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WILLIAM MARTIN FAIRBANK SR.  
1917–1989

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*A Biographical Memoir by*  
HORST MEYER, BLAS CABRERA,  
AND PETER MICHELSON

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*Biographical Memoir*

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*William M. Fairbank*

# WILLIAM MARTIN FAIRBANK SR.

*February 24, 1917–September 30, 1989*

BY HORST MEYER, BLAS CABRERA,  
AND PETER MICHELSON

WILLIAM FAIRBANK WAS ONE of the most innovative low-temperature experimental physicists of the twentieth century. His pioneering experiments on properties of the quantum fluids liquid  $^3\text{He}$  and  $^4\text{He}$  with graduate students at Duke University and on properties and applications of superconductors with graduate students and colleagues at Stanford have been a source of inspiration for many scientists, who in subsequent decades extended and refined their results. Especially striking among his investigations at Duke were his measurement of the nuclear susceptibility of liquid  $^3\text{He}$  showing the departure from Curie's law and the onset of Fermi degeneracy; his discovery of the liquid  $^3\text{He}$ - $^4\text{He}$  phase separation; and his demonstration by precision measurement of the specific heat of  $^4\text{He}$  that the onset of superfluidity was a phase transition. Perhaps his most significant experiment was his discovery, with Stanford graduate student Bascom Deaver, that the magnetic flux in superconductors is quantized in units of  $(hc/2e)$ .

Fairbank savored experiments that could test fundamental laws of physics, even when they involved large and complex projects. At Stanford these projects involved antennas to detect gravitational waves; superconducting accelerators to study elementary particles; free electron lasers to investigate

atoms, molecules, and condensed matter; and satellite-borne instruments to test general relativity (the Gravity Probe B) and to reduce the effects of gravity on phase transitions. With students and colleagues he also searched for free quarks, attempted to measure the force that gravity exerts on electrons and positrons, and developed devices and techniques with biomedical applications. The equipment for these diverse projects almost always utilized low-temperature techniques. Fairbank supervised the Ph.D. theses of 7 students at Duke and 47 students at Stanford and published more than 120 articles in scientific journals and conference proceedings.

#### PERSONAL HISTORY

William Martin Fairbank was born in Minneapolis, Minnesota, on February 24, 1917, the second child and first son of Helen Leslie Martin and Samuel Ballantine Fairbank. Just before Christmas 1917, the family moved to Hobson, Montana, where Samuel became president and manager of a flour milling company and William spent his first 13 years. In 1930 the family moved to Seattle, Washington, where Bill, his brother Henry and his three sisters—Elisabeth, Ruth, and Janet—continued their education in public schools. In 1935 Bill entered Whitman College in Walla Walla, Washington, graduating in 1939 with an A.B. in chemistry. During his freshman year, Bill met another Whitman chemistry student, Jane Davenport, the woman with whom he would happily share the rest of his life. In 1940 Bill and Jane both entered the graduate program in physics at the University of Washington, where they were teaching fellows. Soon after Pearl Harbor, Bill and Jane married and moved to the Boston area where, as staff members at the MIT Radiation Laboratory from 1942 to 1945, they helped develop shipborne radar at 1 cm and 3 cm wavelengths. At the end of World War II Bill and Jane moved to Yale University where in 1947, as a

Sheffield fellow and research assistant, he completed work for his Ph.D. degree. He accepted an assistant professorship at Amherst College, from which his father, grandfather, and other ancestors had graduated.

In 1952 he joined the Physics Department at Duke University as an associate professor and started Duke's Low Temperature Physics Research Program. In 1959 he accepted an appointment to the Physics Department faculty at Stanford University, where he continued his role as a distinguished mentor and director of research in low-temperature physics. He died suddenly of a heart attack at age 72 while jogging vigorously near his home in Ladera, California. He was still very active in research at that time.

Bill and Jane's three sons all have had successful careers: William Martin Fairbank Jr. born January 7, 1946, in New Haven, Connecticut, is a professor of physics at Colorado State University; Robert Harold Fairbank, born March 4, 1948, in North Hampton, Massachusetts, is a lawyer in Los Angeles; and Richard Dana Fairbank, born September 18, 1950, is founder and chief executive officer of the bank-holding company Capital One. Bill's beloved wife, Jane, born August 21, 1918, died on July 1, 2003, in Palo Alto, California.

Bill and his younger brother, Henry Allan (born November 9, 1918, in Lewistown, Montana; deceased January 13, 2011, in Durham, North Carolina), were especially close throughout their lives. At Whitman College and over the years both maintained their interest and participation in athletics. Both became low-temperature physicists. Although they often lived on opposite coasts, they stimulated each other intellectually and frequently met at physics conferences and U.S.A. Masters Track and Field meets.

## FAIRBANK THE MAN

Bill was a strongly directed person, very positive about his mission as a scientist, full of optimism, infectious enthusiasm, and confidence that the scientific challenges he had undertaken would work out. Doubters of his challenging projects would not easily dissuade him, but he did work to understand and respond to criticisms. He loved to engage in scientific discussions and to share his ideas; as an experimentalist he particularly enjoyed talking with theorists and derived from them motivation for novel projects. He had many original ideas, and he loved to discuss them at any place and any time, day or night. For those who accepted Bill's invitation to share a room at a physics conference, nights could be rather sleepless. Bill might get up suddenly and call his companion, "Hey, are you awake? I've got this idea; let me tell you about it." Often he returned to his laboratories in the evenings, and he loved to stop those he met in the corridors and talk with them about his physics projects. He greatly inspired his graduate students with his drive and optimism. By contrast, his formal classroom teaching was not a high priority. However, every year that he taught introductory physics classes, he gave a very popular and inspiring lecture on low-temperature physics. The lecture was full of demonstrations, including showing the lambda point transition in liquid helium with a transparent glass Dewar, the fountain effect with superfluid helium, and levitating a superconducting sphere in a magnetic field.

At home he enjoyed lively discussions with his intelligent and assertive spouse, Jane. They and their three sons all took part in little league, scouting, and church activities. They all swam and skied, and each summer they returned to Seattle to visit relatives and friends.

Faith played an important role in their lives, and after their arrival in California, Bill and Jane attended Ladera

Community United Church of Christ. They became prominent church members. To quote from the memorial resolution written by three of Bill's Stanford colleagues:

Though not a philosopher in any formal sense, Bill brought something of the same inquiring spirit to his faith as he did to his physics; one of his favorite quotations was the famous passage at the end of Albert Schweitzer's *Quest for the Historical Jesus*, where Schweitzer moves beyond relentless intellectual inquiry into personal mystical experience.

However, Bill rarely discussed religion with colleagues, nearly always steering conversations away from politics and religion and back to science.

#### RESEARCH AT YALE AND AMHERST (1946-1952)

Bill and his brother, Henry, under the direction of Professor C. T. Lane, carried out experimental investigations of "second sound" in superfluid  $^4\text{He}$ . They published three articles on this phenomenon and one on an acoustical device, the *thermophone*, as a source of sound in liquid helium and hydrogen.

Communication with the Soviet Union was difficult in the years immediately after World War II. As a result, the Yale group first learned of the earlier second-sound measurements that Vasilii Peshkov had performed at the Low Temperature Institute in Moscow when their own investigations were complete. The research by the Fairbank brothers and by Peshkov, how this research relates to predictions by Laszlo Tisza and by Lev D. Landau, and the angry reaction of Lev D. Landau to the Yale results are described in a fascinating article by R. J. Donnelly (2009).

Bill's doctoral dissertation reported on investigations on an entirely different subject: the surface resistance of superconducting and normal tin at microwave frequencies. For these studies he drew upon experience gained while at the MIT Radiation Laboratory. This research would prove

useful to him in later work on a superconducting particle accelerator at Stanford.

At Amherst, Bill developed a heat flushing technique for rapidly extracting pure  $^3\text{He}$  from a  $^3\text{He}$ - $^4\text{He}$  solution. The separation technique is described in a paper by Fairbank, a student, and T. Soller, the chair of Amherst's Physics Department (Soller et al., 1953)

RESEARCH AT DUKE UNIVERSITY (1952-1959)

It is the spectacular research that Bill Fairbank carried out during his years at Duke that first earned him recognition as one of the world's most innovative low-temperature experimental physicists. These experiments rapidly became classics in the field of quantum fluids.

In one set of experiments Bill measured the strength of the nuclear magnetic resonance signal in liquid  $^3\text{He}$  at saturated vapor pressure—the nuclear paramagnetic susceptibility of liquid  $^3\text{He}$ —as a function of temperature. Measurements at temperatures above  $1.2^\circ\text{K}$  showed no deviation from Curie's law, but with a cryostat he constructed in which liquid  $^3\text{He}$  under saturated vapor pressure could be magnetically cooled below  $1^\circ\text{K}$ , a clear deviation of the susceptibility from the classical Curie's law was found. The results could be fit to the theoretical curve for a Fermi-Dirac gas with a degeneracy temperature of  $0.45^\circ\text{K}$ . The measurements, which confirmed Fritz London's expectations, were completed in February 1954, only a few weeks before London died of heart failure on March 30. Susceptibility measurements, subsequently performed at higher pressures in the liquid phase of  $^3\text{He}$ , showed that with increasing pressure the Fermi temperature decreased.

In another experiment the phase separation of  $^3\text{He}$ - $^4\text{He}$  liquid mixtures was observed at temperatures below  $0.9^\circ\text{K}$ . This experiment was motivated by theoretical qualitative



predictions for the separation phase diagram advanced by Prigogine and by Chester. The cell in which the successful experiment was performed had three separate compartments for the fluid, one above another. It was, in fact, an early version of a magnetic resonance imaging system. A vertical magnetic field gradient was imposed that, when modulated, would yield three resonance peaks. The nuclear magnetic resonance signal in each compartment was then used to estimate the  $^3\text{He}$  concentration. Below  $0.9^\circ\text{K}$ , enrichment of  $^3\text{He}$  in the top cell and depletion in the bottom cell were recorded. The differences in concentration increased as the temperature was decreased.

A third famous experiment was a measurement of the specific heat of liquid  $^4\text{He}$  in the neighborhood of the temperature at which superfluidity appears. This transition is often called the “lambda point” because the specific heat curve plotted versus temperature resembles the shape of the Greek letter lambda. (The term “point” implies—known now but not then—that at a given pressure there was a sharp transition temperature.) The challenge facing Fairbank was to test the prediction by Blatt, Butler, and Schafroth (1956) that the specific heat at the lambda point of  $^4\text{He}$  had a peak width of a few millidegrees. By contrast, Onsager’s two-dimensional Ising model displayed a sharp (logarithmic) singularity. Bill made a bet with John Blatt that the transition was going to be sharp, in line with the Onsager model. In this investigation Bill found a valuable collaborator and friend in Michael J. Buckingham (1927-2009), a theorist on the Duke faculty. They remained close personal friends even after Buckingham moved to the University of Western Australia in Perth. They later spent time together when Buckingham came to Stanford University as a visitor. Their high-resolution measurements, carried out with graduate student C. Fred Kellers, were the first where the temperature of the cell was recorded versus

time. The first published results indeed showed that, contrary to the prediction by Blatt et al., the specific heat diverges nearly logarithmically, with a peak sharper than 1 microdegree. A detailed, comprehensive, and often cited review by Buckingham and Fairbank appeared in 1961.

This experiment stimulated several research groups interested in the lambda transition to repeat the experiment with greater precision. Inspired by Fairbank, John Lipa at Stanford University and his NASA team designed orbital flight measurements that were carried out on the Space Shuttle in 1992. In these ultrahigh-resolution measurements, performed decades after the original experiment, the effects from gravity on the shape of the lambda peak are suppressed. They are considered the definitive calorimetric measurements of the singularity.

Other experiments originated by Fairbank at Duke study the amplitude dependence of second sound in liquid  $^4\text{He}$ , the longitudinal and transverse nuclear magnetic resonance relaxation times in solid  $^3\text{He}$ , nuclear magnetic resonance in solid hydrogen under high pressure, and the density of liquid  $^3\text{He}$ . These experiments have been continued, modified, and improved by Horst Meyer, Fairbank's successor at Duke. A total of seven students obtained their Ph.D. degree at Duke under Fairbank's direction.

At Duke, inspired by Fritz London's predictions, Fairbank had already begun thinking about and informally discussing experiments that might detect flux quantization in superconductors, and the *London moment*, the magnetic moment produced in a rotating superconducting spherical shell. These became priority projects when he moved to Stanford.

His interest in projects larger than "tabletop" in scale also preceded his move to Stanford. At Duke he collaborated with colleague Martin M. Block on a bubble chamber detector

for experiments at Brookhaven National Laboratory. This interest grew during his years at Stanford.

RESEARCH AT STANFORD UNIVERSITY (1960-1989)

Bill Fairbank died in 1989, more than 20 years ago. In that time the dust has largely settled on much of the remarkable body of scientific work he carried out over 30 years at Stanford. He arrived in 1959 with plans for five experiments involving superfluids and superconductors. The first was a measurement of the quantization of magnetic flux in superconducting rings; the second a measurement of quantized vortices in rotating superfluid helium; the third a measurement of the London moment in a rotating superconductor; the fourth an improved measurement of the lambda point transition from normal to superfluid helium; and the fifth a study of nuclear magnetic moments in  $^3\text{He}$ - $^4\text{He}$  mixtures.

Many believe that Fairbank's most important scientific contribution was his detection of magnetic flux quantization in a superconducting ring. The work was published in 1961 and was coauthored by Bascom Deaver, his graduate student at Stanford. The work is of Nobel Prize caliber. It demonstrates that superconductivity involves a London-like macroscopically coherent quantum state, and the size of the magnetic flux quantum ( $hc/2e$ ) indicates directly that the composite particles making up the supercurrent carry twice the electron charge. The latter may be viewed as the first experimental demonstration that the current is carried by Cooper pairs. Fairbank recounted that the editors of *Physical Review Letters* had phoned him, prior to publication of the article, telling him that the German group of Doll and Näbauer had submitted a manuscript on the same subject that had arrived three days after the Fairbank and Deaver manuscript. They were willing to publish the Fairbank-Deaver

article in the next issue and the Doll-Näbauer article in the following issue. Fairbank responded by suggesting that the two articles should appear in the same issue, as was done.

How credit should be apportioned to the two groups is a matter on which people have different views. A detailed discussion of the history of both experiments, and of when and how the two groups learned of each other's results has recently been published by Dietrich Einzel (2011). As to theoretical interpretation, the possibility and significance of the unit of flux quantization being  $(hc/2e)$  and not  $(hc/e)$  was recognized earlier and more clearly by Fairbank and Deaver than by Doll and Näbauer but that is only one factor. (Had the Nobel committees been willing to award the prize to four individuals, these four might well have received it. Alternatively, had Nobel committees in later years been inclined to broaden the scope of the award, Fairbank might well have been singled out. Some speculate that Nobel committees might have been hesitant to consider this alternative in light of some of Fairbank's later more controversial work.)

In each of the other four areas of superfluidity and superconductivity for which Fairbank had research plans when he came to Stanford, he and his graduate students performed experiments that led to publications and Ph.D. theses.

In the early 1960s Fairbank launched a number of other remarkable and far-reaching experimental research programs. These included: measurements of the force of gravity on electrons and positrons; the design and construction of superconducting microwave cavities for clocks and for particle acceleration; a search for fractionally charged particles in nature; a satellite program to measure the dragging of inertial frames in a cryogenic gyroscope orbiting Earth; and the development of antennas to detect gravitational waves. He also undertook a series of biophysics and biomedical inves-

tigations entailing magnetocardiology, pion accelerators for cancer treatment, and the measurement of the magnetic susceptibility of organic molecules.

Considering each of these in turn, the effort to measure the force of gravity on electrons and positrons was never completed although four Ph.D. theses were generated by the work. The measurement of the force of gravity on falling, singly ionized helium atoms was convincing; the force on electrons and positrons less so. In order to understand how it might have been possible to measure the force of gravity on such light particles, surface states inside copper tubes were invoked to shield the interior of the tube from the known patch effect electric fields. Follow-up work by the last two graduate students did not confirm the earlier results; however, there were indications of a transition occurring within the copper drift tube at low temperatures.

By the end of the 1960s niobium superconducting cavities were used in the development of the first superconducting linear accelerator (SCA) which was operated in the High Energy Physics Laboratory (HEPL) at Stanford. The HEPL scientists, including Allan Schwettman, who became a Stanford faculty member, demonstrated a continuous beam of mono-energetic electrons up to an energy of 250 MeV with full width at half maximum approaching 0.01 percent and 10 microA current. It turns out that the original Stanford geometry for the niobium microwave cavities suffered from single-point multipacking that caused heating in certain regions of the cavity walls and limited the energy gain per length. Motivated by this early demonstration, CERN (European Organization for Nuclear Research) improved on the geometry and immediately demonstrated a factor of five greater energy gain for each unit length. This technology has become the basis for accelerator design at CERN (Switzerland) and later at DESY (Germany), CEBAF (Newport

News, Virginia), and CESR (Cornell University). This first superconducting accelerator at Stanford was used to demonstrate the principle of the free electron laser, first proposed by John Madey, then a member of Bill's group, which is now used extensively in more than a dozen light source facilities throughout the world and most recently in the first X-ray free electron laser at SLAC (Stanford Linear Accelerator Center). An excellent book by H. Padamsee (2008) details these pioneering technologies and their impact on the field.

In addition, similar high-Q niobium superconducting microwave cavities led to clocks of unparalleled stability that were used in a number of fundamental comparisons between the superconducting oscillators and atomic maser clocks. These measurements by John Turneure and a Ph.D. student set stringent limits on the variation of the fine structure constant with time.

Fairbank's most controversial research program involved the search for fractional electric charges or free quarks on magnetically levitated niobium superconducting spheres. Although the first graduate student to work on the experiment concluded that systematic errors prevented a reliable result, a second student was sufficiently convinced by the experimental results to report the observation of fractional charge in several articles in *Physical Review Letters*. Many in the community remained skeptical and several follow-up experiments did not confirm the results. A subsequent Stanford Ph.D. student using the same apparatus also was unable to reproduce the results.

When Joseph Weber announced the discovery of gravitational waves with a room-temperature resonant bar antenna, Bill Fairbank immediately started a gravitational wave program based on resonant bar antennas first cooled to 4°K using liquid helium and later cooled to 50°mK using a dilution

refrigerator. For more than a decade these most sensitive detectors found no evidence for gravitational waves, thus refuting the Weber claim.

Most remarkable was the satellite test of frame dragging in general relativity, a program called the Gyro Relativity Experiment. R&D began in 1963, and the satellite mission (Gravity Probe B) was successfully launched in April 2003 under the leadership of Francis Everitt. Several unexpected and interesting systematic effects involving resonant coupling between the rigid-body polhode motion of the superconducting spherical gyroscope rotors and the roll rate of the satellite complicated the analysis. After understanding these effects in detail and backing them out of the data, the team was able to demonstrate the frame-dragging effect in general relativity to a precision of 20 percent, the most direct measurement of this general relativistic effect (Everitt et al., 2011).

#### PRIZES AND HONORS

Recognition of Bill's crucial experiments came soon after he joined the Stanford physics faculty. In 1962 he was named California Scientist of the Year by the California Museum of Science and Industry. In 1963 he received the Oliver E. Buckley Prize in Condensed Matter from the American Physical Society, and was elected to membership in the National Academy of Sciences. In 1965 the Research Corporation awarded him their prize for "an outstanding contribution to science." In 1967 Yale University awarded him the Wilbur Cross Medal given to distinguished alumni. He received the Fritz London Memorial Prize in 1968, and became a fellow of the American Philosophical Society in 1978. Honorary D.Sc. degrees were awarded by his alma mater, Whitman College, in 1965; Duke University in 1969; and Amherst College in 1972.

Several of Bill's colleagues and friends organized a meeting in his honor at Stanford University March 23 to 27, 1982. Titled "Near Zero: New Frontiers of Physics." The meeting featured papers and posters on many topics to which Fairbank had made significant contributions. The proceedings of this meeting were published in 1988 in a 987-page book edited by Jane Fairbank. The book contains interesting articles by his colleagues, postdocs, and students detailing much of the work summarized in this memoir. In one article, "The Shape of the Lambda Transition," Michael Buckingham includes perceptive reminiscences on Fritz London and Bill Fairbank when he and they were at Duke University. The closing article, written by Bill Fairbank and titled "Some Thoughts on Future Frontiers of Physics" is a wonderful example of the far-reaching way Bill thought about physics and its many interconnections. In this remarkable summary of his contributions and his future interests Bill discusses many of the most interesting and important areas of current research (J. Fairbank et al., 1988).



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