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A Biographical Memoir by
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Biographical Memoir

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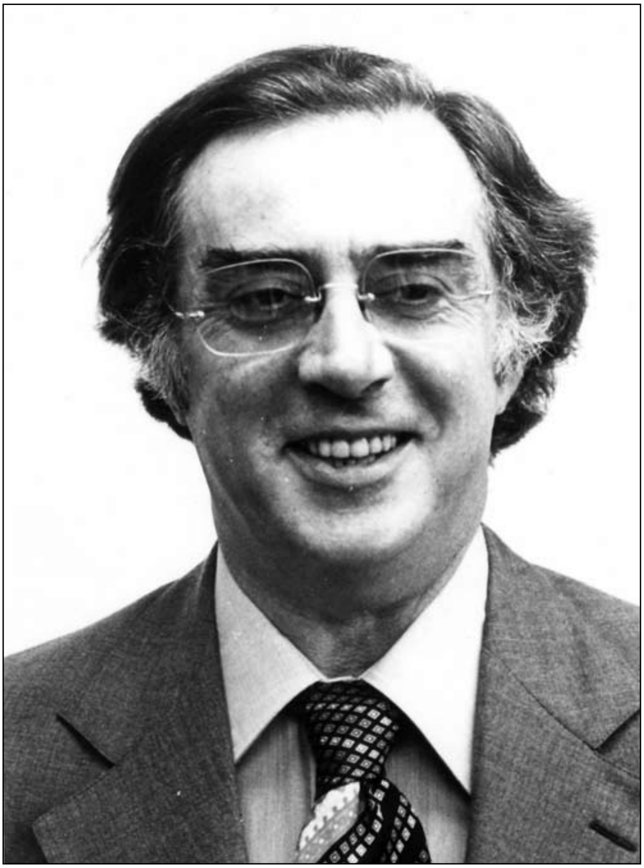

ALBERT VICTOR CREWE

February 18, 1927–November 18, 2009

BY ROGER H. HILDEBRAND

ALBERT CREWE WAS BORN IN SLAITHWAITE, a town on the outskirts of Bradford, England, in what is now West Yorkshire. His paternal grandparents had migrated to Yorkshire from Ireland about the time of the potato famine. His father, Wilfred Crewe, left school at age 12 to become an auto mechanic, later the owner of a garage, and eventually a car dealer. Albert, the only child of Wilfred's first marriage, grew up during World War II in a working-class community still recovering from the worldwide depression. He had average grades in school. At age 15, however, he passed a nationwide examination to determine whether he could continue his education. He became the first in his family to attend high school.

At age 17 he passed a second national exam which allowed him to attend college. He won a military scholarship to the University of Liverpool to pursue an undergraduate degree in physics. Under the conditions of World War II, then prevailing, this scholarship would have required him to work for the army upon graduation. But he received a first-class degree with high honors, and that allowed him another scholarship to continue as a physics student at Liverpool.

LIVERPOOL

As an undergraduate student Crewe studied sculpture and drawing at the Liverpool School of Art across the street from the physics labs. His interest in painting and sculpture continued throughout his career. During and immediately after the war, there was a shortage of manpower on the farms. In 1946 Crewe was among the college students gathered to help with the harvest. There he met his future wife, Doreen Blunsdon. They married three years later.

Crewe began work on his Ph.D. thesis at a time when physicists were using models to determine particle masses from measurements of scattering in cloud chambers and emulsions. Several experimenters claimed to have found new particles by virtue of mass values derived from scattering observations. To investigate this problem Crewe measured the scattering of known particles of known energies: 8 MeV deuterons in photographic emulsions and 180 MeV muons in a cloud chamber that he built in collaboration with Wynn Evans. He made a counter system with absorbers and suitable coincidence and anticoincidence circuitry to trigger the cameras for the cloud chamber, and used high-pressure gas in the chamber to reduce track diffusion and provide denser tracks. His thesis, "The Multiple Scattering of μ-Mesons" (1951), provided a sound basis for interpreting scattering results and for discarding the claims of new particles. At age 24 when he received his Ph.D. in physics, he was hired by the university.

BEAM EXTRACTION

Synchrocyclotrons, constructed at Chicago, Liverpool, and other laboratories in the 1950s, reached higher energies than could be attained with fixed-frequency cyclotrons. A difficulty for these machines, however, was that as the orbits of the protons expanded, the successive orbits were no longer spaced so that electrodes could be inserted between turns to deflect the particles out of the magnetic field: the interactions had to be studied in targets placed inside the vacuum tank.

Herbert Anderson, director of the Chicago cyclotron project, had asked me to work on that problem, but before I had made any progress, I learned that someone at Liverpool had successfully solved the same problem. I promptly visited the Liverpool cyclotron laboratory and found that Albert Crewe, then a lecturer at the university, had mastered both the principle and the practice of the extraction technique.

An extraction scheme had been proposed by Tuck and Teng in 1951. They showed that by inserting static magnetic field perturbations around the orbit of near maximum radius, the vertical oscillations of the beam could be stably maintained while the amplitude of radial oscillations could be made to grow sufficiently in a single turn to clear the mouth of a magnetic channel that would guide the ions out of the main field. A quantitative analysis, confirming the principle of the technique, was published by Le Couteur later in the same year.

The step between a theory for perturbing orbits and a working extraction system was difficult. The flux into the magnetic channel had to be optimized by slight adjustments in the positions of the iron inserts (the "peeler" and "regenerator") used to perturb the field. Each adjustment of the inserts meant opening the vacuum tank, making the adjustments, and then re-pumping the tank for another try the next day. The first successful application of the technique was reported by Crewe and Le Couteur (1955) some three years after the publication of the theoretical papers.

When Anderson heard the report of my visit to Liverpool, it was tea time in England. He picked up the phone, called Crewe, and invited him to come to Chicago as a research associate. Crewe accepted immediately. He came to Chicago and within a year had extracted a beam from the Chicago cyclotron.

THE ARGONNE ACCELERATOR PROJECT

In the late 1950s Argonne National Laboratory (ANL) was working on the design of a machine to accelerate protons to 12.5 billion electron volts, an energy sufficient to produce all the then known mesons and nucleon resonances. But this project had not received the support it needed from the Atomic Energy Commission (AEC) or from the scientific community at large.

A rival design project was being pursued at Madison, Wisconsin, under a consortium of universities known as the Midwest Universities Research Association, or MURA. At one point the AEC, under pressure to counter the launch of *Sputnik* (in 1957) and the construction of a record 10 billion electron volt accelerator at Dubna by the Soviet Union, decided that both the MURA and Argonne accelerators should be built. MURA was to pursue an advanced design concept. Argonne was to build a conventional machine as rapidly as possible: specifically a machine that would reach a higher energy than that of the Dubna accelerator. Eventually construction funds were provided only for the Argonne accelerator.

DIRECTOR, PARTICLE ACCELERATOR DIVISION ARGONNE NATIONAL LABORATORY, 1958-1961

Crewe was one of a group from the Physics Department at Chicago making regular visits to Argonne to help with aspects of the accelerator design, which would be of direct benefit to experimentalists. He developed a scheme to bring the extracted proton beam into a readily accessible experimental area. With the success of his work at the Liverpool and Chicago cyclotrons and the concepts he had developed for the Argonne accelerator, he became a natural choice to head the effort to build a "conventional machine over 10 billion electron volts as rapidly as possible."

The ANL design was conventional in the sense intended by the AEC (i.e., not a strong focusing machine like the one being designed for Brookhaven National Laboratory or like subsequent higher-energy machines). But it was unique among "conventional" machines, in that particles were focused as they entered and emerged from sectors of a zero-gradient magnet, hence, the name "zero gradient synchrotron," or ZGS. The accelerator team and the basic design remained essentially as they had been when Crewe became the division director.

During the construction, there were the frustrations that inevitably go with big projects. Late in the game there was a delay when a safety inspector announced that he had found a room where no fire sprinklers had been installed or even specified. The site of this violation proved to be a government-mandated *shower* room in a government-mandated air raid shelter. Albert said that he would hasten to install the sprinklers when the inspector provided a statement of the purpose they would serve. Those sprinklers never had to be installed.

In 1961 when Crewe became the director of Argonne, his position as director of the Particle Accelerator Division passed to Lee Teng, who carried on the job smoothly and rapidly to operation at a higher energy, 12.7 billion electron volts, than had been specified. The first beam was produced by the ZGS less than four and a half years after ground-breaking, a remarkably short span for a machine of that size.

At a dinner party to celebrate completion of the project Crewe gave a blunt account of unnamed contractors asking for more money after failing to deliver on schedule; trying to substitute substandard materials; changes demanded late in the game by the funding agency; and hurdles erected by low-level bureaucrats. He ended his remarks by saying that except for changing a few words here and there, he had been quoting all the time from Michelangelo's notes on building the dome of St Peter's Basilica.

DIRECTOR, ARGONNE NATIONAL LABORATORY, 1961-1967

When Norman Hilberry, the director of Argonne, retired in 1961, Crewe, then a 34-year-old associate professor, was asked to become the third director of the 5000-employee facility. The University of Chicago managed to convince a congressional committee that he could do the job. Because the laboratory was responsible for secret work on the development of nuclear reactors, it was necessary for the director to be a U.S. citizen. Crewe liked to joke about what one had to do to speed up the process of naturalization. As he later confided to his friends, his regret on becoming the laboratory director was that he could not be the one in charge of bringing the accelerator to life: "I wanted to sit in that control room and twiddle all those damn dials that make the machine work."

From the beginning and throughout his service as director, Crewe placed basic research foremost among Argonne's priorities. But implementing that general policy had to be pursued amidst serious distractions: on one hand the AEC was asserting more centralized control over Argonne's operations, and on the other hand there were strained relationships between Argonne and universities in the Midwest.

Signs posted in the Argonne cafeteria read, "Warning: This is not a secure area. Do not discuss classified material." Although those signs came down before the ZGS was in operation, other reminders of Argonne's isolation from the academic world could only slowly be erased. There remained a perception that Argonne was a laboratory where employees with security clearances worked inside fenced areas to carry out directives from the AEC. The result was deep skepticism about Argonne's suitability as a site for a machine that would serve a community focused on basic research and teaching. Representatives of The Associated Midwest Universities argued that they should have a part in developing Argonne policies if university scientists were to rely on Argonne facilities. The concerns they raised led to several administrative arrangements for giving the universities a part in governing the laboratory.

The misgivings of the Midwest universities receded slowly as Argonne shifted its priorities toward basic research, as visiting high-energy physicists were able to work productively at the ZGS, as the universities gained more oversight of the laboratory, and as respected senior faculty members in the region contributed to successful cooperation. But dealing with these difficult relationships consumed much of Crewe's effort. Nevertheless, the years of his administration were productive. During those years, Crewe pushed basic research budgets ahead of spending for reactor development and other technical programs for the first time.

Accomplishments at the laboratory during the Crewe years included successful completion of the ZGS below budget and at levels of performance above the original specifications; first application of superconducting magnets to full-scale high-energy physics experiments; and construction of facilities for the laboratory's scientific programs and support of visiting scientists. These facilities included buildings for solid-state sciences, high-energy physics, mathematics, computer facilities, a new cafeteria, and lodging; and dedication of experimental breeder reactors I and II at the Idaho site, a remote site dedicated to reactor development. Breeder Reactor I was the first to produce electricity with a plutonium core; Breeder

Reactor II began 30 years of operation as a flagship for the nation's advanced nuclear energy program. In the midst of all this Crewe made contributions to international scientific diplomacy in tours of the Soviet Union, South America, Asia, and the 1964 Geneva Conference. On the trip to the Soviet Union he accompanied Glenn Seaborg and eight other prominent American scientists, who were flown to Moscow in *The Caroline,* President Kennedy's personal airplane.

SCANNING TRANSMISSION ELECTRON MICROSCOPE

While at Argonne, Crewe became interested in electron microscopy, an interest stimulated by a major biology program at the laboratory. Although it was clear that better resolution could provide new opportunities, he was not motivated by any specific application. He liked to point out that Galileo could not have said what he would discover when he worked to build a better telescope.

The electron microscope, first described by Knoll and Ruska in 1932, exceeded the resolution of optical microscopes by more than an order of magnitude. This success stimulated attempts to achieve even better resolution; electron microscopy was still far from reaching any fundamental limit. An obvious but difficult goal was to achieve resolutions below the normal spacing between atoms in a solid (i.e., to break the "two-Angstrom barrier").

On a flight home from a conference in England, Crewe sketched a design for a microscope of a type—a scanning transmission electron microscope, or STEM—that would eventually achieve this goal. He set up a group at Argonne to work on the design and had a working model to test in 1967. In this design a beam of electrons focused to a small spot (i.e., the electron probe) was moved across a specimen in a raster scan. The scattered electrons were detected by an annular ring, and the energy of the transmitted electrons was measured by a spectrometer.

Essential requirements for a successful microscope were voltage stability, a pointlike electron probe, and a focusing system free of aberrations—all difficult. The problem of voltage stability was most severe for microscopes built for high voltages. The 1.5 MeV microscope at Berkeley, with an accelerating voltage of 1.5 MeV, remained stable within 0.1 volt. To gain this remarkable stability it was necessary to build an 18-meter-tall silo weighing more than 20 tons. Crewe's efforts were focused on making a pointlike source—the electron gun—and on developing an aberration-free focusing system.

The electron gun. The groundwork for a pointlike source was E. W. Müller's invention of a field ionization technique in which helium atoms are ionized and repelled by the electric field of a needle and stream to a screen where they show the arrangement of atoms on the surface of the needle. With the field reversed and a field-strength of order 10^6 V/cm at the surface of a needle, Robert Gomer obtained a small, bright source of electrons.

Crewe used a cold electron source of this type to produce a diffraction-limited probe. The work on the electron gun required an understanding of field emission and improvements in ultrahigh vacuum technology. Electrons emitted radially from the fine hemispherical tip of the needle diverged from a virtual point source at the center of curvature. Only paraxial rays entered the focusing system.

Aberrations. The energy spread of electrons from this source was low enough to minimize the problem of chromatic aberration. There remained, however, the problem that systems of quadrupole magnets that had been used to focus in two transverse directions—systems familiar to accelerator scientists—introduced significant spherical aberrations. There had been attempts to reduce the aberrations by systems with both quadrupole and octupole magnets. Crewe and his students showed that high-order aberrations could be eliminated by introducing sextupole magnets. The brightness of the electron gun and the near aberration-free focusing system achieved by Crewe and his students made it possible to examine specimens—notably biological specimens—with an order-of-magnitude lower dose of radiation than could be achieved using thermal emitters as electron sources.

A characteristic of the STEM is that there are no post-specimen optics and hence no significant diffraction or interference artifacts. The STEM provides a quantitative map of the specimen based on interactions of the electrons in the specimen and collection of the image-forming electrons. By combining the signals corresponding to elastic and inelastic scattering, the STEM provides a signal proportional to the atomic number of the specimen, a feature particularly valuable to biologists who use this “Z contrast” to measure the atomic mass of structures such as proteins.

Imaging single atoms. Crewe made images of single atoms with the STEM in 1970, and in 1975 obtained motion pictures of atoms moving along an amorphous carbon-film substrate.

He held 19 patents and published over 180 papers on electron microscopes. Approximately a quarter of the papers concerned applications to biology, metallurgy, and mineralogy. He served as a consultant to the Hitachi Corporation of Japan, which developed the first successful commercial version of the scanning electron microscope. More than 3000 STEMs can now be found in semiconductor fabrication facilities worldwide.

Crewe received the Michelson Medal of the Franklin Institute, the Distinguished Service Award of the Electron Microscope Society of America (1976), the Ernst Abbe Award of the New York Microscope Society (1979), and the Duddell Medal of the Institute of Physics (London, 1980). He received honorary fellowships from the Royal Microscope Society (London), and the Electron Microscope Society of China. He received honorary degrees from Elmhurst College, Lake Forest College, University of Missouri, and his alma mater, the University of Liverpool. He was elected to the National Academy of Sciences in 1972.

DEAN, DIVISION OF THE PHYSICAL SCIENCES, 1971-1981

Four years after resigning as director of Argonne, Crewe began a decade of service as dean of the Division of Physical Sciences. There he made high-quality faculty appointments in astronomy and astrophysics, chemistry, geophysics, physics, and statistics. Among the scientists he appointed, one has become a Nobel laureate, one a Wolf Prize laureate, eight have become members of the National Academy of Sciences, and eight have served as department chairs or institute directors.

During his service as a dean, Crewe continued and even intensified his development of the electron microscope. His outstanding contributions to the university were recognized in 1977 by his appointment as the William E. Wrather Distinguished Service Professor.

At age 82 Crewe died of complications from Parkinson's disease. He is survived by his wife, the former Doreen Blunsdon; four children: Jennifer, Sarah, Elizabeth, and David; and 10 grandchildren.

I AM GRATEFUL TO Albert Crewe's family for notes about his early life; Peter Rowlands and Ronan McGrath for information about his student and professional days at Liverpool; Jack M. Holl for his history of Argonne; Lee Teng concerning beam extraction and the ZGS; Ned Goldwasser for comments on Crewe's work at Argonne; and Riccardo Levi-Setti, Oscar Kapp, and the Franklin Institute for material on electron microscopy.

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