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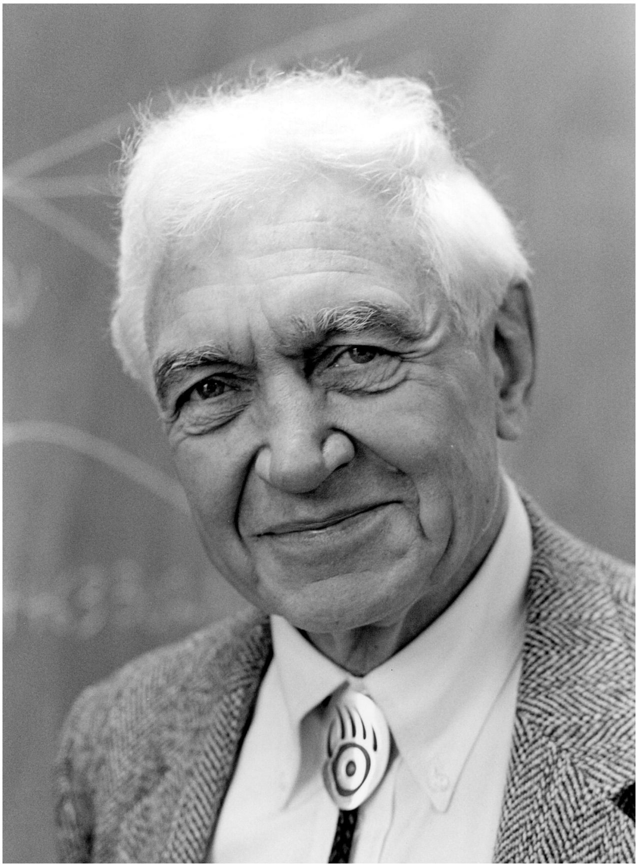

Vernon Hughes

VERNON WILLARD HUGHES

May 28, 1921–March 25, 2003

BY ROBERT K. ADAIR

VERNON WILLARD HUGHES, Sterling Professor Emeritus and senior research associate at Yale University, died on March 25, 2003, at the age of 81 at Yale-New Haven Hospital from medical complications after an operation for an aneurysm. Hughes began research in physics in 1942 when he worked on radar at the MIT Radiation Laboratory. During his terminal stay in the hospital, he wrote letters of recommendation for a postdoc working with him on a major experiment. Thus, Hughes worked at physics research—largely at the cutting edge of atomic, nuclear, and elementary particle physics—for 61 years.

Born in Kankakee, Illinois, on May 28, 1921, Vernon Hughes was raised in the Morningside Heights sector of New York City by his mother, Jean Parr Hughes, who was a librarian at Teachers College of Columbia University. His father, Willard Vernon Hughes, died when Vernon was three years old. As a New York City boy of his time Hughes played stickball in the streets—he later told his sons Gareth and Emlyn that he had been a very good stickball player—and he played tennis on the local Columbia University courts. His sons recounted with amused affection that when he played tennis against them in later years, he gave no quarter.

Entering Columbia in 1938 as a freshman pre-law student with the intention, he wrote, "of doing good things for the world," Hughes took enough time from his studies to play on the tennis team and work on the school newspaper, *Columbia Spector*. He wrote later that while he found some of the Columbia core courses in humanities and contemporary civilization valuable, the mathematics and physics courses were more interesting to him, and he decided to direct his efforts toward mathematics, physics, and engineering. Growing up in modest circumstances during the Great Depression years of the 1930s, he tells of his concerns about a choice of schooling that would result in a job after college.

After completing an especially heavy academic schedule with excellent grades in only three years and winning the Van Buren Math Prize, he graduated from Columbia as a physics major in the spring of 1941 just after his twentieth birthday. Looking for a new environment, Hughes enrolled as a graduate student at Caltech that fall. A picture from that time shows Hughes atop Mt. San Gorgonio in California along with fellow students Pief Panofsky, Bill Eberhardt, and Ed Deeds.

Hughes writes that at Caltech he found Smythe's course in electricity and magnetism, which consisted largely of blackboard presentations by the students of problems assigned from Smythe's book, especially challenging, but he wrote that the acceptance of his work was helped by his "being an acceptable tennis partner for Professor Smythe."

After receiving his M.Sc. degree from Caltech in 1942, with the country at war, Hughes went back east to work on radar at the MIT Radiation Laboratory. Here he joined a group directed by Burton Chance that was especially concerned with accurate time measurements—at the microsecond level—of the reflected radar pulse and thus target range information. He was later coauthor with Chance and others of the Radiation Laboratory volume titled *Waveforms* (1949).

After World War II, in January 1946, Hughes returned to Columbia for graduate study with the goal, he writes, of doing his thesis work with I. I. Rabi. While he found the theoretical work of Yukawa on nonlocal field theories and Selig Hecht's biophysical investigations of vision interesting, he settled on a research topic in molecular beams with Rabi. A decade later Rabi wrote that Hughes "was one of the best students I ever had." With molecular-beam electronic-resonance apparatus that he "built from scratch" Hughes and Lou Grabner measured nuclear electric quadrupole interactions. His thesis for the Ph.D. degree he received in 1950 was based on those measurements. In the course of that work he and Grabner discovered the first clear two-photon transition in their molecular beam electric resonance studies, and Hughes worked out the theory. Hughes commented later that "at that time at Columbia the theoretical course work was extensive and one was expected to handle the theory relevant to one's experiment."

After receiving his PhD in the fall of 1950 Vernon Hughes married Inge Michaelson. German-born Inge had left Germany in 1938 with her family as refugees from the Nazi racial laws. Vernon had met Inge when she was a student in a summer class in mathematics he taught. Inge, who had just graduated from Barnard, took the course in preparation for graduate work in biology. Later Inge received her Ph.D. in biology from the University of Pennsylvania. Their son Gareth was born in 1955 and their son Emlyn in 1960.

After Inge's death in 1979 Hughes married Miriam Kartch, who teaches at the Mannes College of Music. He had known Miriam when he was a student at Columbia. They first met in 1947 when Miriam was assigned as the teacher when the

26-year-old Hughes enrolled as a beginning piano student. He is survived by Miriam, his sons, and four grandchildren.

During a two-year period as a postdoc at Columbia, Hughes, always deeply interested in fundamental matters, found by measuring deflections in an atomic beam that the electron-proton charge difference, $|q_e\text{-}q_p| < 10^{-13}$ *e*, and the neutron charge, $|q_n| < 10^{-13}$ *e*, supporting the view that e was indeed a fundamental quantity. Thirty years later, with his students, he reduced the limits by a factor of 10^6 using atomic measures of these quantities though bulk measures on the charge of gases were by then somewhat more sensitive. In 1953 Hughes left Columbia for a position at the University of Pennsylvania and then joined the Yale faculty in 1955.

While much of Hughes's work was on the properties of atoms, he regarded atoms primarily as laboratories for the study of the fundamentals of electromagnetism and preferred to consider simple atoms "where the theory was adequate." Thus he concentrated on studies of the helium atom, on the electron-positron atom, positronium, the simplest of atoms, and then—arguably his most nearly unique contribution to physics—on muonium, the atom made up of a muon and an electron.

His extensive work on helium from 1950 to 1980, largely using atomic beam methods where Hughes and his colleagues did the experiments and Hughes the theoretical calculations, provided rigorous tests of modern quantum electrodynamics (QED) for two-electron systems and a precise value of α, the fundamentally important dimensionless ratio of the square of the electric charge to the product of Planck's constant and the velocity of light.

With Martin Deutsch discovered the electron-positron atom, positronium, in 1952, Hughes began studies of that simplest of atoms with C. S. Wu, again emphasizing connections with QED. At Columbia, with Wu, he made a measurement of Δv, the interval between the states 1^3S_1 to 1^1S_0, that was somewhat more precise than Deutsch's pioneering measurement. His later high-precision measurements at Yale gave a result about three standard deviations from theory, a discrepancy that has not yet been resolved.

After the discovery of parity nonconservation by Wu, Ambler, and others, Hughes with Jack Greenberg measured the longitudinal polarization of the electrons emitted from Co^{60} as a function of their momentum using Mott scattering as an analyzer and found that the polarization was accurately proportional to the electron velocity, β, a result in accord with the Yang-Lee model of weak interactions. Hughes noted that it was his work on this experiment that kindled his interest over two decades in the design of polarized electron beams.

He focused his efforts to create a polarized electron source on the photoionization of a polarized beam of alkali atoms, especially ^{39}K and ^{6}Li. Ten years of work culminated in 1972 with a source that produced a 1.5 μs pulse of a 20 μA current of polarized electrons. That source was then used to produce a high-energy polarized electron beam at the Stanford linear accelerator.

About 1960, elaborating on a suggestion by Cocconi and Salpeter, Hughes used nuclear magnetic resonance methods to study the isotropy of mass. Mach considered that the mass of an object should derive from the distribution of distant matter—far-off galaxies—and thus its inertial mass might be slightly different when accelerated in different directions even as the mass of the universe might be slightly anisotropic. Hughes set that anisotropy for the $p_{3/2}$ proton outside of the closed shell in the lithium nucleus as $\Delta m/m < 10^{-22}$, which from Mach's principle meant that the Universe was isotropic to about one part in 10^{22}.

Hughes with his colleagues McColm, Prepost, and Ziock "discovered" the electron-muon atom named muonium, *M*, in 1960 by observing its characteristic Larmor precession frequency. His following 40 years of experimentation on that atom, concentrating on ever more accurate measurements of the 1^3S_1 to 1^1S_0 interval, Δv, the Lamb shift in the $n=2$ state, and the 1S-2S transition, verified to high precision that the muon is indeed a "heavy electron," gave us new avenues into the experimental study of quantum electrodynamics and created a tool to probe the highest energy scales of elementary particle physics. Aside from this "conventional" physics Hughes established important limits on the muonium-antimuonium transition rate, again testing fundamental concepts.

In 1967 Gisbert Zu Putlitz, later rector at Heidelberg, who had just completed his Ph.D. at Heidelberg came to Yale and worked with Hughes for nearly two years before returning to Germany. Hughes wrote that their collaboration, largely on muonium physics, and their friendship and personal association, which continued until Hughes's death 35 years later, was "among the better experiences in my life." Hughes also wrote of the importance of his close association with Val Telegdi to the muon work that engaged them both in the decade beginning in the late 1960s.

In his atomic physics experiments Hughes worked unceasingly to increase the accuracy of his measurements. Quantities such as the magnetic moment of electrons and muons stem primarily from the elementary electric charges of these elements as observed statically. Then there are "corrections" that represent effects at very small distances or complementarily at very high energies. These modifications to the static result connect the simple leptons with all other particles, including the strongly interacting quarks. Thus, the measurements of very small corrections to the simple model of leptons approaches very much the same kind of physics as cruder measurements of the interactions of the leptons at very high energies. Hughes looked in both directions.

A colleague famous for an important breakthrough once said admiringly that Vernon Hughes was the only physicist he ever knew who would mount an experiment to improve the precision of some fundamental measure by a factor of two. But Hughes's attack went on unceasingly, with improvements by two, and two, and two, and two, which added up to new insights.

As early as 1958, Hughes, along with Wheeler, Beringer, and Gluckstern at Yale, began a serious design study of a proton linear accelerator "meson factory." This machine was meant to place a 1 mA beam of 800 MeV protons on a target to produce meson and muon fluxes a thousand times greater than those then available. Such a meson factory, the Los Alamos Meson Physics Facility, based largely on the Yale design was built, but not at Yale. (Hughes later wrote that Rabi advised him: "If you can't beat them, join 'em. . . . Its a wonderful place to spend the summers with your family." Indeed Hughes did start going to Los Alamos in the mid-1960s to help develop the muon facility there.)

Those summers were wonderful and led to Hughes's longtime friendship with the San Idlefonso Indians neighboring Los Alamos and a special appreciation of their remarkable art—especially their pottery and sand paintings. With his wife, Inge (and after Inge's death and his remarriage, with Miriam), Hughes amassed a collection of that art that gave the comfortable living rooms of their home in New Haven some of the ambience of a charming museum set.

Hughes's close association with Los Alamos and the Los Alamos Meson Physics Facility (LAMPF) continued until

1996, when LAMPF was shut down. During that time his major program directed toward the properties of muonic atoms was conducted there. In particular, Hughes's group measured Δv and the ratio of the magnetic moments of the muon and proton, μ_μ/μ_p, with ever increasing accuracy. As he did always and everywhere, Hughes worked intensively at LAMPF. In 1988 the director of LAMPF wrote an unsolicited letter to the Yale department chair saying that Hughes, then 67 years old, "was still absorbed in physics, indifferent to fashion, and is a true inspiration to younger scientists. . . . He insists on taking the 4:00 AM shift [the experiments on accelerators always ran three shifts, 24 hours a day, every day] so that he can still put in a full working day in addition to taking a shift."

Hughes's development of polarized electron ion sources was fundamental to the use of polarized electrons in high-energy accelerators beginning in 1963, when he developed the first polarized source for the Stanford two-mile accelerator. That vision led to the observation of parity nonconservation in deep inelastic electron scattering and in electron-positron scattering and to measurements of the spin-dependent structure of the proton.

After the groundbreaking Stanford linear accelerator experiment led by Friedman, Kendall, and Taylor identified partons, with quark-like properties, as point-like physical constituents of nucleons, Hughes became deeply interested in measuring the spin-dependent structure of the proton. Thus, he began in 1972, with Peter Schüler, Kunita Kondo and his group from the University of Tsukuba, and a Stanford linear accelerator (SLAC) group led by Dave Coward, measurements of the deep scattering of polarized electrons by polarized protons. The large asymmetries—electrons and protons with their spins opposed scattered more than those with their spins parallel—that were measured over the next five years supported the general quark-parton model of the nucleon.

Following a suggestion by Charles Prescott, the group also investigated the parity-violating scattering of longitudinally polarized electrons by unpolarized protons. Initial measurements, using the Yale polarized electron source, showed no effects at a sensitivity level of 10^{-3}. However, with the development at SLAC of a higher-intensity polarized electron source, the group did see effects at a level of 10^{-5} that were in accord with the electro-weak theory of Glashow, Salam, and Weinberg.

Hughes had hoped to continue work with polarized electrons and protons at SLAC and his initial proposals were received positively. SLAC decided, however, to go in other directions at that time. His disappointment was ameliorated somewhat when 10 years later, SLAC resumed measurements of polarized electron scattering with a very successful program led by Vernon's son, Emlyn Hughes (now a professor at Caltech).

In spite of the termination of the SLAC program Hughes was still deeply interested in polarized lepton-nucleon scattering; he was therefore pleased to accept an invitation by Erwin Gabathuler of Liverpool for the Yale group to join the European Muon Collaboration (EMC) at the European Organization for Nuclear Research (CERN). The collaboration had previously discovered a change in the nuclear structure function when the nucleon is in a nucleus (the EMC effect) and most of the EMC collaborators were much more interested in that effect than in polarized muon-nucleon scattering. With the Liverpool group and the Lancaster group lead by Sloan, Hughes with his Yale collaborators directed a portion of EMC efforts toward polarized muon-nucleon scattering in a kinematic region that had not been explored by the previous SLAC experiments.

The results of that work were very interesting. It was known that the spin of the nucleons was generated by the spins of the constituent quarks together with the orbital angular momentum of the neutral charged gluons coupled to the quarks. The charged muons interacted only with the charged quarks and thus measured the portion of the nucleon spin held by the quarks. That portion turned out to be much lower than expected (by the Ellis-Jaffe sum rule); the quarks carry only a small portion of the nucleon spin—a result called the "spin crisis" or "spin puzzle."

After this result a new group was formed in 1987 (the spin muon collaboration), with Vernon Hughes elected as spokesperson. That group, with about 150 physicists from European, American, and Japanese institutes, as well as strong internal CERN contributions, began taking data in 1992 and continued through 1996. The results were in very good agreement with general QCD (quantum chromodynamics) models (the Bjorken sum rule) but strongly violated the conventional view of the nucleon quark structure (the Ellis-Jaffe sum rule) supporting, with more extensive and more accurate data, the previous spin-puzzle results. Hughes continued to work on designs for more extensive and powerful experiments and was planning a trip to Europe to meet with his collaborators at his death.

Over about the same time span Hughes conceived of and led an experiment to improve the measurement of magnetic moment of the muon by a large factor. The deviation of the magnetic moment, *g*, from the elementary Dirac value of 2, in natural units, thus $(g\text{-}2)_\mu$, serves as a benchmark for the testing of new ideas in particle physics. The precession rate of muons moving in a magnetic field is proportional to the product of the field and $(g\text{-}2)_\mu$. Hence, an accurate measure of the anomalous magnetic moment of the muon, $(g\text{-}2)_\mu$, requires very precise determinations of both the magnetic field and the precession frequency.

A previous major experiment at CERN had established the value of $(g\text{-}2)_\mu$ to the remarkable accuracy of 7 ppm (parts per million). That value was in agreement with the theoretical value—also the product of a massive effort—that was considered accurate to 8 ppm, where much of the error reflected uncertainties in the hadron physics contribution to the moment. Thus, that nominal theoretical uncertainty could be reduced by improved hadron experiments, in particular by improved measurements of the production of hadrons in high-energy positron-electron collisions.

A result as accurate as that reached at CERN, and in agreement with theoretical results calculated assuming conventional physics, already served to exclude many interesting and plausible extensions of that conventional physics. Hughes understood that a significantly better measurement of $(g\text{-}2)_\mu$ could place even more rigorous limits to the character of the extensions of the conventional models of elementary particles that were required and that a better experiment could be conducted at the Brookhaven National Laboratory AGS accelerator, which by 1980 generated beam intensities, and then muon fluxes, superior to that available at CERN.

Hence, beginning in 1982 Hughes began serious studies of methods that might lead to a more accurate measurement. Then in 1984 he began to assemble a group of experienced physicists, many with leading roles in the previous CERN experiment, who were prepared to design and conduct the experiment. Aside from significant contributions from the Brookhaven National Laboratory and CERN, major contributions were made by groups from KEK in Japan and the Budker Institute for Nuclear Physics in Novosibirsk.

A highly accurate measurement made at Novosibirsk of the hadron production cross-section by electron-positron collisions was of major importance, because that measurement served to accurately set the hadron contribution to the anomalous moment and thus significantly reduced the theoretical uncertainty.

By 2002 the collaboration had reached an accuracy of better than 0.7 ppm and the theoretical calculations were accurate to about the same level. The values differed but not quite beyond chance. Somewhat more accurate results were still possible, but as of 2003 government fiscal constraints on Brookhaven physics seemed to have precluded further measurements.

At his death Hughes (at 81) was still playing a major role in two international groups, one working on the large muon $(g\text{-}2)_\mu$ experiment at Brookhaven and another on the design of an experimental program to further study nucleon spin constituents and the problem with those constituents that he had been instrumental in uncovering.

Although he spent his youth in physics very much in the trenches building the equipment for his thesis work "from scratch," his early years at Columbia, Pennsylvania, and Yale usually found him in the laboratory or on the accelerator floor with his hands on his apparatus. In the course of time Hughes found himself occupied more with the tasks of organization and leadership.

Over the decades Hughes had worked on the frontiers of physics, and the complexities of experiments had increased greatly. Along with that increased complexity came increased monetary costs and, sociologically most important, a significant increase in the scientific effort required to conduct an experiment. While Hughes's early experiments involved two, three, and four scientists with a few technicians and typically one or two scientist-years of effort, there are 60 authors on the final Brookhaven paper, representing 11 laboratories from 4 different countries. The paper, describing an effort of more than 100 scientist-years of work, was published 20 years after Hughes had begun working on the problem. And there were 142 authors from 24 institutions from 15 countries on the last SMC publication. With so many participants in experiments that are so complex, the organization of effort is important and only a physicist who is knowledgeable about all experiment details and has the trust and confidence of everyone can exercise leadership. Vernon Hughes was special in his broad knowledge of the experiment and singular in how he held the confidence of his colleagues.

This confidence and special breadth led Hughes into leadership positions. (He was usually a senior spokesman for the experimental groups he worked with.) In those positions Hughes often represented his collaborations in the presentations before laboratory program committees, the committees that effectively accepted or rejected a proposed experiment. With his energy and interests—both deep and broad—he was usually involved in several rather different programs, and the program committees were often concerned with the division of his time; committee members wondered whether Hughes was really going to work personally on the experiment he was advocating. With this concern in mind, when Hughes appeared before a European committee addressing a proposal to support an experiment on deep electron-proton scattering (which would be supported by the U.S. Department of Energy budget for elementary particle physics) and knowing that Hughes had heavy commitments on the $(g\text{-}2)_\mu$ experiment at Brookhaven (also supported by the U. S. Department of Energy elementary particle physics budget), the committee chair asked Hughes what portion of his time would he spend on the experiment he was advocating. Hughes answered, "50 percent," noting that he would spend the other 50 percent on the Brookhaven experiment. One of the committee members then said, "but what about your LAMPF experimental programs at Los Alamos?" Hughes answered, slightly affronted, "But that's nuclear physics!" (LAMPF was supported by the Department of Energy nuclear physics division). But all was well; the committee recognized that all his life Hughes had worked at a 150 percent level.

While his researches in physics took the highest priority, Hughes was ever sensitive to the goals of his youth, to do "good things for the world," and lent his weight and substance to social goals that he found meritorious; thus, Hughes worked hard and effectively on administrative tasks that he found worthwhile.

With the impact of the radar that Hughes worked on at the MIT Radiation Laboratory, which was sometimes said to have *won* World War II, and the neutron chain reaction bombs, which could be said to have *ended* the war, the level of financial support of research in physics and other science at major universities increased so greatly as to change forever those universities. The newly configured institutions became "research universities," with research money from the government that reached a level near or in excess of the instruction budget.

While Yale continued to emphasize undergraduate education (at Yale College) more than many other universities, it had to follow other schools in shifting its institutional priorities sharply toward scientific research and graduate education. With its historic emphasis on the humanities, not science, Yale was not well placed to make that change in general, and not well set in physics, in particular.

In the late 1950s Yale president Whitney Griswold became aware that in an era of great physics, Yale was not playing a major role and asked J. Robert Oppenheimer, then director of the Institute for Advanced Study at Princeton, to review the department and report back to him and the corporation. Oppenheimer's critical report was devastating, perhaps to the point of being unfair. Yale had considerable strength in experimental nuclear physics—with Schultz, Beringer, and Bockelman, and the strong effort in nuclear theory by Gregory Breit—but by 1958 many of the more fundamental questions in nuclear physics had been answered, and nuclear physics itself was sliding behind the frontiers of physics. Though the low-temperature work of C. T. Lane and Henry Fairbank was also first rate, Oppenheimer recognized only the work of Hughes as lying at the cutting edge of physics. Hence, at Oppenheimer's urging Hughes was appointed department chair in 1962 and with special resources from the university was given the task of bringing the Yale department into the first ranks.

Hughes served in that office for the university's statutory limit of two terms, or six years. During that tenure he moved aggressively and effectively, bringing in many new faculty members and new programs while constraining some of the roles of older faculty members. Hughes's changes had consequences: In the decade of 1961-70 the average number of students receiving the Ph.D. in physics per year at Yale rose to about 20, giving Yale then by that measure the country's eighth largest graduate school in physics.

Of course, the changes that Hughes instituted did not come without costs in personal relations. Hughes was perhaps Gregory Breit's best friend among the senior faculty, and they had established a tradition of having lunch together each Saturday at a popular campus restaurant. Greatly displeased by Hughes's actions as chair in taking theoretical physics outside of Breit's personal control and broadening its intellectual base, Breit stopped speaking to Vernon for a time, but as Hughes later told a friend bemusedly, they continued to meet Saturdays for a silent lunch. Hughes's very rare clashes with his peers were always without personal animus on his part. While he strongly disagreed with Breit on department matters, his deep respect for Breit's accomplishments in physics was untouched. In 1999, when Hughes was 78, he organized a symposium at Yale on Gregory Breit's lifework in physics to mark the 100th anniversary of Breit's birth.

Hughes also contributed administratively by serving on the Board of Trustees of Associated Universities, Inc., for more than 40 years, from 1962 until his death. An independent organization created by scientists and administrators from nine northeastern universities, including Yale, Associated Universities established Brookhaven National Laboratory in 1947 and the National Radio Astronomy Observatory 10 years later.

Hughes was elected to the National Academy of Sciences in 1967. In 1978 he was awarded the Davisson-Germer Prize in Atomic Physics and in 1990 the Tom R. Bonner Prize in Nuclear Physics, both from the American Physical Society.

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