

Manhattan District at the Radiation Laboratory of the University of California, Berkeley and at Oak Ridge.

After World War II Starr went to Rockwell International, where he was a leader in the development of nuclear propulsion for rockets and ramjets and of miniature nuclear reactors for use in space, as well as in the design of nuclear power plants.

Over the next 20 years, he rose to become vice president of Rockwell and president of its Atomic International division. From 1967 to 1973 Starr was the dean of the school of engineering and applied science at the University of California, Los Angeles. While at UCLA, Starr published seminal papers in risk analysis.

Starr left UCLA to become the founding president and vice chairman of the Electric Power Research Institute, started in 1973 by the electric utilities to conduct technology development. He is now president emeritus.

OBITUARIES

John S. Bell

John Stewart Bell died suddenly of cerebral hemorrhage on 1 October 1990, at the age of 62. The loss to physics, and to natural philosophy in general, is irreparable, for Bell not only made the most profound contribution of his generation to the foundations of quantum mechanics but had continued to explore new ideas on the subject.

John Bell was born in Belfast, Northern Ireland, into a working-class family. Since free secondary education was not provided at the time of his youth, he was able to continue school after age 14 only because a special fund was raised for him. At Queen's University in Belfast, he earned one BSc degree in experimental physics (1946), followed by another in mathematical physics (1949). In 1949 he joined the Atomic Energy Research Establishment at Malvern and Harwell, where he initially worked on nuclear reactors for some months before turning to theoretical work on particle accelerators. On leave from AERE, he worked in 1953–54 on quantum field theory at the University of Birmingham. He returned to AERE, Harwell, in 1954, and continued his researches on field theory and nuclear theory until 1960, meanwhile receiving a PhD at the University of Birmingham (1956). At Malvern he met Mary Ross, also an accelerator physicist, whom he married in 1954. From 1960 onward both

John and Mary Bell were on the staff of CERN.

In a sense John Bell had two careers. He contributed directly to the main mission of CERN by his research in nuclear physics, field theory, elementary-particle theory and accelerator design. But he also studied the foundations of quantum mechanics with great intensity, even though he jokingly referred to this work as his "hobby." His delightful exposition "Bertlman's Socks and the Nature of Reality" resulted from his attempt to explain his hobby to one of his collaborators in field theory. That article, together with other related papers by Bell, was reprinted in *Speakable and Unspeakable in Quantum Mechanics* (Cambridge University Press, 1987).

As an undergraduate Bell was already dissatisfied with textbook presentations of quantum mechanics, and was particularly disturbed by Niels Bohr's thesis that a measuring apparatus must be described classically and not treated quantum mechanically. Bell felt that there should be a unified description of the physical world applying to both microscopic and macroscopic systems. While at Birmingham, Bell was intrigued by two papers written by David Bohm in 1952, proposing a hidden-variables interpretation of quantum mechanics, which seemed a promising way to achieve the desired unification. According to Bohm's construction, something was amiss in John von Neumann's oft-cited demonstration of the impossibility of a hidden-variables interpretation. Bell seriously turned his attention to this matter after attending Josef Jauch's seminar in 1963 at the University of Geneva on

the foundations of quantum mechanics. In his paper entitled "On the Problem of Hidden Variables in Quantum Mechanics," Bell proved the impossibility of simple hidden-variables theories, without relying on a dubious premise that von Neumann had used. In the same paper Bell also pointed to a more complex family of hidden-variables theories (later called "contextual") that are not excluded by his own theorem.

The fact that Bohm's construction required a kind of "action at a distance" between spatially separated particles led Bell to pose a penetrating and fruitful question: Is it possible for a hidden-variables theory to recover all the statistical predictions of quantum mechanics without postulating action at a distance? His negative answer to this question was published in 1964 in a paper called "On the Einstein-Podolsky-Rosen Paradox." The remarkable result contained therein is now commonly called Bell's theorem. To prove this theorem Bell first showed that any hidden-variables theory that abstains from action at a distance implies that the correlations between pairs of observables of spatially separated particles must obey a certain inequality, subsequently known as Bell's inequality. Then he showed that this inequality is violated by the predictions of quantum mechanics for a pair of spatially separated spin- $\frac{1}{2}$ particles in the singlet spin state. (Later work showed many other quantum mechanical violations of Bell's Inequality.)

Over the last two decades more than a dozen experiments inspired by Bell's work have shown that nature violates Bell's inequality but agrees with quantum mechanics. As a result of these experiments Bell accepted that nature must be in some sense "nonlocal" in a way that Einstein almost certainly would have found uncongenial. Nevertheless, Bell still did not accept Bohr's interpretation of quantum mechanics, and he continued to investigate reinterpretations and modifications that would achieve his vision of a unified microscopic-macroscopic physics, entirely free of anthropocentrism. For example, one paper, "Beables for Quantum Field Theory," presents an explicitly "nonlocal" hidden-variables theory, and another, "Are There Quantum Jumps?" explores a stochastic modification of the time-dependent Schrödinger equation.

Several qualities made Bell the generally acknowledged leader of research on the foundations of quantum mechanics in the last two decades: a

John S. Bell



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full recognition of the practical power of quantum mechanics, a set of ideals for a perfected physical theory, a willingness to criticize quantum mechanics for falling short of those ideals, great imagination and open-mindedness in exploring innovations, intellectual rigor and clarity in assessing radical proposals, and generosity in encouraging the work of others along unconventional lines.

In addition to pursuing his "hobby," Bell made contributions to field theory and particle physics that spanned a wide range, from fundamentals to direct applications. In his thesis, based on work done in 1955, Bell established the relation between Lorentz invariance and time reversibility, better known as the *CPT* theorem. From this theorem follow such important results as the equality of the masses and lifetimes of particles and antiparticles. Bell's work on the *CPT* theorem is not as well known as it should be, because Pauli, adding to the results found earlier by Gerhart Lüders, published a paper on that very subject at the same time as Bell, inevitably overshadowing the then-unknown physicist from Ireland. (Pauli's article appeared in *Niels Bohr and the Development of Physics*, McGraw Hill, New York, 1955.)

In 1964, the same year in which Bell wrote his most influential paper on the foundations of quantum mechanics, he also wrote a paper with J. K. Perring on another fundamental issue, namely the *CP* violation observed in *K* decays. In the famous experiment of James Cronin, Val Fitch and their collaborators, the long-lived kaon, K_2 , was observed to decay into two pions. *CP* conservation requires that only the short-lived kaon, K_1 , decay in that way. The wonderful idea of Bell and Perring was to suggest a new long-range field that was analogous to the well-known electromagnetic field except that it couples to baryon number and strangeness (hypercharge) rather than charge, and the coupling is about 23 orders of magnitude weaker. Such a field, generated by the nucleons in the Earth and the Galaxy, would cause a transition of the K_2 to the K_1 , leading to an apparent decay of the K_2 into two pions. This proposition, an analysis of its compatibility with the Eötvös experiments, and an immediately testable prediction were presented in less than one page. The prediction was that the induced decay rate of the K_2 would depend quadratically on its energy. Subsequent experiments did not verify this. Nonetheless, the paper is a classic, reminis-

cent of Einstein's paper on the photoelectric effect.

In another fundamental paper, published in 1967, Bell investigated the basics of the famous Adler-Weisberger relation, an experimentally well-verified connection between pion-nucleon scattering and the axial-vector coupling constant in beta decay. Bell demonstrated that the validity of this relation is strongly suggestive of a gauge structure for the weak interactions. This paper, unknown except to a few who learned its lesson, was seminal for subsequent studies of the renormalizability of gauge theories.

In 1969, Bell and Roman Jackiw (and independently Stephen Adler) discovered the now-famous Adler-Bell-Jackiw anomaly. This apparent internal contradiction between gauge invariance related to vector and axial-vector currents, respectively, remains largely mysterious to this day. Nature seems to know about this anomaly. Avoiding it requires the sum of the charges of elementary fermions to be zero, which indeed appears to be the case: There are three families of fermions, and each family has three quarks of charge $\frac{2}{3}$, three quarks of charge $-\frac{1}{3}$ and a lepton, such as the electron, of charge -1 .

Like his work in other branches of physics, Bell's contributions to particle physics stand out for their insight and direct relation to fundamentals.

In nuclear physics, Bell worked on the many-body problem, starting after Keith Brueckner developed his method of adapting parameters from nucleon-nucleon scattering data to calculations in nuclear matter. Using parameters obtained by Tony Skyrme, Bell extended Brueckner's technique to finite nuclei. Bell also explored the effects from the hard core in the two-body interaction. Although this work was stimulating, very little of it remains useful today, because it was too empirically based and not sufficiently tied to the fundamentals, that is, to the exchange of particles. Of course, these fundamentals were not known at that time.

Throughout his career, Bell contributed significantly to accelerator theory. Even before receiving his DSc, he was already a most productive "house theorist" for the AERE group. In that role he invented a "lineac with spiral orbits," which included, in essence, a form of strong focusing. This approach was superseded in 1952 by the work of Ernest Courant, M. Stanley Livingston and Hartland Snyder. Bell instantly recognized the importance of their paper, and formulated its mathematics

in his own way, introducing the important quantity known as the Courant-Snyder invariant. (Unbeknownst to Bell, Nicholas Christofilos had discovered strong focusing earlier.) Furthermore, Bell decisively clarified a subject (the effect of accelerator gaps) in the theory of linear accelerators that had received the attention of John Slater, Robert Serber and Wolfgang "Pief" Panofsky. At CERN Bell contributed, in papers published in 1981-82, to the theory of cooling and, together with his wife, Mary, in 1987-89, to the theory of quantum "beamstrahlung." In both areas he displayed once more his ability to solve complicated and partially controversial questions.

Another of Bell's accomplishments in accelerator theory, perhaps of broader general interest, was his explanation (arrived at in collaboration with Richard Hughes and Jon Leinaas) of the fact that the spontaneous polarization of electrons in a synchrotron can, even under ideal circumstances, never obtain 100%. This explanation was an application of theoretical demonstrations by Stephen Fulling and William G. Unruh that an observer who is accelerated in a region of space-time containing an electromagnetic vacuum will detect blackbody radiation whose temperature is proportional to the acceleration. According to Bell and his collaborators, the effective blackbody radiation "observed" by the electrons has a depolarizing effect. This use of abstract considerations to explain a concrete terrestrial phenomenon was a wonderful achievement. John Bell influenced a generation of physicists and natural philosophers as much by the force of his character and personality as by his intellect. Although he was a reserved man, his speech was eloquent, precise, playful and pungent, enhanced by his lilting Irish accent. His combination of commitment, open-mindedness, daring and complete intellectual honesty had a direct effect upon everyone who was fortunate enough to know him, and an indirect effect upon a wide circle of readers. His early death was an irreparable loss to his profession, and a cause of deep sadness to his countless admirers.

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Darrell W. Osborne

Darrell W. Osborne, friend and colleague, was released from his suffering on 3 December 1989 after a progressively debilitating illness. He was 75 years old.

During World War II Darrell did research on rockets for the National Defense Research Council for which work he received a certificate of merit from President Truman. After the war he joined Argonne National Laboratory, where he worked until his illness forced him to retire in 1980.

In 1948 Darrell, Bernard Abraham and Bernard Weinstock began a collaboration to study the properties of liquid ^3He that continued for almost a quarter of a century. This group was the first to work with macroscopic quantities of pure ^3He . Until the mid-1950s the knowledge that tritium, the parent of ^3He , was being stockpiled was a military secret. Therefore the quantity of ^3He that could be mentioned in a publication was severely restricted. Experiments to measure the vapor pressure, boiling point, critical temperature and flow of ^3He were performed with 28 cc of gas at STP (or about 0.04 cc of liquid). The flow experiment showed that down to 1 K liquid ^3He did not display the superfluid properties of liquid ^4He . The vapor pressure measurements produced a correction to the thermodynamic temperature scale below 2.2 K. This correction was timely as anomalies were showing up around 2 K in heat capacity measurements because of an error in the temperature scale. Darrell's expertise as a calorimetrist guided the group in determining the heat of vaporization and the heat capacity over the range 0.25-1.5 K.

Although now regarded as fundamental, the role of particle statistics in determining the properties of liquid helium was at that time a subject of much debate, as is clearly brought out in the second volume of London's treatise, "Superfluids." The high low-temperature heat capacity of ^3He provided an essential clue to Lev Landau that ^3He could be modeled as a Fermi liquid. In the second of his famous Fermi-liquid papers, Landau used the heat capacity measured by Darrell's group to make the first estimate of the Fermi-liquid parameter, F_1 .

Darrell was a first-rank calorimetrist, and he created one of the world's outstanding calorimetry laboratories at Argonne. I can safely say that none of his measurements has been superseded. He served on the Nation-

al Research Council's Evaluation Committee of the heat division of the National Bureau of Standards, and he was chairman of the Calorimetry Conference. He spent the academic year 1958-59 at Oxford University as a Guggenheim Fellow.

Darrell Osborne made seminal contributions to experimental low-temperature physics. In doing so, he set a standard of competence and ethics for all to meet. It was a privilege to have known him and to have worked with him.

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Harrison E. Farnsworth

Harrison Edward Farnsworth died in Tucson, Arizona, on 14 November 1989, at the age of 93. One of the founders of modern surface physics, his active research career spanned an incredible period of nearly 70 years. With his passing, the world has lost its last direct contact with the events that led to the discovery of the wave nature of the electron in 1927.

As a graduate student of the University of Wisconsin, Farnsworth began work on the secondary emission of electrons from metals. In his first paper, published in 1922, the year he received his PhD, Farnsworth reported that some secondary electrons were "reflected" without loss of energy—a result that was inexplicable by classical physics. Among those who were initially critical of the young scientist's claim was Charles Davisson, who argued that the scattered electrons surely must lose some energy. Davisson would later confirm Farnsworth's observation and go on to share the Nobel Prize with George P. Thomson for the discovery of electron diffraction.

The years following graduate school were difficult for Farnsworth. His teaching responsibilities at the University of Maine left little time for research, and he returned to Wisconsin in the summers—without pay—to continue his studies of the anomalies of secondary emission. In 1926 he moved to Brown University, where he would remain until his retirement in 1970. After Davisson and Lester Germer's elegant demonstration of electron diffraction from the surface of a nickel crystal in 1927, Farnsworth embraced the new technique of low-energy electron diffraction. While other physicists, including Germer, moved on to high-energy electron diffraction, Farnsworth and