



Roger Dashen

1938–1995

BIOGRAPHICAL

Memoirs

*A Biographical Memoir by
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NATIONAL ACADEMY OF SCIENCES

ROGER DASHEN

May 5, 1938—May 25, 1995

Elected to the NAS, 1984

Roger Dashen was a profoundly insightful theoretical physicist who made major contributions to our modern understanding of how the phenomena of particle physics emerge from the mathematics of quantum field theory. He was also deeply interested in applied physics and made innovative contributions to acoustics, wave propagation in random media, and oceanography. His intellectual generosity and broad interest in physics made him an exceptional mentor of young theorists and, later in his career, a wise and effective institution builder. He was, more than anything else, a theoretical physics natural—gifted with an uncanny ability to quickly grasp the essence of complex physical problems and to create, seemingly effortlessly, effective mathematical realizations of his insights.



Roger Dashen
By Curtis G. Callan Jr.

Early life and education

Dashen was born in Grand Junction, Colorado, in 1938. His mother was a schoolteacher, and his father, who had come to the United States from Eastern Europe as a child, was an electrical engineer who helped design dams for the U.S. Bureau of Reclamation. The family lived in various parts of the West during Roger's childhood—including several adventurous years in a remote part of Wyoming at what had been a Japanese relocation camp during World War II—eventually settling in Billings, Montana. Roger was a gifted student who blossomed academically during his high-school years, but he also had many other interests: he was an Eagle Scout who enjoyed exploring the Montana mountains; he played tackle on his school's football team; and he wrestled, winning the title of Montana State Heavyweight Wrestling Champion. Roger would probably have followed in his father's footsteps and become an engineer had it not been for a visit to his school by the then dean of admissions at Harvard University, who was touring the mountain states to increase the geographic diversity of its college's applicant

pool. Roger was intrigued by what he heard, applied to Harvard, was accepted, and went East in the fall of 1956 (as one of the inaugural holders of a National Merit Scholarship).

The details of how Roger discovered physics at Harvard—or how physics discovered him—are lost, but it seems that he was not initially focused on science. He eagerly took (and excelled in) the liberal-arts courses required for a bachelor's degree, and he even played varsity football during his first two years. However it came about, he eventually discovered his true affinity and became a physics major. He spent his summers doing internships at national laboratories (Sandia, Argonne, and the Naval Research Laboratories), experiences that may have laid the foundation for his lifelong interest in “applied” theoretical physics. Roger received his A.B. degree *summa cum laude* in 1960 and was awarded a Sheldon Traveling Scholarship, a distinction given each year to two graduating students with outstanding grades. The Sheldon required him to travel the world for a year, staying in no one place more than a few weeks, which was an experience he eagerly embraced. After this refreshing break, Roger entered the California Institute of Technology in the fall of 1961 to begin the serious business of graduate study in theoretical physics.

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Scientific career

Dashen's trajectory at Caltech was nothing short of extraordinary; he rose in six short years from beginning graduate student to full professor. Theoretical physics was in a state of ferment at the time, with no consensus on what kind of fundamental theory might explain the rich world of phenomena being discovered with the aid of high-energy particle accelerators. Radical new ideas came (and went) quickly, and Caltech was a particular hotbed of innovation under the leadership of Murray Gell-Mann and Richard Feynman. It quickly became clear that Dashen had an unusual talent for the kind of freewheeling theoretical speculation, coupled with incisive analysis, that characterized this period's best work in particle theory, and by the time he defended his Ph.D. thesis in 1964 he was already widely known as a brilliant young theoretical physicist. It was at this time that Dashen met and married Mary Kelleghan, to whom he would stay married until his untimely death (at age 57) and with whom he soon had two daughters, Monica and Melissa. There followed a very happy and productive few years for him at Caltech, first as a postdoc and then as a young faculty member exploring the wonders of the new world of current algebras side-by-side with Gell-Mann.

But in 1966, the “mysterious East” (to use a jocular term coined by Dashen’s thesis advisor Steven Frautschi, referring to stylistic differences between particle theory as practiced on the U.S. East and West Coasts) called again. The Institute for Advanced Study in Princeton, New Jersey, had suffered serious losses in its theoretical physics faculty, and the remaining faculty of the School of Natural Sciences (Freeman Dyson and Tullio Regge) made the bold proposal to remedy the situation by recruiting, almost directly out of graduate school, the two most promising rising stars at the time in theoretical physics. Dashen was one of this stellar pair (the other being Stephen Adler, another future NAS member). Caltech tried to retain Dashen by immediately promoting him to full professor, but the challenge of revitalizing such a storied institution as the Institute for Advanced Study was too intriguing to pass up.

Dashen moved to Princeton in 1966 on a trial basis (on leave from his Caltech professorship) and in 1969 was appointed professor in the School of Natural Sciences, a position he would hold until 1986. His two decades at the Institute were a period of sustained productivity and growing influence in the world of physics: Dashen made many contributions to the foundations of what we now call the Standard Model of particle physics; he discovered a talent for mentoring young theoretical physicists and helped turn the Institute into a mecca for ambitious postdocs; and he also was active in applied physics, making notable contributions to fields seemingly far removed from his primary interest in particle theory.

Dashen’s scientific achievements were honored by a number of distinctions, including election to the National Academy of Sciences in 1984. His advice on scientific and professional matters was widely sought and generously given. He served the U.S. Navy as a high-level advisor on advanced technology, and he was particularly proud of his active role in the establishment of the National Science Foundation (NSF)-funded Institute for Theoretical Physics (ITP) at the University of California, Santa Barbara (he was a founding member of the ITP Advisory Board). In 1986 Dashen left the Institute for Advanced Study to become a faculty member at the University of California, San Diego. He served for five years as chairman of the UCSD Department of Physics, presiding over a period of impressive growth in its quality and impact. He had recently stepped down from that position at the time of his death.

Adventures in particle theory

Dashen's career spanned a remarkable period in the evolution of theoretical physics. At the beginning, in 1964, the foundations of particle theory were uncertain and quantum field theory was regarded by many as a useless anachronism. At the end, in 1995, the central problem had been reduced to that of solving a very specific quantum gauge field theory. Dashen made essential contributions at every step of this evolution.

As a graduate student and young postdoc at Caltech, Dashen was a major player in the struggle to convert the new ideas of $SU(3)$ symmetry and current algebras into a dynamical theory of hadrons. These efforts were inspired by the success of Gell-Mann's $SU(3)$ symmetry, which organized the zoo of new particles into representations of a symmetry group generalizing ordinary $SU(2)$ isospin symmetry, and by the success of a parallel expansion of the concept of symmetry—the extension of $SU(2)$ isospin to chiral $SU(2) \times SU(2)$. The latter included an axial vector partner to the usual vector isospin current, and was an approximate symmetry that would be exact in the limit of zero pion mass (we now say that it would be exact if certain quarks were massless). Neither of these global symmetries was exact in the real world, and Dashen first became famous for papers in which he gave a dynamical explanation of the striking and puzzling fact that the observed breaking of $SU(3)$ is concentrated in one special representation of $SU(3)$ (in agreement with experimental data on particle masses). Dashen and Gell-Mann then collaborated on ingenious attempts to turn the much richer local $SU(2) \times SU(2)$ current algebra into a predictive tool for hadron physics. These grander goals were not ultimately realized, but much of value was learned and the seeds were sown for future developments, including the Kac-Moody algebra approach to solving two-dimensional field theories (something that plays a central role in our modern understanding of string theory).

At the Institute in the late 1960s and early '70s, Dashen returned to using broken chiral symmetry to make quantitative predictions about the masses and interactions of strongly interacting particles. It was not yet known which specific quantum field theory (if any) accounted for this realm of phenomena, and Dashen wanted to see how far one could get using only general features of quantum field theory together with symmetry principles. Just as $SU(2)$ isospin could be extended to an approximate chiral $SU(2) \times SU(2)$, so too the larger $SU(3)$ symmetry could be extended to $SU(3) \times SU(3)$. But this larger symmetry was even more approximate because its explicit breaking was due to the K-meson rather than to the much lighter pion. In a series of insightful and elegant papers, Dashen showed how to make controlled and practical use of broken chiral symmetry to under-

stand many aspects of strong interaction physics, in the process clearing up many misconceptions that were then current in the literature. We now know that $SU(3)$ and $SU(3) \times SU(3)$ symmetries are a somewhat accidental consequence of the fact that three of the quarks (the “up,” the “down,” and the “strange”) have masses that are anomalously small on the scale of strong-interaction energies, but this was only vaguely understood at the time. Despite this situation of conceptual uncertainty, Dashen’s masterful use of general principles allowed him to derive a number of relations between measurable properties of strongly interacting particles and to place chiral Lagrangians—effective field theories that capture all the legitimate consequences of chiral symmetry for arbitrary processes—on a clear and sound footing. These results have stood the test of time and many of them play an important role today in extracting physical results from lattice gauge theory calculations.

In the mid-1970s Dashen, Brosl Hasslacher, and André Neveu developed the quantum theory of solitons using the path integral approach (DHN). They applied semiclassical methods to the Sine-Gordon theory, a field theory in one space dimension that was known to have classical collective excitations called solitons. In a bravura performance, they were able to determine the soliton mass and its excitation spectrum as explicit functions of the theory’s coupling constant. Although DHN worked in the semiclassical WKB approximation, they conjectured that many of their results (in particular, the binding energy of the breather mode) should be exact, a conjecture later verified by Sidney Coleman. The DHN papers are the standard reference for path-integral quantization of solitons; they are landmarks in that they represent the first time that nonperturbative physics was reliably extracted from a quantum field theory. They show in detail how it can come about that the observable physical particles in a quantum field theory are completely different from the particles represented by the fundamental fields themselves: with strong enough interactions, the nature of the particle spectrum can be completely remodeled. This phenomenon turned out to be an essential ingredient of our understanding of the Standard Model, where the fundamental quarks are confined, and only dynamical composites of multiple quarks (such as the nucleon and pion) can exist as observable particles.

The DHN demonstration of the power of semiclassical methods in two-dimensional quantum field theories raised the question of whether they might also yield important insights into the behavior of the fourdimensional gauge quantum field theories that, by the mid-1970s, were generally believed to underlie both the strong and the weak interactions. The question was soon resoundingly answered in the affirmative with Polyakov’s

discovery of instantons in quantum chromodynamics (QCD) and with 't Hooft's realization that these objects solved the “axial $U(1)$ problem” (the apparent existence of one too many spontaneously broken global symmetries in the Standard Model of strong interactions as a gauge theory of quarks and gluons). Dashen and collaborators Curtis Callan and David Gross and, independently, Roman Jackiw and Claudio Rebbi further discovered that the instantons implied the existence of an infinity of unsuspected vacuum states of QCD and an also-unsuspected new coupling constant, the θ -angle, on which all physical quantities depend in a nonperturbative way. Understanding how real-world QCD chooses a value for θ is a fundamental problem not fully resolved to this day.

In the early 1980s Dashen turned his attention to the lattice approach to solving gauge theories. Shortly after the earlier work of Giorgio Parisi and collaborators, Dashen and Herbert Neuberger realized that the conjectured triviality of $\lambda\phi^4$ theories, applied to the Higgs field of electroweak theory and combined with the use of the lattice as a short-distance cutoff, could be used to establish a theoretical upper bound on the Higgs mass! Simple estimates based on this innovative line of reasoning put the upper limit in the vicinity of 1 TeV. Comprehensive lattice investigations by Julius Kuti, Lee Lin, and Yue Shen, and by others, verified the triviality scenario and put the upper bound on the Higgs mass in the Glashow-Salam-Weinberg model at about 700 GeV. This result is one of the reasons why the particle physics community was convinced that TeV-scale accelerators should be built: they would either find the Higgs or reveal qualitatively new realms of physics. As this memoir is being written, the Large Hadron Collider, the discovery machine that Dashen's work suggested would be worth building, has just announced the discovery of the Higgs at a mass of about 125 GeV, well within Dashen's limit (perhaps disappointingly so for those who hope that “beyond Standard Model” physics is within reach of current accelerators).

At the time of his death, Dashen was working with UCSD colleagues Elizabeth Jenkins and Aneesh Manohar on applying the $1/N_c$ expansion of QCD to understanding the static properties of hadrons, thereby returning to a problem that had intrigued him since his student days (N_c is the number of colors in the $SU(N_c)$ strong-interaction gauge theory, with $N_c=3$ in the real world). With his collaborators, Dashen showed that there exists a spin-flavor symmetry for baryons that is exact in the $N_c \rightarrow \infty$ limit and he worked out the $1/N_c$ corrections. A remarkable result was that the $1/N_c$ corrections vanished for certain quantities, such as the pion-nucleon couplings. In such cases, the large- N_c predictions agree with the experimental measurements to 10 percent accuracy.

Looking back, one can see that Dashen's work in particle physics, the core of his scientific legacy, had a consistent theme: finding, and then learning how to master, the dynamical theory that underlies the strong interactions. More than anything else, he wanted to understand how the rich phenomena of a strongly interacting quantum system can arise from simple underlying dynamics. At the beginning of his career, as noted earlier there was no agreement on even the most general outlines of what theory might describe the strong interactions; at the end, 30 years later, it was universally agreed that the strong interactions were a very specific (and simple) gauge quantum field theory of quarks and leptons. This remarkable development was the work of many people, but Dashen's influence and contributions are evident in each of the steps that led from confusion to certainty.

In parallel with his career in particle physics, Dashen had a second scientific career in applied theoretical physics. He was an early member of "Jason," a group of physical scientists convened by the Department of Defense to work, in a unique quasicademic style, on scientific problems related to national defense.

Applied physics and national security

In parallel with his career in particle physics, Dashen had a second scientific career in applied theoretical physics. He was an early member of "Jason," a group of physical scientists convened by the Department of Defense to work, in a unique quasicademic style, on scientific problems related to national defense. The group had staying power—it recently celebrated its 50th anniversary—and eventually settled into a routine of gathering for two months every summer in La Jolla, California. Dashen participated actively in Jason throughout his career, and he was attracted early on to the problems of detecting (and hiding from detection) submarines as they moved under the water—a scientific endeavor that brought hydrodynamics, sound propagation, and physical oceanography together in a fascinating interdisciplinary challenge.

The propagation of sound in the ocean is complicated because sound speed varies with position and depth (as a result of internal waves) and also because sound waves reflect off the ocean surface, which moves in a random fashion driven by wind-generated waves. In a Jason contribution with major implications, Dashen showed how to use semiclassical methods borrowed from quantum field theory to estimate the rate at which a sound wave propagating through a realistic fluctuating ocean would lose coherence as a wave front; he thereby addressed the question of the distance at which an underwater noise source

could be detected using a sound “telescope.” This result led in 1979 to a major monograph (*Sound transmission through a fluctuating ocean*) and to several collaborations with physical oceanographers on purely scientific problems. The most notable of these efforts was his work with Walter Munk (of the Scripps Institution of Oceanography) on using round-the-world propagation of low-frequency sound to monitor the mean temperature of the ocean, with the goal of detecting variations associated with climate change.

Dashen’s ability to reduce complex problems to their essentials, and to find physically transparent back-of-the-envelope solutions to them, earned him a reputation throughout the U.S. Navy’s submarine-security community as the person to go to for insight, both on specific technical problems and on larger technology-strategy issues. As time went on, he played an increasingly important role (as scientific consultant and as a member of advisory boards) in the Navy’s effort to enhance the security and reliability of the submarine deterrent force through the intelligent application of acoustics, hydrodynamics, and oceanography.

Dashen kept in close touch with several other communities of applied physicists and encouraged his students to broaden their knowledge and enjoyment of theoretical physics by doing likewise. His career was a perfect example of how the skills and attitudes of theoretical physics can be “relevant” to other areas of science and technology, and to society as a whole. In an age of specialization, Dashen was remarkable for the range of scientific problems and societal issues on which he left an imprint.

Scientific institution building

Dashen was a natural scientific leader with a gift for creating around himself an environment in which others, especially young scientists, could flourish. More than anything else, this aura was an effect of Dashen’s basic scientific personality: he was unpretentious, free of ego or intellectual snobbery; completely approachable; and ready to talk to anybody at any time about any scientific question. Although he was not an administrator by nature or temperament (something of an understatement, as those who knew him will recognize), he played an important role in enhancing the climate for research in several institutions over the course of his career.

At the Institute for Advanced Study (IAS), the institution with which he had the longest association, Dashen advanced the notion that the IAS should be a place where senior scientists would serve as mentors to a sizable number of freshly minted Ph.D. theorists. This sort of training activity was not at the time seen as a natural mission for the IAS,

but it was a natural extension of Dashen's way of doing science: his door was always open; and he typically had collaborations on a remarkable variety of topics going on with multiple postdocs (and the occasional lucky graduate student from neighboring Princeton University) at any given time. Under Dashen's guidance, this mentoring activity was so successful that it eventually came to be seen as one of the Institute's core activities, which it remains to this day. In recognition of this history, after his death the Institute established a Dashen Membership, given yearly to the postdoc who best exemplifies Dashen's ability to stimulate outstanding work in others.

As time went on, admiration for what Dashen had done at the IAS led to his involvement in efforts to enhance the climate for research at other institutions. He was particularly proud of his contributions to the NSF Institute for Theoretical Physics at UC Santa Barbara: he served as a member of the founding Advisory Board from the start of the proposal process, and he invested time and effort in helping the local proponents craft their ultimately successful proposal for what proved to be an institution of central importance to U.S. theoretical physics.

As an indirect outcome of his national security work on applied problems, Dashen had an opportunity to advance the role of physical science (and physical scientists) in the petroleum industry. Starting in the late 1970s, Dashen worked with director Michel Gouilloud of the Schlumberger-Doll Research Center to attract first-rate physicists to that lab, with the goal of bringing the attitudes and methods of theoretical physics to bear on problems of importance to the oil industry. The vibrant group of young particle and condensed-matter theorists he helped recruit and advise eventually made significant advances on a wide range of important practical problems—such as the dependence of rock conductivity on the degree of saturation, the viscous fingering instability for multi-phase flow through porous materials, and the use of nuclear-magnetic-resonance measurements to infer transport properties. When financial exigencies eventually led Schlumberger to shut this activity down, the young participants carried their broadened view of what constitutes good physics with them to a variety of U.S. university physics departments.

Finally, when Dashen moved to UC San Diego, it did not take long for his new departmental colleagues to realize that he was the right person to help them make difficult choices about what fields to foster as well as to help them identify the right young people to recruit for advancing these strategic plans. His scientific prestige, his ability to quickly get to the bottom of any scientific subject, and his transparent lack of any agenda beyond excellence and scientific progress, made him the ideal person to lead in a time of change.

The UCSD Department of Physics wisely put these qualities to work by making him chair soon after his arrival. Dashen exercised that office with care and vision, and by all accounts he left the department much stronger and sounder than when he joined it.

Summing up

Roger Dashen—who died of a heart attack on May 25, 1995 in La Jolla, California, at the regrettably young age of 57—was a brilliant scientist, a valued colleague, and a concerned citizen. He was a rare individual, combining intellectual vision and breadth with personal warmth and accessibility. His great joy in doing theoretical physics was infectious, and he gave generously of his time and inspiration to several generations of younger collaborators. He was one of the most gifted theoretical physicists of his era, and those who had the privilege of doing science with him remember his intellectual skills with awe and his personal qualities with affection.

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