the contentious group to agreement on a site. For instance, to put an end to disputes about travel times from airports to final candidate sites, Norman personally timed the travel for each of the sites, picking up a speeding ticket in the process. The group agreed on the site of Camp Yaphank in Upton, Long Island. Worrying that "Yaphank" and "Camp" might not sound attractive to wives, Norman asked Elinor to pick a better name from a list of nearby communities. She selected "Brookhaven," and on January 1, 1947, the Brookhaven National Laboratory became a reality.

Elinor, Norman, Janet, Patty, Margaret, and Winnie, 1955.

Norman agreed to serve as the head of its physics department, splitting his time with his duties at Columbia. During the fall of 1946 Norman and Rabi had tried to recruit Julian Schwinger to Columbia while Harvard was working to attract him to its own physics department. Harvard won, and Schwinger joined Harvard's faculty. The recruiting battle had repercussions—Harvard was so impressed with Ramsey that it offered him a position and was willing to wait while he pondered his options. As the year progressed, it became evident to Norman that his joint appointment with Brookhaven and Columbia was untenable. A major problem was the Long Island Railroad, whose infamous shortcomings finally made commuting impractical. Norman accepted the Harvard position and joined its physics department in the summer of 1947.

The move to Harvard was so rushed that he and Elinor had only a single day to find a new home. A house in Belmont, MA, close to a bus line looked good, and they purchased it on the spot. There, Norman and Elinor raised their family of four daughters: Margaret, Patty, and the twins Janet and Winnie. The children attended local schools and the family vacations were packed with skiing, sailing, hiking, and travel to centers of physics around the world. Norman and Elinor lived happily in that house until 1983, when Elinor succumbed to cancer.

Norman and Ellie, 1988.

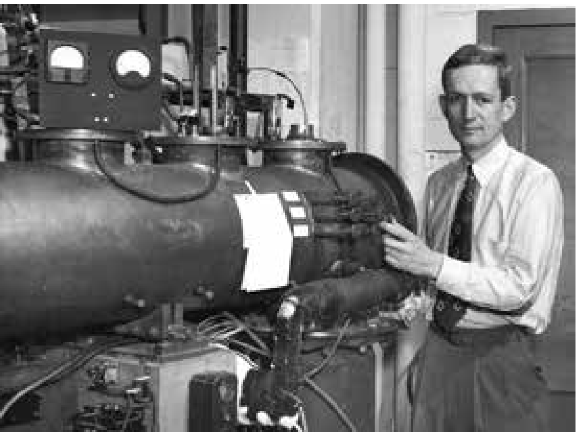
In 1985 Norman married Ellie Welch, who fully shared his passions for hiking, skiing and, traveling. They lived in Brookline and until late in his life Norman commuted to Harvard by bicycle.

At Harvard

When Norman moved to Harvard he envisioned a traditional career of teaching and research, but no sooner had he arrived than his plans were diverted. The physics department had undertaken to construct a cyclotron and appointed a promising young physicist, Robert R. Wilson, to design the machine and supervise its construction. Wilson completed the design but abruptly accepted a faculty position at Cornell, leaving Harvard to build the machine. Because Norman had acquired a reputation for managing technical projects efficiently and he had experience in high-energy physics from his year at the Carnegie Institution, it was natural for the department to ask him to supervise construction of the cyclotron and bring it into operation. Norman accepted the assignment, and he built the cyclotron at the same time that he created his new molecular beam laboratory on the ground floor of Lyman Laboratory for Physics. The cyclotron construction proceeded smoothly, and the facility commenced operation in June 1948. A formal dinner was held in celebration, with many notables, including Harvard's president, attending. But Norman's pleasure in that dinner was short-lived; midway he received word of a leak in the cyclotron's vacuum chamber, and he rushed out in full evening dress to fix it.

In 1950, Richard Wilson joined the Harvard physics faculty and took responsibility for upgrading the cyclotron energy. For about 15 years Norman collaborated with Wilson and others in experiments on the cyclotron, but his major research program involved the molecular beam laboratory. Norman also collaborated in planning the 6-GeV Cambridge Electron Accelerator, working with Wilson, Stanley Livingston at MIT, and others. (A GeV is one billion electron volts.) The accelerator came into operation in 1962 and was used until 1974.

In the course of designing the central apparatus of his molecular beam laboratory, Norman invented the separated oscillatory field method, which later was cited in his 1989 Nobel Prize. To increase the precision of his frequency measurements, he extended the length of the machine, thereby increasing the time during which the molecules interacted with the oscillating radiofrequency field. While struggling with the design Norman recalled a curious fact from the undergraduate lectures he attended at the University of Cambridge: to obtain a sharp image of a small source through a telescope, paint a black strip across the center of the telescope mirror and use only the edges. The image will be faint, but sharper than if you used the whole mirror. Spurred on by this curiosity, Norman calculated the signal to be expected if he replaced the long coil for the radiofrequency fields by two short coils separated by the same overall length. He discovered that the signal was almost twice as sharp, and also that there were even more important advantages. Although it had been assumed that the frequency of the resonance signal depends on the strength of an applied magnetic field, and that the field must be extremely uniform, Norman realized that the signal depends only on the average strength of the magnetic field—thus fluctuations due to magnetic imperfections are smoothed out. Further, while Rabi's method was useful only at relatively low frequencies, in principle the separated oscillatory field method could work at *any* frequency.



Norman with first molecular beams apparatus at Harvard, circa 1955.

Norman's group quickly put the separated oscillatory field method to use and it was soon taken up in laboratories in the United States and abroad. Today it is often referred to simply as the "Ramsey method." In addition to playing a crucial role in Norman's own studies of magnetic interactions in molecules, the Ramsey method made atomic clocks possible. Rabi had pointed out in 1944 that in principle one could use the internal frequency of an atom to control the rate of a clock. Unfortunately, his magnetic resonance technique could not be used at the high frequency required for a clock. Within a few years of Norman's discovery, however, a group at the National Physical Laboratory in England demonstrated the feasibility of an atomic clock by applying the Ramsey method to observe a microwave transition in the cesium atom. A few years later, Jerald Zacharias, an M.I.T. physics professor who had been a member of Rabi's group, led in the engineering of a practical atomic clock, which he called the *Atomichron.* During the following five decades, the accuracy of the cesium beam atomic clock was incrementally improved by about a factor of 10 each decade, with the Ramsey method at the heart of each new generation.

Applications of atomic clocks have been manifold. Atomic clocks made the Global Positioning System possible; they keep communication and power transmission systems synchronized; they are widely used in precision-measurement experiments; and they are found in astronomical observatories that employ very long baseline interferometry. In recent years the Ramsey method has been employed in a new generation of atomic clocks that work at optical frequencies and achieve unprecedented accuracy. And other applications of the Ramsey method continue to appear. It is now employed, for example, in research involving entangled quantum states and quantum information theory, and it may open new paths for geodesy.

A Golden Age at Harvard

Norman's era at Harvard was a golden age for the physics department. His colleagues included Percy Bridgman, Edward Purcell, Julian Schwinger, Roy Glauber, John Van Vleck, and Nicolaas Bloembergen (in the adjacent Division of Engineering and Applied Physics), all of whom were awarded the Nobel Prize; and also Robert V. Pound, who received the National Medal of Science. Norman's own Nobel Prize, for his development of the separated oscillatory field method and the hydrogen maser, was awarded in 1989.

Norman and Ed Purcell had adjacent offices in the Lyman Laboratory, and they talked daily. Purcell was shy and soft-spoken while Norman was gregarious and loud-voiced, but they were intellectually and temperamentally matched and clearly enjoyed one another's company. For instance, when Norman created a graduate course on molecular beam research, Purcell sat in, and he asked penetrating questions that Norman took care to anticipate. One lecture by Norman involved the issue of parity conservation, which generally was taken for granted. He guessed that Purcell would ask what evidence Norman had for this assumption; truth be told, Norman had found none. So Norman took the initiative and asked Purcell if he knew of any evidence. Purcell said he could not find any either, so they promptly surmised that parity might not actually be conserved after all. They published a paper suggesting appropriate tests, and then launched a series of experiments searching for a breakdown of parity conservation, as well as of time-reversal conservation, in the neutron. Their first experimental test was reported in 1957. And Norman reported ever more sensitive tests roughly every five years until about 1990, based on work carried out at Brookhaven, Oak Ridge, and the Institut Laue-Langevin (in Grenoble, France). Unfortunately, as Norman liked to explain, he and Ed had proposed searching for parity breakdown under the so-called strong interaction, using neutrons. They found none. By contrast, the effect was promptly seen for the so-called weak interaction, using muons, and this work led to Nobel Prizes for T. D. Lee and C. N. Yang.

In the fall of 1955 I entered the Harvard physics department as a graduate student and joined Norman's group. Norman valued direct confrontation with data and I spent that summer on the ground floor of the Lyman Laboratory, on hands and knees with ruler and pencil, locating the center of resonance curves recorded on long rolls of recorder paper.

During the 1950s Norman organized a biannual conference on molecular beam physics that was held at Brookhaven. His students traveled with him by car, crossing Long Island Sound in a military landing craft that was so cramped we had to stay seated in the car for the voyage, all the while hoping that the craft would not spring a leak. In the 1960s the conference became ICAP, the biannual International Conference on Atomic Physics, which continues today to be the discipline's major forum.

All of Norman's students took his course on molecular beams; a monograph, *Molecular Beams*, that he had written for the course became the bible of the field. Like many of Norman's students, I recall those years with him in a golden glow. There was an intellectual excitement, solid scientific progress (especially regarding magnetic interactions in molecules), and forays on speculative ideas. The group was dominated by Norman's exuberance, ever-friendly personality, and booming voice. (A colleague recalled that on a bus from Oxford to London Norman was telling a story so loudly in the rear that the driver stopped, walked back, and asked Norman to lower his voice because the story was disturbing his driving!) Norman's Friday group meetings were legendary, as were the travel gymnastics he sometimes executed to get there. I recall one scenario: Thursday morning, fly to D.C. to meet with the Department of Energy; afternoon, fly to Chicago—taking advantage of the time difference—to preside at a meeting of University Research Associates; evening, return to Cambridge and prepare for Friday class; Friday morning, teach class; Friday noon, group meeting.

Norman's group meetings mixed serious science with playful notions and endless anecdotes. He kept a collection of toys and puzzles for displaying scientific paradoxes that

Outdoor group meeting, ca. 1960. At center, Norman standing on his head.

baffled us, and sometimes him. Norman was a famous storyteller—and he could enjoy a story even if he were the butt of its humor. One evening at a Ph.D. party, Norman was in the midst of a story when my wife, thinking I was dozing, nudged me. I whispered to her, "I'm not sleeping, I'm listening. This is a wonderful story and I've never even heard it before!" At that moment there was a lull in the room, so everyone heard my comment. Instead of an awkward silence, however, the room was filled by a roar of laughter from Norman.

In reflecting on his career, Norman said, "During the time when I had graduate students, if I were asked to name my 15 best friends, at least half of them would have been my current graduate students. That is the way we operated, on a first-name basis. I learned a lot from them, and they learned a lot, I hope, from me."

Norman's students not only shared in the intellectual excitement of his group, they also experienced much of the physical excitement offered by the great outdoors. Norman was an avid skier, both downhill and cross-country, and he introduced many of his group to those pursuits. He was also a dedicated hiker. We often went on hikes in New England or, at conferences, in nearby mountains. He skied and hiked throughout his long career. In his 70s he trekked in the Himalayas, the oldest visitor to have done so. Only after the trek did Norman notice that he had ruptured his Achilles tendon. In his 80s Norman walked the week long Milford Trek in New Zealand and the 200-mile coast-to-coast path in England. In New Zealand, Ellie had to dissuade him from bungee-jumping into a gorge. In his 90s he managed to visit both Antarctica and Alaska in the same summer. Norman's catholic connections in science and his warm personality generated walking friends worldwide.

At the start of my second year at Harvard, in the fall of 1956, Norman told me about a new idea that sounded "screwball" (I recall that was his word) but might work. Charles H. Townes had invented the ammonia maser a few years earlier, and Norman speculated about whether it could be possible to employ the maser principle with hydrogen. We carried out an atomic beam experiment to study surface collision using cesium. Fortunately, the results suggested that the hydrogen maser had a reasonable chance of succeeding. In the fall of 1959 I started constructing the maser. At that time Norman was on leave from Harvard, serving as the first science advisor to NATO, but he returned from time to time and we had chances to talk. That summer the maser worked, generating a pure signal at 1420 MHz. We reported the success in a letter written by candle light in Norman's home in Belmont, MA. A hurricane had knocked out the power.

The maser was later developed into a practical atomic frequency standard. Hydrogen masers are now to be found in most international time and frequency laboratories, as well as in radio-astronomy observatories involved in very long baseline interferometer. In Norman's own laboratory, the advent of the hydrogen maser created a new line of research. His group generated a continuous stream of results in basic atomic and molecular physics until he wound down his experimental program in the mid-1980s. In addition, he collaborated in particle physics experiments with colleagues at Harvard and elsewhere until the 1960s, when he became involved with the governance of Fermilab. Norman's research program can be roughly summarized as:

> *MAGNETIC MOMENTS AND MAGNETIC INTERACTIONS IN MOLECULES: Nuclear spins and magnetic moments; magnetic moment of the neutron; rotational magnetic moments; magnetic interactions in diatomic and polyatomic molecules; magnetic susceptibilities and magnetic shielding. These studies laid the foundation for understanding the chemical shifts that are the key to using nuclear magnetic resonance for chemical analysis. Norman later commented that among all of his research efforts, his studies of magnetic interactions in molecular hydrogen had given him the greatest intellectual satisfaction.*
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> *ATOMIC PHYSICS: Fundamental measurements in atomic hydrogen, deuterium, and tritium; hydrogen maser theory and performance; applications of the separated oscillatory field method in various contexts; and atomic time-keeping and metrology.*
>
> *OTHER FUNDAMENTAL STUDIES: Breakdown of parity and time-reversal symmetries; search for the electric dipole moment of the neutron; and the thermodynamics underlying R. V. Pound's concept of negative temperature.*

PARTICLE PHYSICS: Proton-proton, proton-neutron, and electron-proton scattering; proton-proton triple scattering; electron-deuteron scattering; nuclear form factors; and accelerator design.

Over the years, Norman supervised a total of 83 Ph.D. theses. Generations of his students and his students' students now occupy positions in colleges, universities, federal and industrial research laboratories, and other institutions both in the United States and abroad. Prominent on the Ramsey scientific tree are five Nobel Prize winners. In addition to David Wineland, who was his graduate student and received the prize in 2012, there are four prize winners in the next scientific generation: Bill Phillips (1997) and Eric Cornell, Wolfgang Ketterle, and Carl Wieman (who shared the prize in 2001).

Teacher

Norman was an enthusiastic and popular teacher. In addition to presenting his graduate course in molecular beams and mentoring his graduate students, Norman was a hit with freshmen in Harvard's Nat. Sci. II course and its undergraduate section in quantum mechanics. In the 1970s freshmen seminars were introduced to Harvard, and Norman took up this new mode of teaching with his usual energy and devotion. For the first half of the term Norman talked about the frontiers of physics; in the second half the students did the talking. The seminar was oversubscribed every year.

Norman was widely appreciated as a guest speaker at colloquia, seminars, and other occasions, and he invariably accepted invitations if he could make room in his jammed schedule. His podium was often mobbed following a talk, and wherever he went he made opportunities to talk with the students. To coordinate his seemingly labyrinthine schedule of travel, meetings, classes, and talks, he kept track of everything with a mere tiny notebook distributed annually by the Harvard Coop (department store).

Statesman of science

During his years of research and teaching, Norman also pursued what was effectively a second career, which included his service as president of the American Physical Society in 1978, chair of the board of the American Institute of Physics from 1980 to 1986, and president of Phi Beta Kappa from 2001 to 2003. Beyond these public activities, Norman was highly regarded as an advisor and confidant. His scientist's insight, extraordinary common sense, and remarkable personal skills made him the natural person to turn to when a tough administrative problem arose. A colleague commented, "Beyond

Norman on Meet the Press, December 20, 1953.

Norman's brilliance, friendliness, and other attractive qualities, the quality I most appreciated was his absolute determination to be fair."

Norman first adopted a two-career pattern when he collaborated with Rabi to create Brookhaven National Laboratory and organize its physics department while simultaneously building his own laboratory at Columbia. The pattern continued after retirement, when he had wound down his laboratory but continued to teach at colleges and universities while continuing his advisory work. He did not slow down until late in life, when travel became impractical.

An early incident of civic engagement occurred in 1953 when the nation was swept by anticommunist hysteria generated in large part by Senator Joe McCarthy of Wisconsin. Wendell Furry, a professor in Harvard's physics department, had the misfortune to fall under McCarthy's spotlight. The senator accused Furry of being a communist, which he wasn't, and demanded that he give names of his friends, which he wouldn't. McCarthy, who got headlines in practically every newspaper in the nation, then attacked Harvard for harboring communists. The Harvard Corporation put pressure on Nathan Pusey, the new president, to fire Furry. Norman led a few other colleagues in defending Furry from the Corporation, which eventually agreed not to fire Furry. But McCarthy's attacks continued.

Shortly before Christmas 1953, Pusey was invited to defend Harvard on the TV program Meet the Press. Because the Corporation felt that McCarthy's charges should not be dignified by a response from Pusey, the job fell to Norman. In preparing for his national TV debut, Norman went deeply into the law with Erwin Griswold, head of Harvard Law School. At the end of the show McCarthy phoned to ask Norman to come to his apartment for dinner. The senator, who could be charming, was so enthusiastic about Norman's presentation that he attempted to hire him! In spite of Norman's success in defending Furry, McCarthy called for a public hearing so that he could cite Furry for contempt for not revealing names. A conviction would mean a jail sentence. Norman and Griswold spent long hours advising Furry, and eventually the courts threw out the contempt citation. A few months later McCarthy fell from power.

Early in 1954 Norman became engaged in a second incident of anticommunist hysteria when J. Robert Oppenheimer asked Norman to testify at a hearing about his loyalty convened by the U.S. Atomic Energy Commission (now Department of Energy). Norman knew Oppenheimer well from Los Alamos, was absolutely confident in his loyalty, and had a good understanding of the politics behind the attack. It derived principally from the enmity of Lewis Strauss, a commissioner of the AEC, who Oppenheimer had made look foolish in public; and from the distrust of scientist Edward Teller, who had policy disagreements with him. Norman, I. I. Rabi and Enrico Fermi traveled to Washington together to brief Oppenheimer's lawyer and all three later testified at the hearings before the so-called Gray Committee hearings. The committee's procedures appalled Norman. The purpose of a hearing is to establish facts, not to be a trial for judging guilt or innocence, but Norman later reported that the committee's lawyer behaved like a prosecuting attorney. Worse, that same lawyer wrote the report, thus also serving as the judge. It was clear from these tactics that Oppenheimer would be discredited. Norman was deeply distressed by the affair and considered refusing to consult for the federal government. Fortunately he reconsidered, because a few years later he took on an assignment that ended much more happily.

In 1958 Detlev Bronk, president of the National Academy of Sciences, asked Norman to serve as the first science advisor to NATO. Norman accepted the position but for only one year, during which time he established a postdoctoral fellowship program that enabled young scientists to pursue research in different NATO countries; and he came to the rescue of two institutions—the Les Houches school in France and the Varenna school in Italy—that offered the only graduate physics education in their countries at the time but that also were in serious financial difficulty. Securing resources from NATO, Norman successfully intervened, and both schools continue to flourish today.

The founding of Fermilab

In the 1960s particle physicists recognized the need for, and the feasibility of, constructing accelerators that could achieve energies of tens or hundreds of GeV. The Lawrence Berkeley Laboratory and Brookhaven National Laboratory—the two leading particle physics institutions—started to plan such machines, and others became involved, including the Western Accelerator Group (based at Caltech) and Midwest

University Research Associates. The AEC ruled that only one major new accelerator could be supported, and there was additional constraint: because the political climate for providing the funding was fragile, the window of opportunity would be shut unless the community came to agreement on a common proposal.

Unfortunately, the competition between the laboratories was so acrimonious; it looked like the opportunity would be lost. In this increasingly dire situation, President Kennedy's science advisor, Jerome Wiesner, and the General Advisory Committee of the AEC asked Norman to chair a panel to develop a single proposal. Norman was uniquely matched to the task. He was known to the particle physics community—in fact he was personal friends with many of the leaders—and not affiliated with any of the contending laboratories. Moreover, he had the community's respect as a scientist and an established reputation for fairness.

The Ramsey panel (as it came to be known) first met in December 1962. A few months later it recommended that the federal government authorize construction of a 200 GeV accelerator at Berkeley and, as a second priority, that Brookhaven start planning for an accelerator in the 600–1,000 GeV range. These proposals triggered a series of initiatives that extended across the nation, took the political needs of several powerful states and three presidents—Eisenhower, Kennedy, and Johnson—into account, and culminated in 1967 with creation of the National Accelerator Laboratory in Weston, Illinois (not far from Chicago), and the commissioning of a 500 GeV accelerator. The laboratory name was later changed to Fermi National Accelerator Laboratory, or Fermilab. In 1984 the accelerator's energy was doubled and the machine became known as the Tevatron.

To manage the new laboratory a consortium of universities joined in 1965 to form the Universities Research Association (URA). The consortium elected Norman as its president and he was annually re-elected for 16 years. Among his principal achievements was selecting and then personally recruiting Robert R. Wilson to be Fermilab' s director, and Norman's skillful steering of the laboratory through a series of scientific and political crises. To make time for the URA, Norman took half-time leave from Harvard.

In gratitude for his role in creating and operating the Fermilab, in the year of his retirement from URA (1981) the laboratory's auditorium was named in his honor.

The Kennedy assassination study

In 1979 the National Academy of Sciences asked Norman to chair a study, requested by the House Committee on Assassinations that would evaluate purported evidence for an additional shot from a different site at the assassination. This evidence, which if validated would establish the existence of a conspiracy, was the recording of a shot-like noise from an open microphone on a parked police motorcycle. Norman assembled a panel of a dozen physicists, acoustical engineers, and other specialists to perform the needed analysis. After a laborious effort, they found that the purported shot came about a minute after the fatal shots and therefore was not indicative of a conspiracy.[2]

It is impossible to prove the absence of a conspiracy, however, and as Norman had anticipated, his study did not put an end to conspiracy theories. In 2005, questions were raised about the validity of the study and, again, about the possibility of an additional gunshot. He recruited several members of the study team and they reanalyzed all of the evidence, taking advantage of the significant advances in data processing over the years. The results confirmed the accuracy of the earlier analysis and reinforced the study's conclusions.[3]

Late years

The Age Discrimination in Employment Act had not yet taken force when Norman reached age 70, and he was compelled to retire in 1986. He had wound down his molecular beam laboratory, but his career had so much momentum that he seemed as busy as ever. He continued his participation in the neutron electric dipole moment experiment at the Institut Laue-Langevin, finally withdrawing from the project in 1990 when he felt that he could no longer judge the data critically. Over the years, word of Norman's skills and popularity as a teacher had spread, and he was pleased to accept invitations to teach at Middlebury, Williams, Colby, and Mt. Holyoke Colleges and at the Universities of Virginia, Chicago, and Colorado as a visiting professor.

By this point in his career Norman had been showered with prizes, honorary degrees, and other marks of distinction. Among them were his receipt of the National Medal of Science (1989) and election to the American Academy of Arts and Sciences (1950), National Academy of Sciences (1952) and American Philosophical Society (1958). The capstone to his honors was, of course, the awarding of the Nobel Prize in 1989. His colleagues felt that the award was much belated. The cited work—the separated oscillatory field method and the hydrogen maser—had taken place 30 years earlier. But

2. Ramsey, N. F., L. W. Alvarez, H. Chernoff, R. H. Dicke, J. I. Elkind, J. C. Feggeler, R. L. Garwin, P. Horowitz, A Johnson, R. A, Phinney, C. Rader, and F. W. Sarles. 1982. *Report of the Committee on Ballistic Acoustics (John F. Kennedy Assassination)* Washington, DC: National Academy Press; also *Science* 218:127–133 (1982).
3. Linsker, R., R. L. Garwin, H. Chernoff, P. Horowitz, and N. F. Ramsey. 2005. Synchronization of the acoustic evidence in the assassination of President Kennedy. *Science and Justice* 45(4):207–226.

Norman , August 2010.

Norman viewed the timing to be just right because it left him free to accept the deluge of invitations to visit and speak that typically are visited upon Nobel laureates. He accepted whenever possible and never lost his enthusiasm for engaging the students who often mobbed the podium after his talks. But travel became increasingly difficult as he moved into his 90s, and he gradually slowed his pace of activities.

Toward the end of his life Norman became physically limited and, eventually, confined to a wheelchair. His personality, however, never changed. He never complained, never spoke unkindly of anyone (to this author's knowledge), and was cheerful and ever thoughtful. In his final days a visitor entered his room to find him totally unable to move. Norman looked up with a smile and said, "How kind of you to come. Let me get you a chair!"

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