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,

Herbert B. Callen

Callen spent a year at the MIT Laboratory for Insulation Research, where he developed the theory of electrical breakdown in insulators.

In 1946 Callen received an appointment as an assistant professor in the physics department of the University of Pennsylvania, where, with Theodore A. Welton, he derived the fluctuation–dissipation theorem. This universal theorem, which contained within it Nyquist's theorem of resistance and voltage fluctuations, demonstrated from first principles the equivalence of the linear response of a driven thermodynamic system to the time-dependent equilibrium fluctuation of the system. This work, published in 1951, launched the statistical theory of irreversible processes.

Callen's later research focused on magnetism; he was a pioneer in the use of thermodynamic Green's functions in magnetism. He and his students formulated a many-body theory for spin operators, analogous to fermion- and boson-based many-body theory. They also developed useful approximation methods similar to the random-phase approximation of fermion and boson systems.

Callen delighted in finding interesting physics in the development and improvement of devices, especially those in which magnetism played a role. He assisted J. Presper Eckert and John W. Mauchly, the developers of the Univac computer, in setting up a research group at Univac in Bluebell, Pennsylvania, that concentrated on magnetic effects in solids with the goal of inventing more cost-effective fast computer memory.

Callen's text *Thermodynamics* (Wiley, 1960) is based on the postulatory formulation of thermodynamics in which state functions, energy and entropy are the fundamental concepts; processes enter simply as differentials of the state functions. The second, much revised edition *Thermodynamics and an Introduction to Thermostatistics* (1985) is among the most frequently cited thermodynamics references in the physics research literature.

Callen's teaching at both undergraduate and graduate levels was renowned for its intellectual integrity and clarity of presentation. One of his great strengths was the development of simple "hand waving" arguments to explain seemingly complicated phenomena. He was a strong unifying force within the University of Pennsylvania physics department and was instrumental in recruiting key solid-state physicists to the university in the late 1950s. He played an active role in academic affairs at the university until he retired in 1985. Callen was active on a number of committees for the American Physical Society, IUPAP and the National Magnet Laboratory. He also was a visiting professor at the Hebrew University in Jerusalem, at the Weizmann Institute of Science in Rehovoth, Israel, and at the University of Recife, Brazil.

Herb was a deep and incisive thinker, always rational and with endless intellectual curiosity. He had a mischievous and energetic zest for life and was skeptical of dogma and authority. He was modest about his own scientific accomplishments and was always supportive of his colleagues. He leaves behind a rich intellectual legacy.

ELIAS BURSTEIN
MICHAEL COHEN
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TOM C. LUBENSKY
University of Pennsylvania, Philadelphia

Robert V. Langmuir

Robert V. Langmuir, professor emeritus of electrical engineering at Caltech and a member of the team that first directly observed synchrotron radiation, died of cancer on 7 May 1992, at the age of 80. Langmuir had had a long and productive career as an educator, physicist, engineer and inventor.

After graduating with an AB in physics from Harvard in 1935, Langmuir designed mass spectrometers at the Consolidated Engineering Corporation in Pasadena, California. Subsequently, for his doctoral thesis in physics at Caltech in 1943, he improved the stability and image quality of electron microscopes. During the