Research at an Undergraduate Institution to Roger W. Bland (San Francisco State University) for his "outstanding research in the search for free quarks and for his energetic guidance of undergraduate students of San Francisco State University who have fully participated in the research." He and his students have been using a Millikan apparatus to search for free quarks in a wide variety of materials since the late 1970s.

Bland received his BS from Caltech (1961) and his PhD from the University of California, Berkeley (1968). He held research positions at the Lawrence Berkeley Laboratory; the Ecole Polytechnique, Paris; and Glasgow University before going to San Francisco State as a lecturer in physics and astronomy in 1975. He became a full professor at San Francisco State in 1984.

GRAVITY RESEARCH FOUNDATION ANNOUNCES AWARDS

The Gravity Research Foundation has announced the winners of its 1988 essay competition. Itzhak Bars and Christopher N. Pope (University of Southern California, Los Angeles) received the first prize of $1500 for "Is There a Unique Consistent Theory of Quantum Gravity?" Pawel O. Mazur (Syracuse University) was awarded the second prize of $500 for "An Interacting Geometry Model and Induced Gravity." The third prize of $200 went to Minos Axenides (University of Washington, Seattle) for "On the Phase Transition to Space–Time in String Cosmology." Fourth prize went to Robert C. Myers and Jonathan Z. Simon (University of California, Santa Barbara), and fifth prize went to Ilya Prigogine (University of Texas, Austin, and Free University of Brussels) and J. Geheniau, E. Gunzig and P. Nardone (Free University of Brussels).

OBITUARIES

I. I. Rabi

On 11 January 1988, I. I. Rabi, a creative scientist, an innovative statesman and a philosopher, died at the age of 89. He had received numerous awards and honors, including the 1944 Nobel Prize in physics for inventing the molecular-beam magnetic resonance method and for using it to measure the magnetic, electrical and structural properties of atoms, molecules and nuclei.

Rabi was born on 29 July 1898 in Rymanow, Austria, to an Orthodox Jewish family who soon thereafter moved to New York City, where they lived initially on the Lower East Side, but later in the Brownsville section of Brooklyn. He attended New York public schools and, as an avid reader, gained much of his education and interest in science through books borrowed from the public library. In 1916, after graduating from the Manual Training High School in Brooklyn, Rabi entered Cornell University. He started in electrical engineering, but graduated in chemistry. After three years of uninteresting jobs he returned to Cornell to do graduate work in chemistry; a year later he moved to Columbia University, and to physics. At Columbia, Rabi did his doctoral research on magnetic susceptibility with Albert P. Wills, but, characteristically, it was on a subject of Rabi's own choosing and employed a novel technique that greatly simplified the experiments. The day after he sent in his doctoral thesis, he married Helen Newmark, who remained his lifelong companion.

Rabi soon went to Europe on a traveling fellowship, where he worked intermittently with Arnold Sommerfeld, Werner Heisenberg, Niels Bohr and Wolfgang Pauli. The Stern–Gerlach experiment demonstrating the reality of space quantization had earlier sparked Rabi's interest in quantum mechanics, so he became a frequent visitor to Otto Stern's molecular-beam laboratory in Hamburg while working there with Pauli. During one of these visits Rabi suggested a new form of deflecting magnetic field, and Stern invited Rabi to work on it in his laboratory. Rabi's acceptance of this invitation was decisive in turning his interest toward molecular-beam research.

Rabi returned from Europe to join the faculty at Columbia and to begin atomic-beam research in his own laboratory. In 1931 he and Gregory Breit developed the important Breit–Rabi formula, which showed how the magnetic energy of an atom and its effective magnetic moment vary with the strength of the external magnetic field. These changes occur because the atomic configuration varies from the electron's being coupled primarily to the nucleus at a low external field to its being coupled primarily to the external magnetic field at a high field.

Using the Breit–Rabi formula and an atomic-beam apparatus with inhomogeneous magnetic fields, Rabi, Victor Cohen and others were able to determine the strengths of electron–nucleus interactions and the magnitudes of nuclear spins and magnetic moments. Rabi further improved the precision of the measurements by noting from the Breit–Rabi formula that the effective magnetic moments are zero at certain magnetic fields, which give a marked rise in the intensity of the undeflected atoms passing through an inhomogeneous field. By measuring these zero-moment magnetic fields, Rabi's students and associates determined a number of hyperfine interactions. Although the zero-moment method did not work for atoms with nuclear spin $\frac{1}{2}$, Rabi devised an alternative refocusing technique that did.

Rabi also showed that one could adapt the molecular-beam deflection method to measure the signs of nuclear magnetic moments by determining which transitions occurred when atoms went through a region of space in which the directions of the magnetic fields were successively reversed.

Rabi developed the theory of such transitions in his important paper entitled "Space Quantization in a Gyrating Magnetic Field" (*Physical Review* **51**, 652, 1937). In this paper Rabi assumed for simplicity that the applied field changed its direction ("gyrated") at a fixed frequency. As a result this paper has provided the theoretical basis for all subsequent magnetic resonance experiments.

Rabi initially applied his theory to fields that changed only in space rather than in time. A few months after the publication of that paper, following a visit by C. J. Gorter, Rabi directed the major efforts of his laboratory toward the development of molecular-beam magnetic resonance, with the magnetic fields oscillating in time. A molecular beam was deflected by one inhomogeneous magnetic field and refocused by a similar field. In passing between the two fields the molecules were subjected to a weak oscillatory magnetic field at frequency ν. When ν was equal to the Bohr frequency $\nu_0 = (W_i - W_f)/h$ (where W_f and W_i are the energies of the final and initial states), transitions could take place, with a consequent refocusing failure and a reduction in beam intensity. By measuring the beam intensity as a function of frequency one could thereby determine the spacing of the molecular energy levels.

The first successful molecular-beam experiment was that of Rabi, Sidney Millman, Polykarp Kusch and Jerrold R. Zacharias in 1938, which

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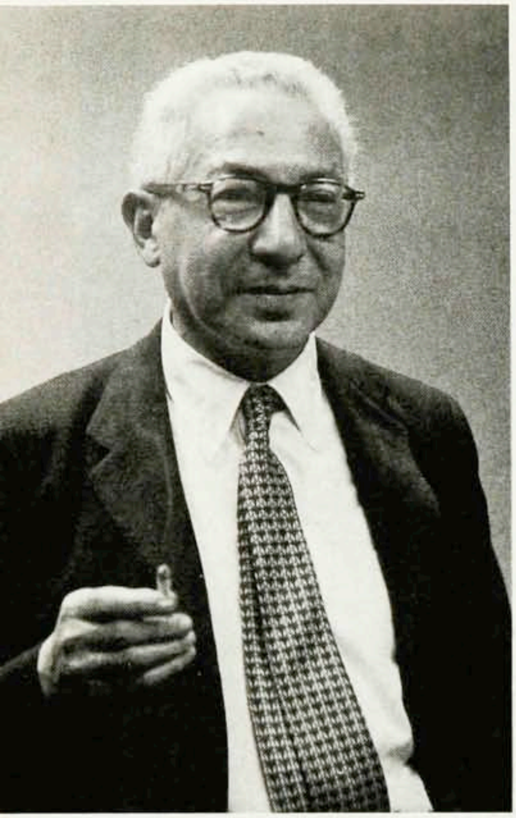

I. I. Rabi

determined the nuclear magnetic moment of Li^7. Soon thereafter Jerome M. B. Kellogg, Rabi, Zacharias and I applied the method to molecular hydrogen and discovered a multiplicity of resonance lines, whose separation arose from the magnetic interactions of the nuclear moments with each other and with the magnetic field caused by the rotation of the molecule. The separations of the resonances for D_2 were much greater than could be attributed to such magnetic interactions, but could be fitted by assuming the deuteron had a nuclear electric quadrupole moment, that is, by assuming it was ellipsoidal like an American football, rather than spherical; such a shape would result from the existence of a previously unsuspected tensor force between the neutron and proton.

In subsequent years Rabi and his associates successfully applied the beam-resonance method to single atoms as well as to polyatomic molecules, and in such experiments they measured numerous nuclear spins, nuclear and atomic magnetic moments, atomic hyperfine interactions and nuclear quadrupole moments.

World War II interrupted Rabi's molecular-beam research from 1940 to 1945, during which time he was actively involved with the development of microwave radar. He headed the magnetron group at the MIT Radiation Laboratory, where he later became deputy director. He was particularly active in developing shorter wavelengths, first from 10 cm to 3 cm at MIT; later he initiated the establishment of the Columbia Radiation Laboratory, which pioneered in the development of 1-cm-wavelength radar.

During Rabi's early European travels he had become a great friend of J. Robert Oppenheimer, so Oppenheimer tried to persuade him to become deputy director at Los Alamos. Although Rabi declined because of his commitment to important work at MIT, he was a frequent visitor to Los Alamos as consultant, friend and adviser to Oppenheimer. Rabi's persuasive advice led Oppenheimer to abandon his original plans for a military establishment with uniformed scientists at Los Alamos in favor of a civilian research and development laboratory.

In his 1945 Richtmeyer lecture, delivered shortly before the end of the war, Rabi discussed the possible use of an atomic-beam magnetic resonance apparatus as the control element of an accurate clock. The *New York Times* report on this lecture is the first published account of atomic clocks, which have now become so accurate that they are the basis of the international definition of the second.

Following World War II, Rabi returned to Columbia to reestablish his molecular-beam laboratory. With his students John Nafe and Edward Nelson, Rabi successfully applied the magnetic resonance method to atomic hydrogen and discovered that the hyperfine separation due to the interaction between the magnetic moments of the proton and electron was slightly different from the theoretical expectation. This was the first indication that the magnetic moment of the electron was different from the expected Dirac value, an observation later confirmed by Kusch's direct measurements of the electron magnetic moment. This experimental anomalous magnetic moment was the principal stimulus for the development of relativistic quantum electrodynamics, the first successful quantum field theory.

Another important molecular-beam development was the adaptation by Rabi and Harold K. Hughes of the resonance method to electric deflecting and oscillating fields. Subsequently improved by Rabi, John Trischka, Vernon Hughes and others, the electric resonance method has been used for many precise measurements of the spin-dependent internal interactions within molecules in specific rotational states.

Although most of Rabi's experiments were with molecular beams, he also participated with William Havens and James Rainwater in a neutron–electron scattering experiment that provided the first experimental evidence for the neutron–electron interaction.

Although Rabi's classroom lectures were often chaotic, he was a stimulating teacher who made his students think. He was an inspiring supervisor of PhD students whose research experiments were innovative and fundamental. Rabi gave his students freedom and independence while maintaining high standards for both the quality and the interest of the research. Rabi and his wife Helen were personally very helpful to his students and associates, most of whom remained lifelong friends.

Rabi's influence extended far beyond his own research through his membership on important committees, his many public lectures and his innovative proposals for new means of cooperation among institutions and nations. Discussions late in 1945 between Rabi and Oppenheimer led to the Acheson–Lillienthal–Baruch plan proposed by the US for the international control of atomic energy. One of Rabi's greatest disappointments was that this forward-looking plan, after initial favorable consideration, was never adopted by the United Nations.

Rabi was a member of the Atomic Energy Commission's General Advisory Committee and joined with Enrico Fermi in writing a strong memorandum supporting the committee's controversial recommendation against a crash program for developing a hydrogen bomb. Later, Rabi became chairman of the committee and an eloquent defender of Oppenheimer in the AEC hearings that culminated in the removal of Oppenheimer's security clearance.

Rabi and Ramsey initiated the first proposals for Brookhaven National Laboratory and were early strong proponents of the construction of the Cosmotron. Later, with the model of Brookhaven in mind, Rabi pioneered in advocating the European collaboration that led to CERN. Rabi was the 1950 president of The American Physical Society and for a number of years was a highly effective chairman of the Columbia physics department; his critical and stimulating presence was clearly responsible for much of the greatness of that department.

Rabi initiated the International Conferences on the Peaceful Uses of Atomic Energy and was a principal speaker at them. Through his friend-

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ship with President Eisenhower, Rabi was largely responsible for the establishment in 1957 of the President's Science Advisory Committee and the Office of Special Assistant to the President for Science and Technology. For many years, Rabi was the US Representative to the NATO Scientific Advisory Committee, where he effectively advocated the establishment of the highly successful NATO-supported summer school and fellowship programs.

Rabi's carefully prepared public lectures were stimulating and presented fresh points of view, as illustrated by his words at the Fourth International Conference on the Peaceful Uses of Atomic Energy:

> Real peace is more than the absence of violent war. To fulfill human expectations peace must be a condition which permits the release of the latent creative energies of all the people to the end of enhancing and elevating the quality of human life on this globe.

NORMAN F. RAMSEY
Harvard University
Cambridge, Massachusetts

Edward C. Campbell

Edward Charles ("Scotty") Campbell died suddenly on 26 January 1988 in Oak Ridge, Tennessee, as a result of a heart attack. He had a long career teaching physics at several colleges and universities, and he worked for 23 years at Oak Ridge National Laboratory, where he conducted many successful research projects.

Campbell was born in Brooklyn, New York, in 1913. After graduating from the University of Michigan in 1934, he attended Ohio State University, where he received his PhD in physics in 1938. He did his thesis under L. H. Thomas on the theory of the ratio of gamma radiation to beta decay in Ag^{106}. He also collaborated with M. L. Pool on the energy level diagram for this isotope. A common thread running through Campbell's later research was his interest in determining the energy level diagrams for various isotopes.

He taught physics and astronomy at Minnesota State College, Duluth, from 1938 until 1942, when he went to Princeton University to teach physics to Army and Navy officers.

In August 1946 Campbell was employed as a senior physicist at Oak Ridge National Laboratory. Here he began by taking a year's course in the theory and engineering of nuclear reactors. He wrote up the lectures by Harry Soodak on the theory of neutron chain reactors, and they were published in 1950 as *Elementary Pile Theory*, by Soodak and Campbell. Within two years the book was translated and published by the Russians. In 1950 Campbell helped develop a laboratory course in experimental reactor physics for the Oak Ridge School.

Campbell constructed a fast pneumatic sample tube, which was irradiated with neutrons in the Oak Ridge Graphite Reactor and then rapidly transferred outside the reator, where gamma spectra and halflives as short as 0.1 sec could be measured. He made calculations on problems such as neutron scattering and thermal neutron transport in pulsed composite reactor systems. With many different collaborators he measured short halflives, neutron cross sections and Doppler broadening, fission product ranges in gases, and gamma-ray spectra. From these spectra he calculated the spin and parity of excited states. He and Fred Nelson developed a widely used technique that employs ion exchange for rapid separation of short-lived radioisotopes from long-lived parents. After the Mössbauer resonance effect was discovered, Campbell, Seymour Bernstein and Charles W. Nestor Jr studied the effects of magnetic fields and chemical combination on the resonance, and the occurrence of optical anomalous dispersion in the reflection of gamma rays.

In 1957–58 Campbell was a guest researcher at the Belgian Atomic Energy Laboratory in Mol, Belgium. There he and P. F. Fettweis built a fast pneumatic tube for the BR-1 reactor and measured rates of decay and nuclear spectra for a number of isotopes with short halflives.

He enjoyed teaching physics, and he gave a number of courses at the University of Tennessee in Knoxville. For several years he was director of the Oak Ridge Resident Graduate Program of the University of Tennessee, and he also taught classes in this program. In 1969 he went to the physics department at the University of North Dakota in Fargo to continue teaching. He retired in 1981 and returned to Oak Ridge in 1983.

Friendly and outgoing, Campbell worked well with other people. He was always ready with good ideas to assist other workers who had problems, and he enjoyed developing theory from underlying assumptions and then checking the results experimentally. He was a skilled experimenter. As a teacher, he made sure that students really understood the question at hand. As a friend, he was loyal, helpful and a pleasure to be with, having broad interests in music, theater, photography and outdoor recreation.

HARRY H. HUBBELL, JR.
Oak Ridge, Tennessee

Bach Thien Vu

Bach Thien Vu, a principal research scientist at Avco Research Laboratory (Everett, Massachusetts) died accidentally on 27 September 1987 while vacationing in Paris, France.

Vu was born in Saigon, Vietnam, on 11 August 1949. He earned his undergraduate degree in mechanical engineering at Washington University and received an MS and a PhD in mechanical and aerospace engineering from Cornell University. He joined Avco in March 1979 as a senior scientist.

Vu was a dedicated scientist who spent most of his time working on his projects in the laboratory or in his private library at home. His technical work at Cornell University consisted of experimental and analytic studies of turbulent swirling flow; by conducting extensive measurements coupled with stability analysis, he developed an understanding of mixing processes and vortex breakdown in coaxial turbulent jets.

At Avco Vu was active in such varied disciplines as reentry physics, energy and the environment, and laser-related topics. His early work involved the analysis of turbulent hypersonic wakes and electron attachment mechanisms by quenchants introduced in wakes. He carried out experiments and analyses for developing a new antipollution process using electron-beam irradiation of stack gas. In later years Vu was primarily involved in projects related to the development of high-power laser systems. For infrared laser systems he conducted studies of laser beam propagation through turbulent media. He was a key scientist on a program to study the effect of diluent, or diluting agent, composition on the performance of a high-energy pulsed deuterium fluoride laser. For excimer lasers Vu helped to resolve advanced flow and acoustic issues that affect the overall output laser power. At the time of his death he was thinking of expanding his research to include optical signal processing of laser radar echoes.

B. N. SRIVASTAVA
Avco Research Laboratory
Everett, Massachusetts ■