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CHARLES CHRISTIAN LAURITSEN

1892—1968

A Biographical Memoir by
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CHARLES CHRISTIAN LAURITSEN, Danish-born physicist, became, in his later years, an elder statesman in science for the defense forces and government of his adopted country, the United States. Through his own work, through the work of the laboratory that he established, and through students and colleagues, he exercised a profound influence on nuclear physics and its applications in astronomy over a span of four decades. During and after World War II he turned his attention to the scientific and technological needs and capabilities of the United States in national defense. By active and continuous engagement for thirty years as participant, adviser, and consultant in the national scientific defense effort, he contributed to the interplay between science and government that is so essential to both.

Charles Lauritsen was born in Holstebro, Denmark, on April 4, 1892. He graduated in architecture from the Odense Tekniske Skole in 1911 and emigrated in 1917 to find his fortune in America. After various undertakings, from designing naval craft in Boston to professional fishing off the Florida coast, he went to Palo Alto in 1921 to work on ship-to-shore radio for Federal Telegraph. There his interest turned to designing radio receivers, and, together with several enthusiastic

* This biography, without the bibliography, appeared earlier in the *Year Book of the American Philosophical Society,* 1969.

partners, he started producing them in a rented garage. In 1923 he went to St. Louis to become chief engineer for the Kennedy Corporation and started making those fifty-pound, ten-tube radio sets that brought music and entertainment to tens of thousands of American households.

In 1926 Robert Andrews Millikan gave a lecture in St. Louis that opened Lauritsen's eyes to a new world. Six years earlier Millikan had become head of a small college in Pasadena, California, which at about the same time took the name, the California Institute of Technology. This was the new world where graduate research in physics was pre-eminent. A certain uneasiness about the future of the radio business, together with the enthusiasm inspired by Millikan, led him to move his wife, Sigrid, and a ten-year-old son, Thomas, to Southern California.

In Pasadena, he found much to his surprise that you could get paid—though not handsomely—for working at a place like Caltech, and he settled down to work. He signed up for the courses of Epstein and Smythe and Tolman and Bowen and Zwicky and Bateman and started to rebuild his intellectual capital. More than that, he went to Millikan and asked for a doctoral research project. What was interesting Millikan in the fall of 1926 was the cold-emission effect: pulling electrons out of metals by high electric fields. If one put in the experimental numbers, it appeared to be easier to get electrons out than the theory would allow, considering that they had to be pulled over a quite formidable potential barrier at the surface. Would Lauritsen look into it? Lauritsen was able to show that the field emission was quite insensitive to temperature and displayed a simple exponential dependence on field strength that agreed very well with a theory developed by Oppenheimer on the basis of quantum-mechanical barrier penetration.

In 1929 Lauritsen received his Ph.D. in physics from the California Institute, with which he remained associated for the rest of his life. He became assistant professor of physics in

1930, associate professor in 1931, professor in 1935, and professor emeritus in 1962.

Field emission, vacuum tubes, and the availability of a million-volt cascade transformer led Lauritsen to x rays. He built a series of x-ray tubes operating up to 750 kilovolts. Three-quarters of a million volts was a considerable step forward in the technology of the time. The largest medical x-ray tubes then available were fragile overgrown glass bulbs rated for 200 kilovolts and worth their weight in gold. It seemed natural, then, to explore whether the bigger tubes offered any new opportunities in medicine, particularly in the treatment of deep-seated malignant tumors. This idea proved quite interesting to Albert Soiland, a distinguished radiologist in Los Angeles, and after some preliminary experiments with animals, treatment of patients with "super-voltage" x rays began in the old High Voltage Laboratory at the California Institute in October 1930. In the following year, Millikan interested W. K. Kellogg in improving the facilities, and the Kellogg Radiation Laboratory was funded and built. Lauritsen was elected a Fellow of the American College of Radiology in 1931, at which time he received the college's Gold Medal.

In 1932 Cockroft and Walton in Cambridge, England, announced that man-made machines could be used to disintegrate nuclei. Lauritsen had a laboratory ready to enter this new and exciting field. H. R. Crane, now professor of physics at the University of Michigan, was still a graduate student under Lauritsen. The x-ray therapy had been transferred from the High Voltage Laboratory to Kellogg. The two immediately converted one of the old x-ray tubes in the High Voltage Laboratory into a positive-ion accelerator using a bottle of helium gas and a primitive ion source. One of the first projects, published in September 1933, was the artificial production of neutrons by bombarding beryllium targets with simple quartz fiber electroscope that Lauritsen had developed for the x-ray work, now furnished with a lining of paraffin. Neutrons had been detected by Chadwick from studies of the rare but potent radiations produced by bombarding beryllium with alpha particles from radium. The discovery that neutrons could now be made "artificially" with machines, in numbers many orders of magnitudes greater than using natural sources, revolutionized neutron physics.

Not long after the discovery that neutrons could be produced using helium ions, G. N. Lewis of Berkeley supplied Lauritsen with a sample of heavy water and Lauritsen and Crane soon found how to augment this supply by electrolyzing ordinary water. They discovered that deuterons produced neutrons even more copiously than helium ions. In addition, in 1934 they were the first to find that deuteron bombardment produced radioactive nuclei as well as neutrons. This was first published by Lauritsen, Crane, and W. W. Harper in early 1934. From carbon there was produced a ten-minute activity that yielded the same positrons that Carl Anderson had discovered in the cosmic radiation in 1932. Lauritsen soon found the annihilation radiation that resulted when a positron met a matching electron. He performed a pretty experiment, remarkably convincing in its simplicity. He placed a graphite target, bombarded side up, on top of one of his sensitive electroscopes and measured a certain discharge rate. He then placed a thin absorber, previously shown not to be radioactive, on top of the target—the discharge rate doubled. The explanation was indeed quite simple. The positrons were created in a thin surface layer of the target slab. The half moving downward were annihilated in the target adjacent to the electroscope and the resulting annihilation radiation discharged the electroscope. When the absorber was not in place, the half moving upward escaped into the atmosphere and were eventually annihilated at some distance from the electroscope—too far, in fact, to affect the discharge rate. The absorber placed on top of the target stopped the upward moving positrons, which then produced a discharge rate practically identical to the downward moving ones—thus, the doubling. To an observer not acquainted with the nature of the radiation, it seemed very mysterious. When explained, the experiment became a simple demonstration of the annihilation phenomenon.

Lauritsen loved experimental work in the laboratory, and he passed this along to his graduate research students. I was one of the first of his students. He taught us everything from how to run a lathe to how to design and build electroscopes, ion sources, cloud chambers, magnetic spectrometers, electrostatic analyzers, and high voltage accelerators. But most of all he taught us how to do experiments—in simple, direct, but very elegant ways.

It was always the case that Lauritsen saw through to the heart of any problem. Whereas most of us tend to overdesign apparatus and to use redundant procedures in our experiments, Lauritsen delighted in designing inexpensive and simple devices that would make the experiment and its theoretical interpretation as straightforward as possible. He delighted too in convincing us in his logical manner that his suggestions were the right ones. When agreement had been reached, he got perhaps his greatest satisfaction in going to the lathe and turning out the most difficult parts and pieces himself. But withal he always taught us why he did thus and so and we learned, insofar as we were able, something of his marvelous insight into how to *do* physics, as he so frequently expressed it.

Lauritsen was primarily an experimentalist, but it was his close personal relationship with theorists that broadened and deepened the experiences of his students. This continued throughout his lifetime, but it was especially true before World War II when what we now call classical nuclear physics was in its golden age. It was truly golden for all the students in Kellogg because first of all there was Charles Lauritsen, one of the great men in the field, along with Rutherford and Cockcroft and Lawrence and Tuve, but also there were his two great and eminent friends Richard Tolman and Robert Oppenheimer.

They were giants—all three in their different ways—but all three truly great men. It was exciting and even awe-inspiring to listen to their discussions about our experiments and what the experimental results meant in terms of the nuclear theory of that time. Tolman and Oppenheimer were delighted with the discoveries in nuclear physics that came out of Lauritsen's laboratory—the discovery of resonance in proton-induced reactions; the first production of high-energy gamma rays, neutrons, and radioactivity with accelerators; the discovery of the "mirror" nuclei as well as the proof of the annihilation of positrons, among many other firsts. Oppenheimer played a key role in elucidating the significance of "mirror" nuclei such as ^{11}C—^{11}B, ^{13}N—^{13}C, ^{15}O—^{15}N, and ^{17}F—^{17}O. The laboratory measurements on the positron emission between these pairs showed that the beta decay energy increased uniformly up the series. At Oppenheimer's suggestion a calculation showed that the energy increase was entirely due to the coulomb interactions between the protons in these nuclei and that the intrinsic nuclear interactions between pairs of protons and pairs of neutrons were identical, thus establishing the charge symmetry of the nuclear forces. At a later date Lauritsen and his students and collaborators went on to show that the excited states of "mirror" nuclei were identical in energy, except for well-defined effects due to particle emission. This was part of a comprehensive study of the excited states of all the light nuclei undertaken in Lauritsen's laboratory.

Lauritsen was also a close friend of H. P. Robertson who left Caltech for Princeton in 1929 but returned in 1948. They both had a broad range of interests in the physical sciences, from nuclei to galaxies, and they also shared a common interest in the interrelationship of science and society. In addition

Lauritsen was instrumental in bringing R. F. Christy, one of Oppenheimer's students, to Caltech in order to provide theoretical guidance in the nuclear research.

One of Lauritsen's most significant discoveries was that of the capture of protons by carbon with the emission of gamma radiation. This process, called radiative capture, was a matter of considerable theoretical controversy until Niels Bohr introduced the concept of long-lived compound nuclei in connection with the radiative capture of neutrons.

The full significance of Lauritsen's discovery did not come until 1939 when Bethe at Cornell and Von Weizsäcker in Germany independently suggested that hydrogen could be converted into helium in stars by means of a catalytic process involving the isotopes of carbon and nitrogen that came to be called the CN-cycle. The first reaction in the cycle is the radiative capture of protons by ^{12}C. The second and third reactions involve similar capture by ^{13}C and ^{14}N. The fourth reaction is the emission of alpha particles in the interaction of protons with ^{15}N in which ^{12}C is the residual nucleus thus closing the cycle. Lauritsen also studied this reaction.

Bethe and Critchfield suggested another process, the proton–proton chain, by which hydrogen could be converted directly into helium in stars. Bethe thought that the CN-cycle was the dominant process in the sun and that the pp-chain predominated only in somewhat cooler stars than the sun. It is now known from measurements in Lauritsen's laboratory that the pp-chain dominates in the sun and that the CN-cycle takes over in stars somewhat hotter than the sun. Even so, it was quite clear in 1939 that problems in the application of nuclear physics to astronomy could only be solved by detailed and accurate measurements of nuclear reaction rates.

A start was made in this direction, mainly the construction of a 2-million-volt electrostatic accelerator capable of high-resolution direct-current operation, but World War II put a stop to all nondefense related research and teaching. At the end of the war Lauritsen had to decide the future direction of research in his laboratory. He did not hesitate, and under his direction the laboratory staff enthusiastically returned to the field of low-energy, light-element nuclear physics. It was resolved to spend a good part of the effort on the study of those nuclear reactions thought to take place in stars. Lauritsen was encouraged in this by Ira Bowen, who became director of the Mount Wilson and Palomar Observatories early in 1946. Bowen held a series of informal seminars in his home, where physicists and astronomers discussed problems of mutual interest over beer and pretzels. In 1948 Jesse L. Greenstein came to Caltech to lead the work in astronomy, and his interests, particularly in the abundances of the elements in stars, stimulated much of the experimental research.

Studies of the hydrogen-burning processes in main sequence stars such as the sun began in earnest in 1946. Two additional electrostatic accelerators were built, and in 1958 the Office of Naval Research funded the purchase and installation of a tandem accelerator capable of accelerating protons to 13-million-electron-volts energy in the new Alfred P. Sloan Laboratory of Mathematics and Physics. On the basis of laboratory observations made with these accelerators and with auxiliary electrostatic analyzers and magnetic spectrometers designed by Lauritsen and of theoretical calculations on stellar structure and evolution, it is possible to predict with considerable accuracy, for example, the flux of neutrinos from the sun at the surface of the earth. Attempts are now under way to detect these neutrinos, the observation of which will mark a culminating stage in one phase of the work that Lauritsen originated and encouraged in his laboratory.

In the decade of the 1950s the big question was "How does helium burn in stars?" The question was solved in 1957 when the energy, angular momentum, parity, and decay modes of the

7.65-million-electron-volt excited state of ^{12}C were determined in the laboratory. It is through this state that the Salpeter–Hoyle process, $3\,^4He \rightarrow {}^{12}C$, occurs in helium burning in red giant stars.

In his later years, when he personally became more and more involved in national defense matters, Lauritsen encouraged the staff of his laboratory to continue experimental work in nuclear astrophysics and to use the laboratory accelerators in other fields. Beam foil spectroscopy for the study of atomic transition probabilities and proton channeling for the study of properties of the solid state were introduced. These developments were a mark of Lauritsen's broad and far-ranging interests in all aspects of nuclear physics and its applications.

In the summer of 1940, Lauritsen went to Washington to join the newly formed National Defense Research Committee as vice chairman of the section on Armor and Ordnance under Tolman. His principal work in the initial stages of this effort lay in organizing the development of proximity fuses and artillery rockets and in promoting the interest of the armed services in the exploitation of scientific research in the war effort. One of the earliest substantive results of this work was the establishment of a group at the Department of Terrestrial Magnetism for the development of the proximity fuse under Merle Tuve. Lauritsen participated actively in the work of this group during the latter part of 1940 and early 1941, until the development of bomb and rocket fuses had reached the service test phase and the shell fuse development was well under way.

At this point, partly as a result of a visit to England, Lauritsen concluded that a major effort on artillery rockets was needed. Under the aegis of the Office of Scientific Research and Development, he set up a project for that purpose at the California Institute of Technology in the summer of 1941. This project, which he directed all through the war, made a number of major advances in rocket technology and developed some dozens of service weapons, many of which were adopted and used by the armed services. Among these were the "Mousetrap" antisubmarine rocket, the 4.5-inch Beach Barrage Rocket, and the 3.25-inch, 5.0-inch, and 11.75-inch aircraft rockets. A large part of the success of this effort may be ascribed to the close relations that Lauritsen maintained with the services. Through these connections, he was able to appreciate, and sometimes to anticipate, tactical requirements and to insure that the newly developed weapons were properly introduced into use. On many occasions he participated in the training programs and advised field commanders in the early phases of service applications. Thus, for example, he led a mission to England in 1944 to introduce U.S. Air Force pilots to the 5.0-inch aircraft rocket; these pilots made effective use of their training in the Saint-Lo breakthrough after D-day.

With the rocket development project well under way, Lauritsen turned his attention in 1944 to the atomic bomb project. During 1944 and 1945, he spent a considerable fraction of his time at Los Alamos with Oppenheimer, participating in the technical steering committee and in the scientific development work. Some parts of the development were carried out in Pasadena, again under his direction.

Late in the war, when it became apparent that a continuing development and test facility would be needed by the armed services, he persuaded the navy to establish the Naval Ordnance Test Station at Inyokern, California. He took an active part in the planning of this facility and supported its work over the years, both informally and as a member of its Advisory Board. In recognition of his contribution to the war effort, he was awarded the Medal for Merit by President Truman in 1948.

Possibly the most far-reaching of Lauritsen's endeavors was his early influence on the establishment of the Office of Naval Research, an organization that played an important part in the recovery of scientific research after the war, and whose operation set the pattern for broad federal support of science in this country. Together with Captain R. D. Conrad, of the Office of Research and Inventions of the United States Navy, and with other members of the scientific community, he helped to lay down the ground rules for the Office of Naval Research and to bring it into being. He served the Office of Naval Research for many years on its Advisory Committee and through informal consultation with its administrators. He was the first recipient of the Conrad Award for Scientific Achievement in 1958.

Starting in 1950, Lauritsen took an active part in a number of major scientific study projects, carried out at the request of the armed services. Among these were Project Hartwell, 1950; Project Charles, 1950–1951; Project Michael, 1951; Project Vista, 1951–1952; and the Lincoln *Ad Hoc* Study Group for Continental Defense, 1951–1953.

At the time of the Korean War, he traveled to Korea for the Weapons Systems Evaluation Group to observe the Inchon landings and generally to evaluate the role of new-weapons development in that action. He continued these activities through his membership in a number of scientific advisory boards, where he was involved in both scientific development and tactical problems embracing the whole spectrum of defense activities.

Lauritsen also became heavily involved in the scientific and military aspects of the ballistic-missile development program. He served on the Panel on Weapons Technology for Limited Warfare for the President's Scientific Advisory Committee, the Strategic Weapons Panel and other advisory groups for the Department of Defense, the U.S.–U.K. Ballistic Missile Scientific Advisory Committee, the Advisory Committee on the Intercontinental Ballistic Missile, the Air Force Space Study Committee, the Minuteman Flexibility and Safety Group for the U.S. Air Force, the Advisory Board, Pacific Missile Board for the U.S. Navy, and the *Ad Hoc* Committee on the Role of the

Army in Space for the U.S. Army. As their names suggest, these activities were directed to the scientific evaluation of national needs and capabilities in the currently most conspicuous example of the effect of science and technology on national defense. In his participation in this work, Lauritsen's understanding of both the detailed scientific considerations and the broad tactical and strategic problems made an invaluable contribution to the sound conception and to the ultimate success of these programs.

Lauritsen received many honors in his lifetime. In addition to those already mentioned he was elected to the Royal Society of Copenhagen in 1939 and was made Kommandor of Dannebrog by the King of Denmark in 1953. He was elected president of the American Physical Society in 1951 and was awarded the Tom W. Bonner Prize of the Society in 1967. He became a member of the National Academy of Sciences in 1951 and of the American Philosophical Society in 1954. The library of the Aerospace Corporation, which he was instrumental in founding, was dedicated to Lauritsen in 1968. The degree of Doctor of Laws was conferred upon him by the University of California at Los Angeles in 1965.

Charles Christian Lauritsen was an eminent research scientist and teacher. More than one hundred graduate students have received their doctoral degrees in the laboratory he founded, many under his direct supervision. He authored or co-authored approximately one hundred papers. He gave unstintingly of his time and effort to the scientific aspects of the national defense of his adopted country. He was a man of great integrity and character and his influence on his students, his colleagues, and his times is immeasurable.

IN PREPARING this biography of Charles Lauritsen I have made abundant use, in some cases *verbatim,* of notes and papers by his son, Thomas Lauritsen. I am grateful for permission to do this.

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KEY TO ABBREVIATIONS

Am. J. Roentgenol. Radium Ther. = American Journal of Roentgenology and Radium Therapy
Phys. Rev. = Physical Review
Phys. Rev. Lett. = Physical Review Letters
Rev. Sci. Instr. = Review of Scientific Instruments

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