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ROBERT HOFSTADTER
1915–1990

A Biographical Memoir by

JEROME I. FRIEDMAN AND WILLIAM A. LITTLE

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R Hofstadter

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February 5, 1915–November 17, 1990

BY JEROME I. FRIEDMAN AND WILLIAM A. LITTLE

ROBERT HOFSTADTER WAS BORN in New York City, educated on the East Coast, but spent most of his academic career at Stanford University. He is best known for his work on determining the distribution of charge and magnetic moment in the nuclei of atoms and of the nucleons themselves, for which he was awarded a Nobel Prize in 1961. He extended the work done in the early part of the twentieth century by Ernest Rutherford, who had shown that atoms were composite, containing electrons and a nucleus many thousands of times smaller than the atom. Rutherford discovered this by scattering alpha particles from thin metal foils of the elements and measuring the number of particles scattered as a function of the angle. The surprisingly large number of particles that were scattered through large angles could only be explained by collisions with a heavy, very small, perhaps point-like, positively charged object, which he called the nucleus.

Some 40 years later Hofstadter determined the internal structure of such nuclei by scattering high-energy electrons from thin targets and measuring the distribution of the number of these electrons as a function of angle. In these experiments he built on earlier work by others on electron-

electron scattering from atoms and electron-nuclear scattering by Hanson, Lyman, and Scott at Illinois done at lower energies in 1951. Hofstadter showed that the nuclei had internal structure extending over a small but measurable distance and that the heavier nuclei had a relatively uniform density within a thin surface skin. The Nobel committee considered this to be the first “reasonably consistent” picture of the structure of the nucleus.

Hofstadter fully appreciated the significance of his work on nuclear structure, but nevertheless said on a number of occasions that he felt his major contribution to science was not this but rather his discovery of the photofluorescence of NaI crystals, activated by thallium, which could be used to measure the energy of X rays and gamma rays. This discovery, which he made in his early thirties, became the pre-eminent way to detect and measure the presence and concentration of radioactive elements for studies in biology and medicine, and such detectors have also been used extensively in particle physics, gamma-ray astronomy, geology and many other areas of science.

Bob was born on February 5, 1915, in Manhattan to Louis Hofstadter, a cigar-store owner and salesman, and Henrietta Koenigsberg and attended public school there before entering City College of New York. He showed exceptional ability in mathematics and physics and was particularly stimulated by the clarity and precision of the teaching of Irving Lowen and Mark Zemansky at City College. Bob graduated with a B.S. degree magna cum laude in 1935 at the age of 20, and was awarded the coveted Kenyon Prize in Mathematics and Physics. He also received a Charles A. Coffin Foundation Fellowship from the General Electric Company, which enabled him to attend graduate school. He chose Princeton University, where he began graduate work in physics. A stipulation of the fellowship was that the recipient should be involved in research even in the first year of graduate study. As a result, Bob was exposed to a number of different projects early in his graduate career. These included experimental work on a Wilson cloud chamber, the study of the infrared spectra of organic molecules, and theoretical work on the development of a new type of mass spectrometer. This research left him little time for his course work, and he felt it interfered with his study of quantum mechanics, which he took from Eugene Wigner, and with his goal of becoming a theorist.

These pressures were eased in his second year, when Bob became an assistant to E. U. Condon, who at that time was writing with George Shortley *The Theory of Atomic Spectra*, a text that was to become a classic in the field. Condon's elegance of thought and expression, his blackboard manner, and his humor made a long-lasting impression upon Bob. But after a brief stint as a theorist calculating energy levels for Condon, he joined R. Bowling Barnes's experimental group in the infrared laboratory. Shortly after this, both Barnes and Condon left the university, and Bob was without an advisor. He completed his master's and Ph. D. degrees the following year, very much on his own, at age 23. His thesis included the determination of the oxygen-hydrogen spacing in light and deuterated formic and acetic acids. This work helped elucidate the nature of the hydrogen bond and earned a footnote in Linus Pauling's book *The Nature of the Chemical Bond*.

Through his association with Barnes and Condon, Bob got to know Frederick Seitz, who had been a student of Wigner's and was a frequent visitor to Princeton. Seitz, who much later became the president of the National Academy of Sciences, invited Bob to spend the summer of 1938 at the General Electric Laboratory to study the photoconductivity of willemite (zinc silicate), a fluorescent compound used in television screens. He accepted this invitation and upon his return to Princeton, with a prestigious Proctor postdoctoral fellowship for the 1938-39 academic year, he worked with Robert Herman, also from the infrared laboratory. Together they discovered crystal warm-up currents in willemite, which established the theory of deep traps in crystals. This work provided the background in solid-state physics that was to become important in Bob's later work on NaI(Tl) scintillation counters and other nuclear detectors.

In 1939 Seitz, who had taken a faculty position at the University of Pennsylvania, invited Bob as a Harrison fellow. Bob took him up on the offer, but joined Louis Ridenour's Van de Graaff group in nuclear physics rather than the solid-state group Seitz had expected him to join. It was not a particularly fruitful time for his research, and in 1941 he moved for one semester to City College of New York. While at the University of Pennsylvania he had established a lasting friendship with Leonard Schiff, who was later to become the chairman of the Physics Department at Stanford and a colleague with whom Bob collaborated extensively in his later work on nuclear structure.

With the entry of the United States into the war in 1941, Bob applied to and was accepted by the National Bureau of Standards in Washington, D.C., for work on the optical proximity fuse. There he worked with Joseph Henderson and Seth Neddermeyer. The optical fuse proved less effective than the radio proximity fuse developed at the Harry Diamond Laboratory. This led Bob to resign from the NBS in the middle of the war and join the Norden Company, which was noted for its success in developing the famous Norden bombsight. There Bob worked on a radar altimeter until the war's end.

Bob's interests went well beyond physics and included among other things an appreciation and enjoyment of classical jazz. It was the sound of this music from his apartment in Philadelphia that first brought him to the attention of neighbor Nancy Givan, who also was a music devotee. Together they enjoyed the jazz scene of New York and Philadelphia, the Apollo Theatre in Harlem, and music and dancing at the Savoy Ballroom. They married in Washington, D.C., on May 9, 1942.

In 1946 Bob joined the Department of Physics and Astronomy at Princeton University as an assistant professor. He began research on means for detecting gamma rays, which he hoped would be useful for work on the Princeton cyclotron. After learning of a scintillation counter using naphthalene developed by Hartmut Kallmann in Germany, Bob used his knowledge of solid-state physics, acquired during his studies at the General Electric Laboratory before the war, to develop a detector using activated alkali halides instead of organic crystals. He found that NaI(Tl) sodium iodide, with a few hundredths of a percent of a thallium compound added, was far more effective in detecting gamma rays than was naphthalene or anthracene. The improvement was due to three factors: the high transparency of the material to its own fluorescent emission; the high density of the NaI relative to the organic materials; and the presence of the high atomic weight element, iodine, which made the compound much more effective in stopping gamma rays. He filed a patent on this for the detection of ionizing radiation in 1948. Two years later Bob and his second graduate student, Jack McIntyre, discovered that sharp gamma ray lines could be seen with this detector, making possible gamma ray spectroscopy with a relatively simple apparatus.

The potential of the new detector attracted the attention of physicists at Berkeley, where Bob and McIntyre had worked during the summer of 1949. Princeton did not offer Bob a promotion to associate professor; instead, he received two offers from the West Coast, one from Berkeley and another from Stanford, where Leonard Schiff was the chairman of the Physics Department. Bob accepted the Stanford offer of an associate professorship and with his family left Princeton in August 1950 to drive across the country to California. En route to Stanford, he and his wife, Nancy, visited Hilda and Eugene Feenberg at Washington University in St. Louis. There Bob discussed his plans for work at Stanford using his NaI(Tl) crystals for the detection of high-energy electrons and gamma rays, and for studies of electromagnetic showers. In the course of this conversation, Eugene is said to have remarked, "Why not do electron diffraction (on nuclei) like the earlier work on atoms?" This was the stimulus that led Bob to his Nobel Prize work and set his mind working on the design of the spectrometer needed to do it. He learned later that Leonard Schiff, in a Stanford Microwave Laboratory Technical Report, had already proposed in 1949 just such studies of nuclei, including that of hydrogen, by electron scattering.

In his first three years at Stanford, Bob worked closely with Jack McIntyre, who had followed him to Stanford as a postdoctoral fellow, and together they extended the application of scintillation counters to the study of X rays, neutrons, alpha particles, and muons. They also applied these counters to the study of electron showers.

This period was an exciting time at Stanford, for it coincided with the development and the successful completion of the world's first high-energy electron linear accelerator. This was the result of work initiated by W. Hansen and E. L. Chu on disk-loaded waveguide accelerating structures and by W. Hansen, J. R. Woodyard, and E. L. Ginzton on the linear acceleration of electrons using high-power microwave sources. These high power sources, multimegawatt relativistic klystrons, were developed at the same time by M. Chodorow and other members of the Stanford Microwave Laboratory staff.

Initially the Stanford Mark III accelerator had achieved an operating energy of 180 MeV, and in November of 1953 the energy was raised to 400 MeV. Within a couple of years the accelerator achieved reliable operation at 600 MeV. The availability of this machine at this time gave Bob the unique opportunity to undertake his pioneering work on the structure of the nucleus.

The concept of using high-energy electrons to study the structure of nuclei was simple in principle, but its realization was not. The new accelerator had to be nursed into stable operation with many hours of conditioning prior to each run. The duty cycle of the accelerator was very low, with the particles bunched into short bursts that were well separated from one another. These bursts, with many electrons arriving at the same time, made it impossible to detect the individual particles using NaI(Tl) crystals. Bob realized that he needed a very good double-focusing magnetic spectrometer to separate the elastically scattered particles from those that were scattered inelastically, and to measure their angle of scattering. He adopted the design of a magnet developed earlier by the nuclear physics group at the California Institute of Technology and built one with the help of a $5,000 grant from the Research Corporation and support from the Office of Naval Research. The magnet weighed 2.5 tons, had a radius of curvature of 16", and could focus electrons of energies up to 180 MeV, the maximum energy the Stanford Mark III accelerator could deliver at that time.

The target to be studied was centered in a 20" vacuum chamber through which a filtered and narrowly defined beam of electrons was passed. The filtered beam was produced by transporting the primary beam from the accelerator through a two-magnet, double-deflection energy filter that defined the energy to about 3 percent, and separated it from the gamma-ray background. This beam filter had been designed and built earlier by J. MacIntyre and Pief Panofsky.

The scattered electrons exited the chamber through an aluminum foil window, passed through air, and then entered the vacuum chamber of the magnetic spectrometer through another thin foil window. The heavy magnet had to be positioned with great precision. This was done by using a twin 40-mm anti-aircraft gun mount as a base for the magnet; this gun mount was obtained from the Mare Island Shipyard and was lent to him by the U.S. Navy. The very first experiments on gold, the same element Rutherford used to reveal the existence of the nucleus, showed strong deviations from the distribution expected for electrons scattered from a point-like nucleus and indicated that the nucleus had a finite and measurable radius. Measurements on hydrogen nuclei in polyethylene were also made and they, too, showed that even the proton was not a point-like object but had a finite structure. Later studies, made at 188 MeV on a target of hydrogen gas, gave a radius for the proton of about 7×10^{-14} cm.

The structure seen in the distribution of scattered electrons results from the diffraction of the incident electron waves by the charge and magnetic moment of the nucleus. To reveal the nucleus in greater detail, shorter wavelengths were needed, which in turn required higher electron energies. In characteristic fashion, undaunted by the technical details, Bob designed a magnet more than double the linear dimensions of the first, now weighing 30 tons, to accommodate electron trajectories with a radius of curvature of 36". This was built by Bethlehem Steel and, together with a 10-ton shield, was mounted on a larger, double 5" anti-aircraft gun mount, which again was provided by the Navy. This magnet could focus electrons of energy up to 510 MeV. At this time, in late 1955, the Mark III accelerator had been upgraded and operation at 600 MeV had been achieved. Bob and his postdocs and graduate students completed the next series of studies with this spectrometer, and these revealed the structure of various nuclei and of the nucleons in greater detail.

In the next two years, the length of the Mark III accelerator was increased another 90 feet, and with the addition of more klystrons, the accelerator achieved an energy of 1 GeV in 1960. Bob designed yet another double-focusing spectrometer, this one 200 tons in weight with a radius of curvature of 72", which could focus and analyze 1-GeV electrons.

It was during the late 1950s that we first met Bob, and we remember being deeply impressed by the bold manner in which he made the transition from the first 16", almost tabletop spectrometer to this 200-ton behemoth. It was in a similar manner that he made a suggestion in 1954, while sitting in the Schiffs' living room with Felix Bloch, Ed Ginzton, and Leonard Schiff, to build a multi-BeV (GeV) linear accelerator at Stanford. This he wanted in order to provide electrons of shorter wavelength to probe still deeper into the nucleon. He believed that the transition to these energies was simply a matter of engineering. To him the need was clear. His suggestion was followed up shortly thereafter by the formation of a study group that ultimately led to the establishment of the Stanford Linear Accelerator Center (SLAC) and the construction of the two-mile accelerator under the direction of Professor Wolfgang "Pief" Panofsky, which achieved a beam energy of 20 GeV in January of 1967.

The award of the 1961 Nobel Prize in physics to Hofstadter, which he shared with Rudolf Mössbauer, recognized Hofstadter's work that had revealed the structure of nuclei and nucleons and the manner in which he had done the crucial experiments. His citation recognized "the precision [that Hofstadter attained] that has scarcely been attained before in high-energy physics. . . . You have achieved this precision by improving unrelentingly your methods and equipment in the course of time." The saga of the development of the magnetic spectrometer described above was but one of these items; in addition, beam position control, beam intensity, extraction of an essentially mono-energetic beam from the accelerator, and control of the spectrometer magnetic-field strength all played a critical role in achieving this precision.

As Bob acknowledged some years later, this period in the 1950s was an extraordinary one, one in which he and his small group, with excellent support from the Office of Naval Research, had a virtual monopoly of the field of nucleon and nuclear structure. Further, it provided the basis for his belief, which he defended strongly in subsequent years, that high-energy and elementary-particle physics could be done effectively by small groups, not necessarily by the huge collaborative kinds of teams that we see today. In this he was bucking the trend towards "big science." However, much later he is said to have conceded that this trend towards big science was inevitable and that the halcyon days of the 1950s were unlikely to be seen again in this field.

Early in the 1960s I (W.A.L.) had the good fortune of seeing for myself the way Bob approached obstacles. Stanislav Safrata, Bob, and I were collaborating on an experiment to measure directly the shape of the heavily deformed Ho^{165} nucleus by electron scattering. A large magnetic field had to be applied to a single crystal target of holmium metal to switch it from the antiferromagnetic to the ferromagnetic state. This would align the internal field of the 4f electrons with the applied field, which at low temperatures would align the nucleus itself. The target needed to be held at a few tenths of a Kelvin in the beam of the accelerator. We considered adiabatic demagnetization of a paramagnetic salt as a means to produce these temperatures, but Stan and I were discouraged when we realized just how large was the thermal load from the beam. We spoke to Bob about this, and his immediate response was to say, “Why not use 100 kilograms of the salt? That should be enough!” We were bowled over, for neither Stan nor I had ever thought in such terms. Prior to this, samples of 100 grams or less had been used in cryostats familiar to us. On further consideration, we saw that it was indeed entirely feasible to do it in this way. We had just never thought on such a scale! As it turned out, He^3 became available in sufficient quantities a short time later and this enabled us to use instead a simple He^3 cryostat for the experiment, and the large demagnetization cryostat was, in fact, never built. This illustrated the way Bob approached a problem: He thought nothing of proposing a cryostat a thousand times larger than had ever been considered before, just as he had proposed a two-mile accelerator, many times the length of the Mark III accelerator, because higher energies were needed to see the details of the nucleon. The engineering challenges that would have to be overcome to accomplish these aims never discouraged him.

Bob was elected to the National Academy of Sciences in 1958 and named California Scientist of the Year in 1959. He received many other awards, including the Roentgen Medal in 1985, the U.S. National Medal of Science in 1986, and the Prize of the Cultural Foundation of Fiuggi (Italy).

A decade later, experiments at SLAC using much higher energies employed electrons to probe the nucleon as Hofstadter did. Instead of utilizing the elastic process these experiments studied inelastic scattering from the proton and neutron and provided the first direct evidence of the presence of point-like quarks within the nucleons. The award of the 1990 Nobel Prize to Friedman, Kendall, and Taylor[1] recognized this work. Bob was very pleased to learn of this award, only weeks before the end of his life.

During the 1950s changes began to occur in the academic environment that were of great concern to Bob. Government funding of research was increasing, and many universities saw in it the opportunity to expand their faculties by the use of such “soft money” to offset faculty salaries during the academic year. Stanford was among them. Bob and many of his colleagues in the Physics Department were strongly opposed to this, fearing that it would result in an over-expansion of the university, that individuals would be beholden to the government for their jobs, and that it might lead to charges that the university was gouging the government. Also it was feared that it would result in expansion only in areas for which funding was available and a reduction in the support of basic research in other areas. But others within the faculty welcomed it and saw in it the possibility of creating a much larger department with a broader range of offerings. This difference in viewpoint eventually led to a split within the Physics Department, and the creation of a Division of Applied Physics at Stanford that was partially supported by government funds. Many years later, when government support of research diminished, much of what had been feared came to pass. The university was obliged to re-absorb the additional faculty and to re-allocate teaching. Even though agency support had always played a vital role in his research, Bob believed as a matter of principle that the university’s role was the support of teaching and the full support of its faculty, and that this was not the business of government.

He was also opposed to a requirement that emerged, as more government funds came to the universities, that all faculty, students, and staff involved in research should assign to the university all rights, title, and interest related to inventions that they might conceive in their research. He felt again, on principle, that this was not something in which the university should be involved and that it was an interference in the rights of an individual. Eventually, this requirement did become mandatory, and the few who had objected to it ultimately conceded that the fight had been lost.

The coming of SLAC to Stanford raised a number of problems for the university. It was recognized early that a two-mile accelerator was too large to be accommodated within the Physics Department and that an independent university entity would have to be established for it. This was to become the Stanford Linear Accelerator Center (SLAC), a high-energy laboratory funded by the Atomic Energy Commission and later by the Department of Energy.

The presence of SLAC raised the concern that the availability of funds to support the appointment of high-energy physicists at SLAC would result in the university creating fewer positions for appointments in other areas of physics. Bob, although a high-energy physicist, thought that these funds should not be permitted to distort the offerings of the department.

Another issue revolved around the proposed use of the professorial title for SLAC appointments. Bob and others thought that such titles were inappropriate, for they would imply a teaching responsibility, something that was considered to be entirely within the jurisdiction of the Physics Department. On the other hand, Wolfgang Panofsky and

Sidney Drell, who had resigned from the department to become director and head of the Theory Group at SLAC, respectively, thought that, in order to be able to hire the best, such titles were essential.

Related to this was the concern that the existence of a large number of persons of professorial rank at SLAC would result in an inordinately large demand for graduate students. This could result in the Physics Department becoming a service department that would only provide undergraduate teaching and the first two years of graduate teaching for students, the bulk of whom would go on to work at SLAC. Bob worried about this and argued for limits on the number of SLAC faculty, as well as for departmental control of graduate admissions and all aspects of the teaching of physics.

These were some of the difficulties that arose as the transition was made between the regime of the individual investigator in high-energy physics, characterized by Bob's earlier work, and today's big science, which requires large facilities in which hundreds of individuals participate in research projects. The effect of these repercussions was that Bob played a much smaller role in SLAC than might have been expected, considering his interests, his original proposal, and that the accelerator was at his own backdoor. As a consequence, Bob's interests turned to other areas of physics, to which he made several other significant contributions. This was exemplified by his development of a new class of high-energy detectors, detectors for gamma-ray astronomy, and the application of high-energy physics techniques to medicine.

Bob's belief that the study of elementary particles would require the precise measurement of high-energy gamma rays led him to consider the use of large crystal detectors for this purpose. It became apparent to him that there was virtually no limit to the highest energies that these devices could detect. The reason is that high-energy electrons, positrons, or gamma rays produce a shower of charged particles and gamma rays, all of which can be absorbed in a crystal of quite modest size, irrespective of the initial energy. The intensity of the resultant pulse of light emitted by the crystal from all these shower particles is then directly proportional to the energy of the incident particle. The resolution attainable in the GeV range is of the order of 1 percent, providing precision spectroscopy in this energy range. The size of a crystal necessary to absorb 95 percent of the incident energy for such a total absorption shower cascade (TASC) detector can be shown to increase only logarithmically with the incident particle energy. The significance of this can be appreciated when compared with the magnetic spectrometer used by Bob in his earlier studies of the nucleons. There the linear dimensions of the magnet scaled with the energy of the scattered electrons. This, as we saw earlier, led to the requirement that the weight of the magnet scaled with the cube of the energy! Therein lies the advantage of the TASC detector. These TASC and related TANC (total absorption nuclear cascade) detectors for strongly interacting particles have made possible precision spectroscopy in the 100-GeV energy range. As with Bob's work on electron scattering, the concept here was simple, in that the size of the detector scaled logarithmically with energy, but the reduction to practice was not simple. It required, in particular, the development of a new technology for the fabrication of very large crystals of high clarity and the means for preparing these crystals in complicated, space-filling forms to make this happen. Bob described, in a fascinating personal account (1975), the development of these counters and the impressive role that scintillation counters of all types have played in high-energy physics.

One such detector, the "Crystal Ball," developed at Stanford and SLAC was built of a large number (672) of tapered prisms of NaI(Tl) assembled in the form of a 42-inch-diameter hollow sphere. This was used at the Stanford positron-electron accelerator ring (SPEAR) to measure the energy of the gamma rays resulting from the decay of charmonium, which is a meson consisting of a charm quark and antiquark.

Another detector based on the same total absorption principle was incorporated in the Energetic Gamma-Ray Experiment Telescope (EGRET), a NASA project for which Bob was one of the principal investigators and in which Barrie Hughes, a long-time associate and friend, also played a major role. Bob had a long-standing interest in space-based gamma-ray astronomy. He realized that much of the nuclear physics of stellar objects, details of element synthesis, the formation of nebulae, and theoretical models of supernovae could be studied by gamma-ray spectroscopy from an orbiting satellite. Gamma rays suffer very little absorption and scattering in space and, as Bob pointed out, they travel in straight lines and thus reveal their sources, in contrast to cosmic rays, which, being charged particles, are deflected by magnetic fields or scattered by interstellar dust. EGRET was launched on the Compton Gamma Ray Observatory on April 5, 1991, only a few months after Bob's death. It has provided an unprecedented view of the gamma-ray sky and data on enormously energetic gamma-ray bursts. EGRET has now become a NASA observatory class facility accessible to the entire international astrophysics community.

Bob took a strong interest in the application of high-energy physics techniques to medicine. Extensive use had been made of NaI(Tl) detectors in this field, but in collaboration with Edward Rubenstein of Stanford's Medical School and Barrie Hughes, Bob developed a minimally invasive angiography using synchrotron radiation. The method uses the peripheral venous injection of a minute amount of iodine contrast agent that works its way to the heart. By selecting radiation with an energy on either side of the iodine K-edge and digitally subtracting the two images, they were able to image the arterial system of the heart without interference from absorption by bone or tissue. The exceptionally intense beams of X rays that are available from electron storage rings made this dichromatic subtraction technique practical. In recognition of his many contributions to medical science, Hofstadter was elected to the Institute of Medicine in 1984.

Over the years Bob participated in numerous studies for the government on technological problems of importance to the military. He also testified before the House of Representatives Committee on Science and Astrophysics and the House Science and Technology Committee. He also consulted for KMS Fusion, Inc., on laser fusion, and has described in a simple and elegant manner the progress in this field (1976).

In the early 1950s Hofstadter and Panofsky participated in what is now known as the Screwdriver Report. This study was so named because J. Robert Oppenheimer, when asked in congressional testimony how to detect a nuclear weapon smuggled in a box across a U.S. border, answered, "With a screwdriver!" Bob and Pief were asked by the Atomic Energy Commission to analyze general methods for determining what was inside a crate or suitcase either by passive radiation measurements or by measuring any induced emission resulting from the irradiation of the container with an accelerator or radioactive source.

Bob taught many of the large freshman classes at Stanford, and his students still recall with joy his many demonstrations and his meticulous presentations of the principles of physics. He enjoyed the interaction with his students, both undergraduate and graduate, and with his research colleagues. He felt strongly about the importance of teaching, education, academic freedom, the rights of the individual, and the broader aspects of government. His views on these and other subjects can perhaps best be described in words that Hanoch Gutfreund originally used[2] to depict Albert Einstein's opinions on a variety of public, political, and moral issues, which were "bluntly expressed, controversial, often considered simpleminded and naive, [but] his positions nevertheless had a significant impact." This was very much the way it was with Bob. You always knew where he stood on such issues, and he had little taste for those promoting expediency or compromise.

The Hofstadters had three children: a son, Douglas, and two daughters, Laura and Mary. Douglas obtained his Ph.D. in physics in 1975 from the University of Oregon with a thesis describing the behavior of electrons in crystals in high magnetic fields, effects that are closely related to the quantum Hall effect. Doug, a professor of cognitive science at Indiana University, won the Pulitzer Prize for non-fiction in 1980 for *Gödel, Escher Bach: An Eternal Golden Braid*, an enormously stimulating book linking concepts of mathematics, art, and music, and he is also well known for his contributions to *Scientific American*. Laura, too, is a writer and has written extensively on the medical field.

My wife and I (W.A.L.) have fond memories of occasions spent with Nancy, Bob, and their family celebrating some of the high points of our lives over the past 35 years, and sharing some of the low. I remember their angst over the war in Vietnam but also the sparkle in Bob's eye on acquiring some critical equipment for his laboratory.

Early in the 1960s Nancy and Bob bought a 700-acre ranch in northern California, off Highway 5 near Red Bluff in the foothills of the coast range. There they kept horses and cattle and later raised pedigreed cattle and managed 40 acres of olive trees. This they did in such a seamless fashion that many of Bob's colleagues had no idea that on many a weekend he lived a different life away from the laboratory, a farmer at home on the ranch!

The Hofstadters had a long and happy marriage, punctuated with periods of great joy, but also, especially in the early years, with periods of worry and financial difficulty. They enjoyed living on Stanford's campus. They were strong supporters of the Stanford basketball and football teams and seldom missed a game. Theirs was a beautiful home enriched with flowers, music, art, and memorabilia of their travels. We, and many of the Stanford community, enjoyed the hospitality of their home and the pleasure of conversation with them, their family, and their guests from around the world.

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NOTES

1. Jerome I. Friedman and Henry W. Kendall, Massachusetts Institute of Technology, and Richard E. Taylor, Stanford Linear Accelerator Center, Stanford University, "for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics."

2. Remarks by H. Gutfreund in *Einstein's 1912 Manuscript on the Special Theory of Relativity*. Jerusalem: Israel Museum, 1996.

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