NATIONAL ACADEMY OF SCIENCES

RAYMOND GEORGE HERB

1908—1996

A Biographical Memoir by
HENRY H. BARSCHALL

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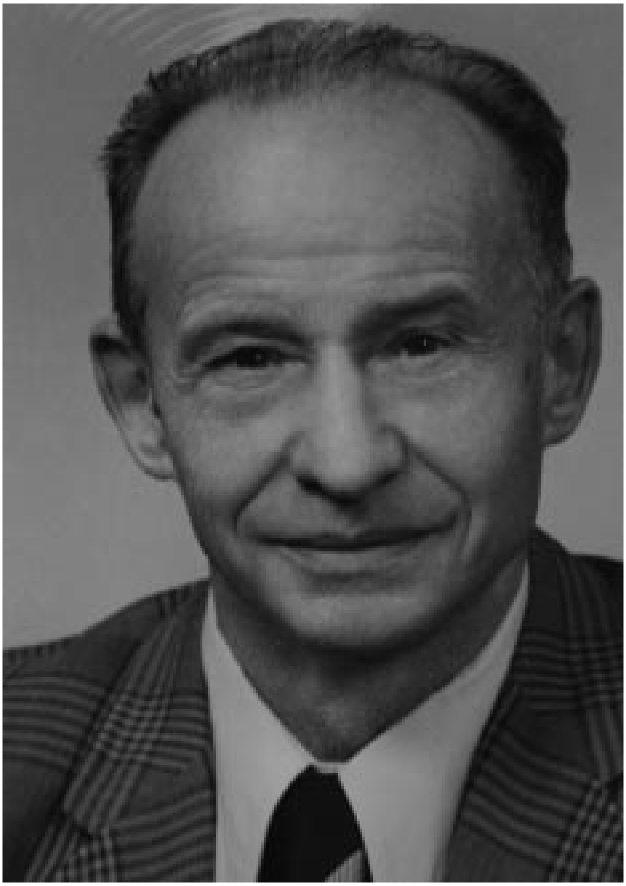
NATIONAL ACADEMIES PRESS
WASHINGTON D.C.



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RAYMOND GEORGE HERB

January 22, 1908–October 1, 1996

BY HENRY H. BARSCHALL

RAY HERB IS FAMOUS for the design and development of pressurized electrostatic accelerators, which were the most widely used tools for nuclear physics research in the post-World War II period. This was, however, only one of his great contributions to physics and technology. He also used his accelerator to perform precision measurements in nuclear physics, supervised the Ph.D. research of over fifty physics students, and pioneered many advances in accelerator and vacuum technology. In his later life he founded a company that produced over 100 electrostatic accelerators not only for nuclear physics but for such diverse applications as detecting forgeries at the Louvre museum and inspecting cargoes passing through the Chunnel connecting England and France.

Ray was born in 1908 in Navarino on a small farm in north-central Wisconsin, one of eight children. He did his undergraduate and graduate work at the University of Wisconsin in Madison where he received a Ph.D. in physics in 1935. He spent his entire life in Wisconsin, except for the summer of 1935 when he worked at the Department of Terrestrial Magnetism of the Carnegie Institution in Washington and from 1940 to 1945 when he was at the Radiation Laboratory at the Massachusetts Institute of Technology working on microwave radar development. He was on the faculty of the University of Wisconsin-Madison from 1935 until his retirement as the Charles Mendenhall professor of physics in 1972. (Charles Mendenhall, a member of the National Academy of Sciences, was head of the Wisconsin physics department and Ray's major professor).

Ray was elected to the National Academy of Sciences in 1955. He received honorary degrees from the University of Basel, Switzerland, University of São Paulo, Brazil, University of Lund, Sweden, as well as the University of Wisconsin; the latter was in recognition of his accomplishments following his retirement. He was awarded the Tom W. Bonner Prize by the American Physical Society.

In 1945 Ray married Anne Williamson, the daughter of a University of Florida physics professor. They had five children: Stephen, Rebecca, Sara, Emily, and William. Stephen followed in his father's footsteps and became an experimental physicist. Ray died in 1996 of multiple myeloma. Although disabled physically for many months, he remained active full-time in his work until the last days of his life.

The first particle accelerator used for a nuclear physics experiment was developed by Cockcroft and Walton, using high-voltage transformers, rectifiers, and a four-stage voltage multiplier to produce a voltage of 710 kV. In 1931 Robert J. Van de Graaff at Princeton attempted to attain higher voltages by transporting electric charges on a rapidly moving canvas belt to the high-voltage terminal. The attainable voltage of this electrostatic generator was limited by corona discharges from the high-voltage terminal. Henry A. Barton, D. W. Mueller, and J. C. Van Atta at Princeton were able to attain about 1 MV by enclosing Van de Graaff's belt-charging system in high-pressure air, but they did not attempt to accelerate charged particles.

In 1933, just after receiving his bachelor's degree, Ray worked with Glen G. Havens at Wisconsin on a vacuum-insulated electrostatic generator of the Van de Graaff design, but this device could not be pushed above 300 kV. There was no understanding of the discharges that limited the attainable voltage. Ray therefore decided to try to use high-pressure insulation. Two other graduate students, D. B. Parkinson and D. W. Kerst, joined Ray in this endeavor. Ray discovered accidentally that the dielectric strength of air could be greatly increased by the addition of carbon tetrachloride, an electronegative gas. Ray told the story that he tried other chemicals. When he threw a rag soaked in acetone into the tank, the first spark started a fire. He was easily able to reach 1 MV in a pressure tank 1 m in diameter and 2 m long filled with air and carbon tetrachloride. Ray then proceeded with the more difficult task of building an accelerating tube for this machine. It was limited in length to 50 cm. He used sections of Pyrex tubing, 6 cm long and 5 cm in diameter. The tubing was sealed to brass separators with red sealing wax. He then built an ion source and detection equipment and used the accelerator for his Ph.D. thesis, which involved the measurement of the yield of the Li(p,α) reaction at 400 keV.

Later in 1935 Ray with Parkinson and Kerst designed a larger machine. It used a tank 1.7 m in diameter and 6.4 m long. It could be operated at 2.6 MV. The accelerating tube for this machine used a design that was adopted for all future electrostatic accelerators (i.e., a column enclosed by closely spaced metal rings graded in potential). Although this machine did not attain the particle energies that could be obtained with a cyclotron, the energy of the particles accelerated with the electrostatic accelerator was much more uniform and could be controlled with high accuracy.

Enrico Fermi had performed experiments with slow neutrons that showed that the reaction probability of the neutrons increased sharply at certain bombarding energies, a process called resonance. These sharp resonances were believed to occur only at very low bombarding energies. Using the beam of well-defined energy from the electrostatic accelerator Ray and his coworkers showed that resonances as narrow as 1 keV occurred when light elements, such as fluorine and aluminum, were bombarded with MeV protons. These resonances persisted to the highest energies available, 2.6 MeV. This observation made it desirable to extend the studies to higher proton energies and to redesign the accelerator to reach higher energies.

The news of Ray's accelerator spread rapidly, and visitors from all over the world came to Wisconsin to admire the machine and to obtain copies of the drawings. The tank that Ray had used was limited in size by the requirement that it had to pass through a basement window in the physics building. Those who planned to build improved copies of Ray's machine did not have this limitation and were sure they could reach 10 MV or more. Ray gave the visitors much help and advice, but none of the improved copies worked nearly as well as the original—to Ray's quiet amusement. Ray, with the help of graduate students, especially J. L. McKibben and C. M. Turner, was able to remodel the accelerator to produce 4.5-MeV protons by 1940. This energy was surpassed only by cyclotrons until 1955 when a commercially produced electrostatic accelerator was installed at Oak Ridge National Laboratory.

The basic features of Ray's design, which have been incorporated into all modern electrostatic accelerators, include aluminum hoops surrounding the acceleration tube, a voltage gradient controlled either by corona points or resistors, a rotating vane generating voltmeter, high pressure insulation (originally air and carbon tetrachloride, but later nitrogen and Freon or sulfur hexafluoride).

In 1939 Ray with D. W. Kerst, D. B. Parkinson, and G. J. Plain published a seminal paper titled "Scattering of protons by protons." The analysis of these measurements by Breit et al.[1] gave accurate information about the short-range forces between protons and about the charge-independence of nuclear forces.

In the fall of 1940 war was imminent. Ernest Lawrence visited Wisconsin on a recruiting trip for the MIT Radiation Laboratory which was being organized for radar development. For the next five years Ray was at this laboratory, serving on the steering committee and as part of the field service group. He helped to install radar near the front lines in Europe and on a ship in the Pacific.

The Los Alamos Laboratory in New Mexico, known during the war as Project Y, was founded in 1943 to develop nuclear explosives. For the design of a nuclear explosive nuclear data, especially neutron cross sections, were needed. The founders of the laboratory decided to bring to Los Alamos accelerators that could provide the necessary data. The Harvard cyclotron, a Cockcroft-Walton accelerator from the University of Illinois, and the two electrostatic accelerators from the University of Wisconsin were secretly shipped to Los Alamos. The two electrostatic accelerators were dubbed "the short tank" and "the long tank." They ran around the clock at Los Alamos and provided the bulk of the needed nuclear data. Their advantage over the other accelerators was their production of neutrons in the energy range of greatest interest for the project. A target of lithium was bombarded with protons to produce neutrons. The energy of the neutrons could be varied by modifying the energy of the accelerated protons.

I had measured neutron cross sections with a Cockcroft-Walton accelerator at Princeton and was recruited by Los Alamos to perform similar measurements there. I soon realized that the electrostatic accelerators allowed the acquisition of more relevant data, and I spent much time taking data with the "long tank." I became quickly convinced that this machine opened up a new area of research.

After the end of the war Ray paid his first visit to Los Alamos to discuss the future of the two accelerators. This was the first time I met him. He agreed to the sale of the short tank to Los Alamos; this accelerator ran there for many years and produced a wealth of nuclear research. Ray arranged to have the long tank shipped back to Wisconsin. The success of the Manhattan Project had enhanced the standing of nuclear physics, and Ray was authorized to add a couple of nuclear physicists to the faculty of the Wisconsin physics department to reactivate the Wisconsin nuclear physics program. In 1946 the department offered positions to two nuclear physicists who had worked at Los Alamos with the electrostatic accelerators, Hugh Richards and me. I accepted the offer with enthusiasm and so did Hugh Richards. In addition, Ray added experienced students and postdoctorates, mostly from Los Alamos and MIT Radiation Laboratory.

It took a while for the nuclear research program at Wisconsin to get into full swing, but by the summer of 1947 it was well under way under Ray's enthusiastic leadership. One of the important developments Ray started at that time was precision measurement of the energy of the accelerated particles. The particle beam was bent through 90° by passing it between two concentric insulated electrodes, which were kept at a potential difference that could be measured with high precision. This made it possible to perform measurements at accurately known energy, which was particularly important for measurements involving sharp nuclear resonances.

The nuclear research at Wisconsin was generously supported by the Wisconsin Alumni Research Foundation, and Ray shared this support with all the members of the group, but we soon realized that we could not expect the foundation to support a program of the magnitude that was developing. In the fall of 1947 Ray and I visited Robert Bacher whom we both knew and who was a member of the newly created Atomic Energy Commission. Bacher encouraged us to make a formal application for financial support, and in April 1948 we received a grant of $50,000. It was the first grant the commission had made to a university in support of an academic research program. The grant was shared by Ray, Richards, and myself. It was renewed at increasing amounts for many years and provided funds not only for equipment and student and post-doc stipends but also for part of our salaries, so that we could devote more time to research.

Ray established close ties with nuclear physics laboratories in other countries and arranged for the exchange of graduate students and postdoctoral staff with the University of Basel, Switzerland, the Tata Institute in Bombay, India, and most actively with the University of São Paulo, Brazil.

In the following years Ray devoted most of his time to development of accelerator and vacuum technology. This program used many undergraduate and beginning graduate students who received a superb training in laboratory and research techniques. Often these graduate students would work on their thesis with another faculty member, and they could complete their research in a relatively short time because of the techniques they had learned from Ray.

An important event in vacuum technology occurred in 1953 when Ray developed the first practical getter-ion vacuum pump. Ray told the following story about the discovery that titanium could be used for getter-pumping of vacuum systems. Ray observed that a vacuum chamber that he machined rusted overnight. He wondered whether he could use the rusting for a worthwhile purpose. He gave the job of testing various materials as getter pumps to an undergraduate. Nothing worked well. At about that time titanium pellets became commercially available. He asked the student to evaporate titanium by electron bombardment. After the first try the student reported that, when he tried to evaporate titanium, the vacuum gauge broke. It just read zero. Fortunately, Ray realized that the zero pressure reading might not be caused by a broken gauge. For the next dozen years Ray and his students continued development work on vacuum pumps and vacuum gauges.

Ray made important advances in accelerator technology. In all the electrostatic machines built until the mid-1950s a source of positive ions was placed in the positively charged high-voltage terminal of the accelerator, and the positive ions were accelerated from the high-voltage terminal to ground. For example, to accelerate protons the orbital electron of the hydrogen atom was removed to form a proton in the ion source. In 1956 Ray built the first practical source of negative ions (i.e., hydrogen atoms to which an extra electron was attached). This source produced 20 μA of negative hydrogen ions. This made it possible to place the ion source outside the pressure vessel, a great advantage since ion sources require frequent servicing. A second equally important advantage is that, for a given terminal voltage, it now became possible to attain twice the energy of the accelerated particle. The negative ions were accelerated from ground to the positive high-voltage terminal. There the two electrons were stripped from the negative ion, resulting in a positive ion, which was accelerated back to ground potential. With an external source of negative ions an accelerator that had a high-voltage terminal at 5 MV could produce 10 MeV protons. Accelerators using this principle were called tandem accelerators, and almost all subsequently built electrostatic machines were tandem accelerators. The High Voltage Engineering Corporation soon manufactured tandem accelerators. The first tandem accelerator was installed in Canada. In part because of Ray's contribution to the development of the tandem accelerator, the Atomic Energy Commission placed the first tandem accelerator in the United States at the University of Wisconsin.

Another important advance in accelerator technology that Ray made was the construction of an accelerating tube using metal-ceramic bonding. But the most important advance that Ray, with his student J. A. Ferry, made was the replacement of the canvas charging belt, which had been used in all electrostatic accelerators since Van de Graaff's first electrostatic generator, by chains of metal pellets. The charging belts had been a frequent source of problems in many machines; they often would tear, be difficult to replace, tended to absorb moisture when exposed to humid air, and sometimes would not carry the charge properly to the high-voltage terminal. Ray named electrostatic accelerators that used pellet chains "pelletrons." In 1965 Ray together with J. A. Ferry and T. Pauly founded the National Electrostatics Corporation, which was to manufacture pelletron electrostatic accelerators. The company was located in Middleton Wisconsin, a town adjacent to Madison. An important motivation for founding the company was Ray's loyalty to his home state and his desire to provide employment for scientists and engineers in Wisconsin and boost the economy of the area. It was actually a very risky decision. The demand for accelerators for nuclear research had dwindled, and there was no obvious market for pelletrons. Ray's hard work and good judgment made the gamble pay off. In 1972 Ray retired from the University of Wisconsin to devote full time to the National Electrostatics Corporation. He served as president and chairman of the board of the corporation until his death.

Ray's challenge was to persuade a customer to invest a large sum in an accelerator manufactured by a company without a track record. At that point Ray's long-time cooperation with the University of São Paulo came to his rescue. Oscar Sala, who had worked with Ray at Wisconsin and with whom Ray had maintained a close cooperation for many years, placed the first order for a pelletron for nuclear research. Once Ray had demonstrated that his pelletrons worked as promised, the company received orders for large machines from all over the world. The Oak Ridge National Laboratory ordered the largest machine, which was designed for operation at 25 MV and reached a terminal voltage of 32 MV without an accelerating tube.

National Electrostatics had produced by the time of Ray's death 130 pelletrons. The company at the height of its activity had 140 employees; at the time of Ray's death the number of employees was just under 100. Although the early pelletrons were designed to operate at high voltages for nuclear research, the most recently built machines were used for a variety of applications, such as ion implantation, accelerator mass spectroscopy, and as analytical tools.

When Ray returned to Madison at the end of the war, he moved into a house in the country just outside Madison. Before long his house was surrounded by other houses, and he decided to build a house on a hill outside of Madison overlooking the beautiful countryside. After a few years a shopping mall and a large new high school were constructed within his view. This time he decided to build a home on a hill twenty-five miles from Madison, where a large corn field was in front of the house and a densely wooded area was behind the house. Ray enjoyed watching the wildlife from his window, maintaining hiking trails in the woods behind the house, and almost until the end of his life to cut large piles of firewood. The Herbs' home in all three locations was not only the center of his family life, but Anne and Ray maintained effectively an open house for students and staff.

Ray was an ardent canoeist. On many weekends he would set out on camping trips, often on the nearby Wisconsin River. In 1993, when Ray was eighty-five years old, the award of an honorary degree in Sweden became the occasion for a lengthy canoe trip on Swedish lakes and rivers in the company of Anne, his son Steve, and Steve's wife. They had several adventures, including a severe storm, and the rescue of a young girl who had become lost and for whom a search had been started. This event was reported in the local papers.

In 1936 Eugene Wigner was dismissed from his position at Princeton and asked Gregory Breit at Wisconsin for help. According to Wigner's recollections[2] Breit persuaded the University of Wisconsin to offer Wigner a position. Wigner says, "The University of Wisconsin was rapidly becoming a center of nuclear physics research . . . A physicist named Ray Herb was the one who really kept the department together. He was about five years younger than me . . . But Ray was a great enthusiast about physics and life, enormously unselfish and tireless. He seemed to work day and night, and the whole department was infused with his spirit." On the occasion of the award of the Nobel Prize, Wigner paid tribute to the three teachers who had most influenced him[3]. One was Ray Herb. Wigner said, "In leadership, a young man at the time, Ray Herb was my tutor." Wigner's description of Ray remained appropriate for those who joined the University of Wisconsin physics department in later years.

D. A. Bromley[4] described Ray's contributions as follows: "His inventive genius has enabled him, perhaps more than any one other man, to give nuclear scientists everywhere the tools and the techniques which have been essential to major progress in the field."

NOTES

1. G. Breit, H. M. Thaxton, and L. Eisenbud. Analysis of the scattering of protons by protons. *Phys. Rev.* 55(1939):1018.
2. A. Szanton. *The Recollections of Eugene P. Wigner*, p. 176. New York: Plenum Press, 1992.
3. Quoted by D. A. Bromley in *Rev. Bras. Fis.* 2 (1972):14.
4. D. A. Bromley, *Rev. Bras. Fis.* 2(1972):13.

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