the age of 74. Bohm had been for more than four decades one of the world's leading authorities on quantum theory and its interpretation.

Bohm was born on 20 December 1917 in Wilkes-Barre, Pennsylvania. A student of J. Robert Oppenheimer, he received his PhD from the University of California, Berkeley, in 1943. He worked at the UC Radiation Labs, mainly on nucleon scattering, from 1943 to 1946, when he became an assistant professor at Princeton University. While at Princeton, Bohm made seminal contributions to plasma physics and to condensed matter physics, developing the theory of plasma oscillations with Eugene Gross, and the collective description of electron interactions, involving the random phase approximation, with David Pines. From 1951 to 1955 Bohm was a professor at the University of Sao Paulo, Brazil. He then spent two years as a professor at the Technion, in Haifa, Israel, and was a research fellow at Bristol University, England, from 1957 to 1961. Bohm was professor of theoretical physics at Birkbeck College from 1961 until he retired in 1983.

In 1950 Bohm completed the first of his six books, *Quantum Theory* (Prentice–Hall), which became the definitive exposition of the orthodox (Copenhagen) interpretation of quantum mechanics. Here Bohm presented his reformulation of the paradox of Albert Einstein, Boris Podolsky and Nathan Rosen concerning the possibility of there being simultaneous values of position and momentum for a pair of separated particles. Bohm's version of the EPR analysis involved components of spin in place of position and momentum. It would become the basis of the enormous expansion over the next several decades of research on the foundations of quantum theory, focusing on nonlocality and the possible incompleteness of the quantum description (the question of "hidden variables").

At the Technion in 1957, Bohm and Yakir Aharonov made the first major step in this research when they demonstrated the existence of what they called a "rather strange kind of correlation in the properties of distant things." This work was a forerunner of John Bell's famous inequality, published in 1964, which considerably sharpened the Bohm–Aharonov result. Bell demonstrated, using extremely benign assumptions, that nonlocality is a consequence of the *predictions* of experimental outcomes made by quantum theory—predictions confirmed by Alain Aspect, Jean Dalibard and Gérard Roger in 1982—and is not merely an artifact of formal quantum theoretical elements such as quantum entanglement and collapse of the wavefunction.

In 1952 Bohm accomplished what John von Neumann had claimed to have demonstrated to be impossible with his "proof," decades earlier, that there are no hidden variables. Through a refinement of Louis de Broglie's pilot-wave model, Bohm constructed—as an alternative to the prevailing, observer-oriented Copenhagen interpretation of quantum theory—an objective, fully deterministic account of nonrelativistic quantum phenomena in terms of a theory describing the motion of particles under an evolution choreographed by the wavefunction.

It is ironic that many physicists continue mistakenly to claim that Bell's inequality has eliminated the possibility of any deterministic alternative to the Copenhagen interpretation, and in particular Bohm's. Bell was, in fact, led to his inequality by trying to understand how Bohm had succeeded in this "impossible" endeavor.

In 1959 Bohm again collaborated with Aharanov, this time on a paper concerned with a very different sort of nonlocality. The result was the Aharonov–Bohm effect, according to which a magnetic field can influence the behavior of electrons confined far away from the field. This effect was seen as incompatible not only with classical physics but also with the spirit of the Copenhagen interpretation. The Aharonov–Bohm effect remains, some three decades after its discovery, a subject of intense research.

Bohm was a person of extraordinary commitment to principle, both moral and scientific. His refusal in 1951 to testify against his colleagues before the House Un-American Activities Committee led to his indictment for contempt of Congress and his banishment from Princeton University and, indeed, from all of American academia. During most of his last 40 years he was engaged in an often lonely pursuit of scientific truth, showing little regard for prevailing fashion or orthodoxy. He was an outstanding scientist and an exceptional man. We will miss him.

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Lawrence Randolph Hafstad

Lawrence Randolph Hafstad, physicist and engineer, died on 12 October 1993 at his home in Oldwick, New Jersey. He was 89.

Larry Hafstad was one of that elite group of physicists who participated in the blossoming of nuclear physics in the 1930s. During World War II he had a role in the rapid development and large-scale production of highly effective, electronically activated proximity fuses. After World War II he had a distinguished career in management of science and technology.

Born in Minneapolis, Hafstad received a bachelor's degree in physics from the University of Minnesota. He received a PhD in physics from Johns Hopkins University in 1933. From 1920 to 1928 he was employed by the Northwest Bell Telephone Company. In 1928 he began a long-term association with Merle Tuve at the Carnegie Institution of Washington, DC.

Tuve, Hafstad, Gregory Breit and others collaborated in the first studies using pulsed oscillations (which would later be called radar) to investigate the ionosphere. Then followed an arduous effort to develop methods of accelerating protons to what were then high energies. Ultimately, with Tuve and Odd Dahl, Hafstad developed the first Van de Graaff-type electrostatic generator that could be operated at precisely controlled voltages up to 1.2 MeV. The steadiness and precision of the voltage facilitated reproducible studies of bombardment of light elements with protons and deuterons.

The most fundamental achieve-

Lawrence Randolph Hafstad

ment with the generator was a very careful series of proton–proton scattering experiments, conducted mainly by Hafstad and Norman Heydenburg. The results, interpreted by Breit, Edward U. Condon and R. D. Present, showed that the net force between protons at nuclear distances is attractive. During the period 1934–39 Hafstad participated in nuclear experiments that led to more than 20 publications. In one study he and Tuve bombarded ^{7}Li with protons and found a large cross section for emission of gamma rays at 440 keV. This discovery led to the Breit–Wigner resonance formula for nuclear reactions. In 1938 Hafstad wrote a paper with Edward Teller pointing out the possible relevance of a cluster model for explaining the mass defects of ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si and ^{32}S.

In late January 1939 Niels Bohr appeared before a gathering of physicists in Washington, DC, where he revealed that Otto Hahn, Lise Meitner and Fritz Strassman had chemically identified fission products from uranium. The next day Hafstad and Richard Roberts assembled the equipment necessary to observe the production of high-energy fission products. Subsequently Roberts demonstrated the phenomenon to a group that included Bohr and Enrico Fermi. A few weeks later Roberts and Hafstad discovered the emission of delayed neutrons accompanying the fission process—a phenomenon that today facilitates control of nuclear power reactors.

Hafstad's familiarity with high-amplification vacuum tubes was one of the assets that he brought to nuclear physics research. That capability also was useful when he became involved in defense research in August 1940. Tuve was then leading an effort at the Department of Terrestrial Magnetism of the Carnegie Institution to develop an electronics-based fuse for an artillery shell that would cause the missile to explode when it detected the proximity of an aircraft. One critical step in proving its feasibility was the demonstration by Roberts and Hafstad that certain radio tubes could withstand accelerations approaching the 20 000 g experienced by artillery shells.

Tuve, with Hafstad as his assistant, recruited a team of physicists to create prototype proximity fuses. Small-scale commercial production began in the autumn of 1941, accompanied by intense transfer of know-how and technology. Hafstad was particularly effective in dealing with industry.

To expand efforts to devise more reliable fuses, the research and development activity was moved in March 1942 from the Carnegie site to the newly formed Applied Physics Laboratory of the Johns Hopkins University, located in Silver Spring, Maryland. There Tuve, Hafstad and others overcame many obstacles to reliability of the fuses, and in October 1942 the Navy authorized large-scale production of the proximity fuse. Fused shells were fired with great effect from combat ships in the Western Pacific, used to destroy buzz bombs in the European Theater and later used against infantry in the Battle of the Bulge.

After World War II Hafstad succeeded Tuve as director of the Applied Physics Laboratory. More than anyone else, Hafstad set the laboratory's postwar course, preserving a national asset that has functioned brilliantly to this day. In 1948 Hafstad returned to nuclear physics, becoming the first director for reactor development with the Atomic Energy Commission.

In 1955 Hafstad was presented with a new and quite different challenge. General Motors Corporation was just completing a new Technical Center in Warren, Michigan, which would house the 1200-person GM Research Staff. To succeed Charles Kettering, who had led the research staff from 1920 until 1951, and to lead the organization in the postwar era, GM management sought a scientist with breadth as well as depth.

Hafstad was the choice, and in 1955 he was named GM vice president and executive in charge of GM Research. Hafstad's clear thinking and elegantly simple speech were exactly what was required to explain the role of research to the pragmatic managers of GM and to gain their confidence. Hafstad thereby earned the freedom and resources to change and build GM Research.

Hafstad initiated research in safety, air pollution, biomechanics, computer technology, mathematics, alternative power plants, transportation theory and systems, operations research and defense-related activities. He drew into GM Research many leading scientists.

In 1959 he created the GM Defense Research Laboratories, with a staff of 800 persons in Santa Barbara, California. Under Hafstad's leadership, the lab's staff learned much about oceanography for underseas warfare and reentry physics for missile defense.

While working at General Motors, Hafstad served on many high-level advisory bodies, including the General Advisory Committee of the Atomic Energy Commission, acting as chairman of the advisory committee from 1964 to 1968.

Hafstad led GM Research until his retirement in 1969. He once told one of us: "This car business is simple. Just remember two things: Make cars as different as possible where people can see, and as alike as possible where people cannot see; and make them squareish for a few years and then make them roundish for a few years." Another example of his homespun way of cutting through complexity was the time he likened the skill of a researcher to that of the pilot of a sailboat in light and variable winds: Much tacking is required to reach a goal. By contrast, he said, a development engineer is like a powerboat driver, setting a fixed course and expecting a payoff in proportion to the power input.

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Herbert B. Callen

Herbert B. Callen, professor emeritus of physics at the University of Pennsylvania, died on 22 May 1993 from complications of Alzheimer's disease. He was 74. Callen is recognized internationally as one of the founders of the modern theory of irreversible thermodynamics and statistical mechanics.

Herb was born in Philadelphia, Pennsylvania, on 1 July 1919. He was awarded an AB degree in 1941 and an AM degree in 1942 from Temple University, both in physics. He started on a PhD dissertation in physics at MIT with Laszlo Tisza, but his progress was interrupted by work on the Manhattan Project for the Kellex Corporation in New York, New York (1944–45) and on the US Navy's Bumblebee project (which concerned telemetry of guided missiles) at Princeton University (1945). Tisza was concerned about the theoretical basis of the Kelvin relations of thermoelectricity and suggested that Callen attempt to derive the relations from Onsager's reciprocal relations for irreversible processes. Callen succeeded in doing this, and he also derived the Kelvin relations for the thermomagnetic effects. A further consequence was a clarification of the reasoning underlying Onsager's reciprocal relations theorem.

On completing his PhD in 1947,