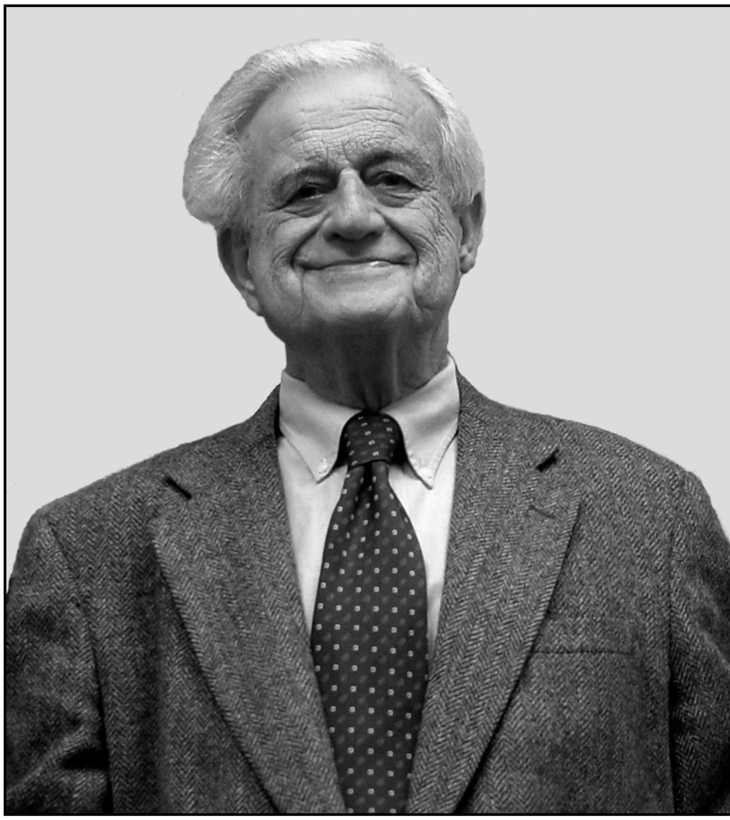
MARSHALL N. ROSENBLUTH



UCSD/LAURA MOORE

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MARSHALL ROSENBLUTH was for forty years one of the leaders of the international community of scientists and engineers trying to develop fusion as a clean and inexhaustible source of energy. In the United States he was the most important fusion theorist. He combined in one person two unusual gifts. He was a master of applied mathematics, with unrivaled ability to analyze the complex patterns of behavior of high-temperature plasmas. He was also an international diplomat, with unrivaled ability to cross barriers of culture and language and build friendships with plasma physicists all over the world. For him, the understanding of plasma physics was not merely an intellectual challenge. The driving force of his life and work was his conviction that the power of hydrogen fusion reactions, the power of the bombs that could destroy cities and civilizations, could also be used in peaceful reactors to bring wealth and prosperity to all mankind.

Rosenbluth was born in Albany in 1927 and was a student of Enrico Fermi at the University of Chicago from 1946 to 1949. As a student at Chicago, he published, together with his student contemporaries C. N. Yang and T. D. Lee, a letter in the *Physical Review* with the title "Interaction of Mesons with Nucleons and Light Particles," presenting evidence for a universal weak interaction operating with equal strength between light and heavy particles. This one-page letter was an important milestone, pointing the way toward the unified theory of weak interactions that was discovered many years later. During his student days, Rosenbluth also published the first fully relativistic calculation of electron-proton scattering. He would certainly have become a leading particle physicist if his attention had not been distracted by plasma physics.

After a year as an instructor at Stanford, Rosenbluth was recruited by Edward Teller to work on the crash program to design a hydrogen bomb at Los Alamos. Unlike Teller, he was a good team player and had the combination of qualities—perseverance, technical skill, and meticulous attention to detail—that the hydrogen bomb program required. He arrived at Los Alamos in time to make major contributions to the design of the first hydrogen bomb, which was exploded in the Mike test of 1952. When Stalin died in the spring of 1953, Rosenbluth decided to leave Los Alamos, but he did not leave immediately. He continued to work on the next generation of bombs, and in 1954 he was present in the South Pacific at the Castle Bravo test, which exploded with a yield of 15 megatons. The Castle Bravo bomb showered Rosenbluth's ship, in addition to the ill-fated Japanese fishing-boat *Fortunate Dragon*, with radioactive fallout. He said later, "There was a huge fireball with these turbulent rolls going in and out. The thing was glowing. It looked to me like a diseased brain up in the sky. It spread until the edge of it looked as if it was almost directly overhead. It was a much more awesome sight than a puny little atomic bomb. It was a pretty sobering and shattering experience." He then decided that he had had enough of bombs and would devote the rest of his life to the development of peaceful fusion.

Before leaving Los Alamos, Rosenbluth worked with his first wife, Arianna, Nick Metropolis, and Edward Teller on new methods for simulating physical processes with the electronic computers that were then coming into operation. They developed the Monte Carlo method, studying the statistical behavior of atoms and molecules by looking at them one at a time, letting the state of each molecule be determined by random throws of dice. The Monte Carlo method was a profound innovation, moving away from the continuous variables and differential equations that had dominated the physical sciences since the time of Newton. Continuous variables were replaced by discrete events, differential equations by simple counting of events with various outcomes. The basic idea and the name of the Monte Carlo method were suggested by Stanislaw Ulam some years earlier, but Rosenbluth, Rosenbluth, Metropolis, and Teller were the first to understand how it could be used to calculate efficiently the behavior of many-particle systems in thermal equilibrium. The method that they developed has been enormously useful and is now a standard tool of numerical analysis in many branches of mathematics, physics, and chemistry.

In 1956 Rosenbluth moved with his friend Frederic de Hoffmann from Los Alamos to General Atomics, a company that was founded by de Hoffmann in San Diego to develop peaceful and commercial applications of atomic energy. At General Atomics, de Hoffmann started an experimental fusion program that was jointly supported by the American and Japanese governments and is still flourishing today almost fifty years later. Rosenbluth was the guiding spirit of the San Diego fusion program from the beginning. He also contributed substantially to the development of commercial fission reactors at General Atomics. In 1958 he returned briefly to the subject of bombs, writing a paper with Ted Taylor, examining the feasibility of a spaceship propelled by a large number of fission bombs. The bomb-propelled spaceship became Project Orion, a project that continued at General Atomics until it was canceled in 1965. Rosenbluth remarked at the time that the bomb-propelled spaceship was the only way he could think of to achieve unilateral nuclear disarmament. He hoped that, if we went ahead with Project Orion, the Soviet Union might follow our example and make the nuclear disarmament bilateral.

I came to General Atomics in 1958 to work on Project Orion with Taylor. My work consisted mainly in repeating at much greater length the initial theoretical analysis that had been done by Rosenbluth. Many times I came to Rosenbluth, asking him a question about Orion and receiving an answer in two minutes. Then it would usually take me a week of hard work to understand in detail why Rosenbluth's answer was right. He had an amazing ability to see through a complicated physical situation and reach the right answer by simple arguments. Enrico Fermi was the only other physicist I have known who was equal to Rosenbluth in his intuitive grasp of physics. Rosenbluth's papers were written in the Fermi style, cutting out inessential details and making the main points easy to understand.

The central theme of Rosenbluth's life and work was plasma instabilities. Plasma instabilities are the main reason why controlled fusion is a hard problem. A hydrogen plasma at high temperature must be confined by a strong magnetic field, but it can find many ways to escape or leak out of the field as a result of various instabilities. Magneto-hydrodynamic instabilities are unstable modes of motion of the plasma as a whole. Microscopic instabilities are unstable modes of motion of ions and electrons within the plasma. Rosenbluth once told me that he had studied 144 different instabilities. Many of them he had discovered himself. All of them must be brought under control before a power-producing fusion reactor can be designed. His passion was the understanding and defeat of instabilities. He always stayed in close touch with the experimenters who were observing various instabilities in experiments that he helped to design. A large part of the experimental effort was devoted to the diagnosis of instabilities. Since the interior of a high-temperature plasma is inaccessible, diagnostic instruments must be carefully designed to observe it from the outside.

During his San Diego years, Rosenbluth not only guided the plasma research at General Atomics, but also taught plasma physics at the nearby campus of the University of California. In 1967 he came to the Institute for Advanced Study in Princeton as a professor and held a concurrent appointment guiding research at the Plasma Physics Laboratory at Princeton University. During his Princeton years, he brought a stream of visitors to the Institute from all over the world. Leaders of fusion programs were frequent visitors: Bruno Coppi from MIT, Lev Artsimovich and Roald Sagdeev from Russia, Brian Taylor from England. Rosenbluth successfully maintained friendly relations with Soviet physicists of all political persuasions, with strong supporters of the Soviet system as well as with dissidents. Artsimovich was one of those who believed in the Soviet way of doing things. He came once to Princeton at a time when students were protesting violently against the university administration. Artsimovich said to Rosenbluth, "Why don't you put them in jail?" Rosenbluth explained that the freedom to protest was one of the things that the American educational system was designed to protect. Artsimovich was not impressed, but continued to come to

Princeton. Rosenbluth himself traveled indefatigably to Garching and Novosibirsk, to Culham and Tsukuba, wherever in the world fusion research was pursued. He was one of the strongest links holding together the worldwide fraternity of plasma physicists.

For thirteen years, Rosenbluth's gang of young plasma physicists interacted strongly and fruitfully with John Bahcall's gang of young astronomers at the Institute for Advanced Study. Since most of the visible matter in the universe is in the form of plasma, plasma physics is an essential tool for understanding how the universe works. It was a sad day for Princeton when Rosenbluth decided to leave in 1980. He could not be replaced. No other plasma physicist of his intellectual stature existed. The plasma physics group at the Institute for Advanced Study disappeared. Rosenbluth went to the University of Texas to direct a new Institute of Fusion Studies there. He built up his new institute with high hopes, but the funding that he needed for it was not sustained, and in 1987 he resigned his position in Texas. We tried to persuade him to come back to Princeton, but he decided to return to his old haunts in San Diego. He became once more a professor at the University of California, San Diego, and supervisor of the fusion program at General Atomics, now under new management and renamed General Atomic. After he retired in 1992, he continued to live in San Diego and to be active in international fusion programs. For many years he was chief U.S. scientist in the ITER (International Thermonuclear Engineering Reactor) project, an international effort to build a prototype fusion reactor to demonstrate the feasibility of fusion power.

Rosenbluth received many national and international awards for his leadership of fusion research, among them the U.S. National Medal of Science in 1998. He died on 28 September 2003, after a long struggle with pancreatic cancer. Even after his doctors told him that he had only three months to live, he fought on bravely and continued to give talks at meetings with his usual good humor for another year. His friends, knowing his indomitable spirit, were almost expecting him to beat the odds.

His second wife, Sara, whom he married in 1980, is a well-known artist. She brought him into contact with a wide circle of artistic friends in San Diego, and helped him immeasurably during his last illness.

Elected 1998

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