

and nature of organic matter in meteorites." With M. Ebihara in 1982 and N. Grevesse in 1989, Anders studied the abundances of the elements in the solar system, and he has also studied the volatile inventory of the terrestrial planets.

Anders received a PhD in chemistry from Columbia in 1954. He joined the Chicago faculty the following year, and in 1973 he became the Horace B. Horton Professor of Chemistry. He retired in 1991.

Also honored at the November meeting was Richard Binzel of MIT, who received the Urey Prize, which recognizes achievements by a scientist under 36 years. Binzel was chosen for his "observational and theoretical research on asteroids and the planet Pluto." By measuring and comparing the physical properties of various asteroid clusters, he has been able to estimate the initial conditions of their parent bodies. His observations of Pluto and its moon Charon between 1985 and 1990 are now being used to map their surfaces.

Binzel earned a PhD in astronomy from the University of Texas at Austin in 1986 and is currently an associate professor in the department of Earth, atmospheric and planetary sciences at MIT.

The division's first Harold Marsury Award, for meritorious service to planetary science, was presented to Carl Sagan of Cornell University. Sagan was cited for "his role in the overall development of planetary science, not only through his research accomplishments, but also through his service to the broader community." Sagan's research has included studies of planetary atmospheres and surfaces, and he has also played a prominent role in communicating science to the public.

Sagan received a PhD in astronomy and astrophysics from the University of Chicago in 1960. He joined the faculty of Harvard University in 1962 and moved to Cornell in 1968. He is currently the David Duncan Professor of Astronomy and Space Sciences and director of the Laboratory for Planetary Sciences.

OBITUARIES

Edwin M. McMillan

Edwin Mattison McMillan's life ended on 7 September 1991, after several years of declining health. He was just 11 days short of 84 years of age. McMillan was one of the great physicists of the middle decades of this century. He was a pioneer in the

development and application of the cyclotron, he opened the way to the study and utilization of transuranic elements, and he elucidated one of the basic principles of modern high-energy accelerators.

McMillan received his BSc from Caltech in 1928 and his MSc from the same institution the following year. He studied more chemistry than was usual for a physics student and was greatly influenced by a close association with Linus Pauling, who was a National Research Fellow at Caltech at that time. Caltech had had an even earlier influence on MacMillan: As a youth he lived close by, and at an early age his budding interest in all things scientific was nourished by the excellent public programs and lectures at that institution. He continued his graduate studies at Princeton University, where he did research on molecular beams under the general direction of Edward U. Condon. He received his PhD in 1932 and was awarded a two-year National Research Fellowship.

In 1932, at the invitation of Ernest Lawrence, who the year before had founded the Radiation Laboratory at the University of California, Berkeley, McMillan came to the physics department at the university with the intention of doing an experiment to measure the magnetic moment of the proton. However, Otto Stern published his result on that experiment while McMillan was completing his apparatus, so he turned to research on hyperfine structure and published several papers in that field. He also began to take interest in the activities in the adjacent Radiation Laboratory. Nuclear physics was being transformed by a succession of startling discoveries: the neutron, the proton and induced radioactivity. McMillan was increasingly drawn to that field, and he recognized the research potential of the cyclotron.

In 1934 McMillan joined the Radiation Laboratory as a research associate and began his association with Lawrence, who early realized McMillan's profound practical and analytic abilities. That association was to last until Lawrence's death in 1958. McMillan very quickly established himself as a meticulous and versatile experimenter in nuclear physics. He discovered new isotopes: ^{15}O with Stanley Livingston and ^{10}Be with Samuel Ruben. In a program of studies of gamma rays accompanying nuclear disintegrations, particularly from fluorine bombarded by protons, he provided the first unambiguous verification of electron-pair production. He took a keen interest in the

operation and development of the cyclotron, then an almost entirely empirical art. He helped to rationalize the understanding of cyclotrons and was responsible for important improvements in magnetic field shaping, ion sources, beam extraction, and power and control systems. He played an especially valuable role in the construction and initial operation of the 60-inch cyclotron in 1939.

McMillan's teaching career began in 1935, when Raymond T. Birge, then the chairman of the physics department at the university, recognized his talents and secured for him an appointment as an instructor there. By 1946 he had become a full professor.

McMillan possessed a broad spectrum of capabilities. He had a command of both theoretical and experimental nuclear physics. He was comfortable dealing with large, complex equipment. But the activity he loved best was conducting very simple but significant experiments and then thoughtfully interpreting the results. An example of this approach led to the discovery of neptunium. With the news early in 1939 of the discovery of fission by Otto Hahn and Fritz Strassman, McMillan undertook a simple experiment: He measured the range of fission fragments by their penetration of a stack of foils in contact with a thin layer of a uranium compound exposed to neutrons from a cyclotron target. But McMillan did more. He examined the uranium layer and found a known 23-minute activity (^{239}U) and a previously unknown 2.3-day beta activity. He immediately suspected that the 2.3-day activity was a beta-decay product of the 23-minute uranium activity and therefore had to be an isotope of element 93. Chemical separation of the new activity from uranium proved to be very difficult. McMillan enlisted the help of Philip Abelson, who had been working on uranium activities and was visiting at the university at that time. They successfully accomplished the separation in the spring of 1940, and so established the existence of the first transuranic element, which they named neptunium.

The daughter product of neptunium, for which the name plutonium was reserved, was expected to be an alpha-active isotope of element 94. McMillan and Abelson did observe an alpha activity, but it was too weak for proper analysis. McMillan produced a stronger alpha activity in uranium bombarded with 16-MeV deuterons. However, the disruption of the world of physics by World War II was beginning, and McMillan left Berkeley for the first of several wartime



Edwin M. McMillan

duties. A group headed by Glenn Seaborg carried forward the chemical identification of element 94. The discovery of plutonium was recorded in a publication by Seaborg, McMillan, Joseph W. Kennedy and Arthur C. Wahl dated January 1941 but withheld until 1946. In 1951 McMillan and Seaborg were awarded the Nobel Prize in Chemistry for "their discoveries in the chemistry of the transuranium elements."

In November 1940 McMillan left Berkeley for the MIT Radiation Laboratory, where he worked on the development and testing of airborne microwave radar. A year later he was drafted to help in the development of sonar devices at the newly organized Navy Radio and Sound Laboratory in San Diego. When Robert Oppenheimer was designated in November 1942 to head what was to become the Los Alamos National Laboratory, he called on McMillan to help find a location for the new laboratory and to help organize it. At Los Alamos McMillan had major responsibilities for development and testing of the gun assembly method used in the uranium bomb and for the implosion assembly used in the plutonium bomb.

As the end of the war neared, McMillan's thoughts returned to accelerators, particularly the central problem of the energy limit imposed on cyclotrons by the relativistic increase in the mass of the circulating ions as they gain energy. McMillan conceived a solution that was startling in its simplicity and that would prove to be far-reaching in practice: In 1945 he showed that under certain conditions ions in cyclotron orbits collect in stable, zero-energy-gain bunches. One may then slowly alter the frequency of the accelerating field or the strength of the magnetic field

to increase the energy of the stable bunches without limit. This principle of phase stability, together with strong focusing, provides the basis for the design of all the great high-energy accelerators today. (The principle of phase stability had been anticipated by Vladimir Veksler in the Soviet Union, but due to the complete breakdown in communications during the war, this was unknown in the West.)

On returning to Berkeley's Radiation Laboratory when the war ended, McMillan had a leading role in formulating and carrying out the laboratory's broad research program based on new high-energy accelerators. Three of these accelerators, the 184-inch cyclotron, the Bevatron and the 330-MeV synchrotron, depended upon phase stability. The construction of the synchrotron was McMillan's special responsibility. He also carried out an extensive experimental program on the 184-inch cyclotron that included measurements of cross sections, excitation functions and the angular distribution of neutrons from targets. When the synchrotron became operational in 1949, he led the successful program of experiments on the photoproduction of mesons.

At Lawrence's death, McMillan was appointed director of the newly renamed Ernest O. Lawrence Radiation Laboratory. This was a very difficult position, because the competition for running time on the then-unrivaled accelerators and other facilities of the laboratory was fierce, and because the need to redirect scientific resources in response to societal needs was becoming increasingly apparent. Although McMillan was much more the scholar than the administrator, his wide knowledge of the sciences and his innate fairness, approachability and modesty enabled him to lead the laboratory successfully until his retirement in 1973.

In retirement he actively participated in the running and analysis of the $g - 2$ experiment at CERN, which measured the magnetic moment of the muon. He wrote several papers on topics in the history of accelerators and kept up an active interest in physics and the laboratory until he suffered a debilitating stroke in 1984.

Edwin McMillan was an unassuming person with a quiet sense of humor. He had a great sense of curiosity about all of nature and a rare fund of knowledge that made "natural scientist" an apt description of him. He served his country, the university and the science community well. The many persons who have been enriched by contact with him, whether as teacher, colleague or

friend, will deeply feel the loss at his passing.

EDWARD J. LOFGREN

*Lawrence Berkeley Laboratory
Berkeley, California*

PHILIP H. ABELSON

*American Association for the
Advancement of Science
Washington, DC*

A. CARL HELMHOLZ
*University of California
Berkeley, California*

Roger Revelle

Roger Randall Dougan Revelle, a research oceanographer at the Scripps Institution of Oceanography, died 15 July 1991 in La Jolla, California, of complications following a heart attack. He was 82.

Roger had many achievements in his long and productive career. Though a geologist, he had an important influence on physics, chemistry and biology as well. Roger was a geology major as an undergraduate at Pomona College, from which he graduated in 1929. In his graduate work he switched to oceanography, which he studied at the Scripps Institution of Oceanography. He earned his PhD in 1936 from the University of California, Berkeley, since the oceanographic campus was overseen by the university's senate at the time. After 1931 he was a research oceanographer at the Institution.

He was a naval reserve officer during World War II and rose eventually to the rank of commander, stationed in Washington, DC. There, as officer in charge of the oceanographic section of the Bureau of Ships, he helped to establish the Office of Naval Research. Roger had a special role in assuring a place for the Earth sciences in the scheme of things at ONR. Unlike the situation for physics, there were very few other lines of support available to them at the time.

Roger was chief of the geophysics branch of ONR in 1946-47. In that position he was responsible for studies of the oceanographic aspects of the Bikini tests of the hydrogen bomb.

Roger became director of the Scripps Institution in 1951, though not without some strong opposition—already an indication of his fierce drive for accomplishment and his insensibility to the diplomatic niceties of bureaucrats.

During his directorship from 1951 to 1964, oceanography grew to be a major discipline in the US, which became the world leader in the field. Roger was partly responsible for this accomplishment, along with the other three giants of the field, Columbus Iselin of the Woods Hole Oceanogra-