BIOGRAPHICAL MEMOIRS

Marvin L. Goldberger

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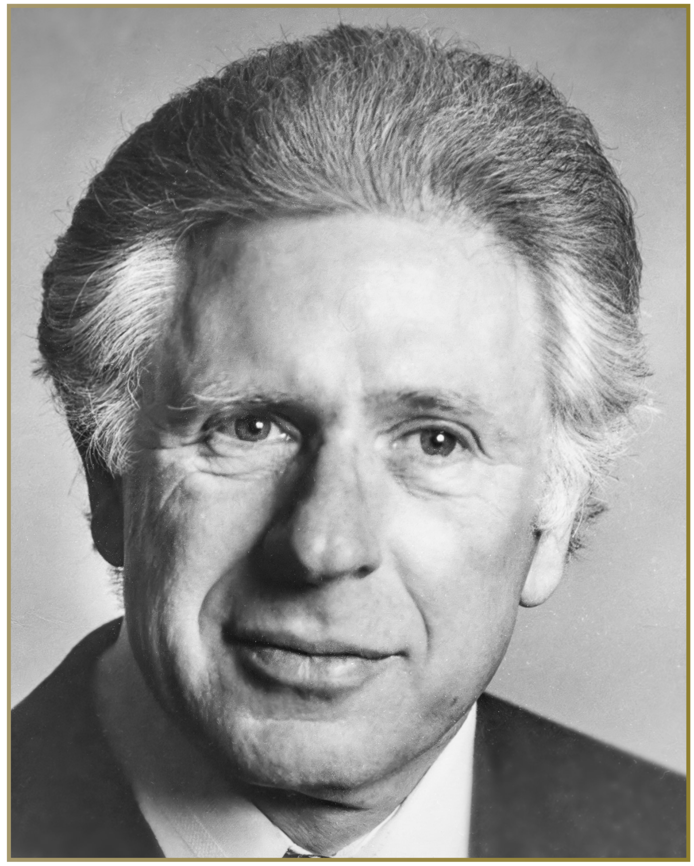
A Biographical Memoir by Barry Barish, Curtis Callan, and John Schwarz

Marvin L. Goldberger was a leading figure in theoretical particle physics during the second half of the twentieth century. After working on the Manhattan Project during World War II, he studied theoretical physics at Chicago under Enrico Fermi and received his PhD in 1948. In the two decades that followed, he played a major role in developing theories to encompass the new particles and interactions then being discovered at high energy accelerators. His research, especially the development of dispersion relations and the Goldberger-Treiman relation, helped lay the groundwork for the establishment in the 1970s of the Standard Model of particle physics. In addition to his research in theoretical physics, from the late 1950s onward he was deeply involved in providing scientific advice to the U.S. government, both through the creation and initial leadership of the JASON group and through service on the President's Science Advisory Committee (under Pres. Lyndon Johnson). In addition to his contributions as a research scientist, Goldberger was a leader in academic administration, serving first as chair of the Princeton University physics department, then as president of the California Institute of Technology for a decade, and then as director of the Institute for Advanced Study. In all these roles. he was valued for his youthful enthusiasm, his vivid sense of humor, and his ability to capture the essence of a situation in a wisecrack, or striking one-liner. He was a man of many dimensions.


Marvin Goldberger's official portrait as chair of the physics department at Princeton University.

Early Life and Education

Marvin "Murph" Goldberger was born in Chicago, Illinois, on October 22, 1922. His father was a real estate broker. His mother nicknamed him Molsh, but his childhood friends morphed this into Murph.[1,2] This is the name by which he was known by all, irrespective of status.

Murph attended high school in Youngstown, Ohio, where he had a very good physics teacher and was (in his own words) "moderately prodigious." In 1940, he enrolled in the Carnegie Institute of Technology (now Carnegie Mellon University), where he studied chemical engineering and physics. After receiving his bachelor's degree in 1943, Murph was drafted into the U.S. Army. Frederick Seitz, who was chair of the physics department at Carnegie, saw to it that he was assigned to the Manhattan Project's Special Engineering Detachment in Chicago. From 1943 to 1945, as a staff member of the University of Chicago's Metallurgical Laboratory, he worked on the design of nuclear reactors and the physics of neutron interactions with solids. Much of this work was done together with a young mathematician named Mildred Ginsburg. In an interview for the *Los Angeles Times,* Mildred recalled that when the Manhattan Project was going to move to Los Alamos, a senior member said to Murph and Mildred, "I'm not going to take you two with us if you don't get married." In the end, the couple stayed in Chicago and were married in 1945. Their marriage would last until Mildred's death in 2006. The couple were inveterate and inventive party givers who enriched the social life of the physics community in the institutions they moved through in the course of Murph's career.

Murph entered graduate school at the University of Chicago in March 1946 and began his studies first with Edward Teller and then with Enrico Fermi. Initially, Teller supervised the theory students and Fermi supervised the experimental students. Murph and his good friend Geoffrey Chew switched to Fermi after Fermi told Teller, "During the war I've sort of fallen behind in theoretical physics. Maybe I ought to take a couple of students and catch up that way."[3] Teller agreed to this switch because he felt that he was too involved in defense work to supervise them properly. The dissertation topic that Fermi suggested to Murph concerned the interactions of high-energy neutrons with heavy nuclei. Murph applied Monte Carlo techniques to follow the trajectories of neutrons through the nucleus. This was a continuation of some of the work that he had done for the Manhattan Project, and so he was able to complete his dissertation very quickly, receiving his Ph.D. in 1948. Other famous Fermi students with whom he overlapped included Chen Ning Yang, Harold Agnew, Owen Chamberlain, Richard Garwin, Jack Steinberger, and Tsung-Dao Lee.

Academic Career

After graduating from Chicago, Murph held postdoctoral positions in physics at the University of California, Berkeley and the Massachusetts Institute of Technology (MIT) before returning to Chicago in 1950 as an assistant professor of physics. He rapidly established himself as a rising star of the new field of theoretical particle physics and was soon promoted to full professor. In 1957, he accepted an endowed chair at Princeton University, where, with his scientific prestige and keen judgment of scientific promise, he soon created one of the leading centers of research and graduate education in particle theory. He would ultimately spend twenty-one years at Princeton, six of them as chair of the physics department. Murph's success in institution-building owed much to a uniquely personal style characterized by breezy informality and irreverent humor. This style, in sharp contrast to traditional Ivy League stuffiness and conventionality, had much to do with Murph's ability to attract a stellar crowd of young physicists to Princeton in those years. A representative sample of his unique "voice" can be found in the transcript of his interview with Martin Sherwin for "Voices of the Manhattan Project."[4]

In 1978, Murph embarked on a distinguished second career in academic administration, becoming president of the California Institute of Technology (Caltech), a position he held for nine years. Following this, he was the director of the Institute for Advanced Study (IAS) in Princeton for four years. In the 1990s, he taught physics at the University of California, Los Angeles for two years and the University of California, San Diego for six years. He also served there as dean of the Division of Natural Sciences.

Research in Particle Theory

Murph made his most important contributions to theoretical physics in the 1950s and 1960s. The goal of Murph and other particle theorists in this era was to construct theories that could account for the new particles and forces that were being discovered at high energy accelerators, while incorporating special relativity and quantum theory in a mathematically consistent way. Two main theoretical approaches were being pursued. One was the construction of theories having a Lagrangian formulation based on quantum fields, one field for each "elementary" particle. The other approach, called S-matrix theory[5], was an attempt to come to grips directly with the strong nuclear force and the many particles that experience this force in a non-quantum field theory way: rather than assigning another fundamental field to each new hadron (and introducing an ever-expanding list of interactions between these fields) S-matrix theory attempted to make quantitative predictions based on general dynamical principles, most notably analyticity (a manifestation of causality) and unitarity (conservation of probability). Murph was a major contributor to both approaches.

A very successful relativistic quantum field theory describing the electromagnetic interactions of electrons and photons, called quantum electrodynamics (QED), had been constructed in the late 1940s. By the 1950s, however, many new particles were being discovered, and their interactions with both the strong nuclear force and the weak interactions (manifested in radioactive decays) needed to be systematized and accounted for. The struggle to comprehend this complexity led to doubts about the utility of quantum field theory, skepticism that was eventually overcome by a burst of developments in the late 1960s and early 1970s. By the mid-1970s, physicists had constructed a highly successful quantum field theory of elementary particles incorporating the electromagnetic, weak, and strong forces, known as the Standard Model (SM). As of this writing (in 2023), the SM remains consistent with all experimental tests, including those at the very highest energies at the large hadron collider (LHC) at the European Center for Nuclear Research (CERN). As will be detailed below, Murph Goldberger's important contributions to theoretical physics helped set the stage for the discovery of the SM.

Despite its amazing success, the SM is expected to break down at sufficiently high energy, though it is unclear exactly what that energy is. One reason for this belief is that the SM does not contain a particle that is a plausible candidate for dark matter. Another is that it does not incorporate gravity.[6] Finding evidence for the breakdown of the SM is the biggest challenge of experimental particle physics in the twenty-first century.

Let us now return to the twentieth century and summarize Murph's contributions. In his graduate student years, and his first few postdoctoral years, Murph worked on topics in nuclear physics. This work, initially directed by Fermi, was a natural outgrowth of his work during the Manhattan Project, which was mentioned in the previous section.

Murph's first significant contribution to particle physics (rather than nuclear physics) was carried out in collaboration with Murray Gell-Mann and concerned particle reactions in which a low-energy photon is scattered by an arbitrary target.[7] Others had shown previously that the leading-order result is determined uniquely by the mass and charge of the target particle. Gell-Mann and Goldberger found an explicit formula for the next order of approximation in terms of the mass, charge, and magnetic moment of the target particle. (The same result was obtained independently by Francis Low.) This paper also introduced the notion of crossing symmetry, which relates incoming particles to outgoing antiparticles in a scattering process.

As mentioned above, the S matrix approach to particle physics is based on exploiting the analyticity and unitarity properties of scattering amplitudes. Analyticity is a consequence of the physical requirement that cause should precede effect (i.e., causality); unitarity is the mathematical implementation of the requirement that the sum of the probabilities of all possible outcomes in a scattering process should be unity. Many years earlier, Hans Kramers and Ralph Kronig had used these ideas in the context of the scattering of light through a medium to derive a "dispersion relation" that expresses the real part of the index of refraction in terms of an integral over its imaginary part (which is responsible for dissipation or loss). A major theoretical movement of the 1950s, and one of which Murph was a leader, was the attempt to adapt these old ideas to come to grips with the expanding zoo of strongly interacting particles. In 1954, Gell-Mann, Goldberger, and Walter Thirring (GGT) applied these ideas to scattering amplitudes for particles in the vacuum, showing how to formulate mathematically correct dispersion relations that constrain scattering amplitudes of strongly interacting particles.[8] The name "dispersion relation" was retained even though it is less appropriate in the particle physics setting. The original discussion of GGT was based on perturbation theory, in which one considers power series expansions in a coupling constant, but Murph quickly showed that the result is valid non-perturbatively, as well.[9] These results were then extended by Goldberger to arbitrary boson fields and (together with Hironari Miyazawa and Reinhard Oehme) to the physically important example of pion-nucleon scattering.[10,11]

In 1957, Murph wrote a pair of influential papers together with Geoffrey Chew, Francis Low, and Yoichiro Nambu.[12,13] The first one applied dispersion relations to low-energy meson-nucleon scattering and the second one applied them to reactions in which a photon strikes a nucleon and produces a final state with a meson and a nucleon (photomeson production). In each case, they demonstrated that it is a useful approximation to suppose that the dispersion integral is dominated by a particularly prominent resonance, described by a pole in the complex energy plane. The resonance in question was known at the time as the (3, 3) resonance. The 3s refer to the angular momentum and isotopic spin of the resonance, both of which are 3/2. Later, the (3, 3) resonance was renamed the Δ resonance. Murph and his collaborators found good agreement with all available theoretical and experimental results.

Murph's research achievement with the greatest long-term impact is certainly the Goldberger-Treiman (GT) relation, obtained in 1958 with his Princeton colleague Sam Treiman.[14,15] The GT relation is succinctly stated as $G_{\pi N} = m_N g_A/f_\pi$, where $G_{\pi N}$ is the pion-nucleon coupling constant[16] (a measure of the strong force between nucleons), m_N is the nucleon mass, f_π is the pion decay constant (governing the rate at which the pion decays by $\pi^+ \longrightarrow \mu^+ + \nu_\mu$, a weak process), and the axial vector coupling g_A governs some features of neutron beta decay (also a weak process). Their derivation of the GT relation required approximations, each of which is good at the few percent level, and the observed values satisfied the GT relation at about that level. The GT relation attracted enormous attention because of the surprising way it tied together the weak and strong interactions. Efforts to better understand the implications of this relation led to a series of theoretical developments in the 1960s that were critical precursors to the establishment of the SM. These included partial conservation of the axial current, spontaneous breaking of chiral symmetry, current algebra and the quark model, and eventually anomalies in current conservation laws. Unfortunately, we do not have space here to trace these downstream consequences of the GT relation in any detail; suffice it to say that it provided a foundation upon which the SM was eventually built.

In 1964, Murph and Kenneth Watson published the monograph *Collision Theory,* an epic work of more than 900 pages that gives an impressive account of a large portion of what had been achieved in the previous twenty years in theoretical particle physics.[17] It presents scattering theory in a form that is applicable to observations and describes some of the most important techniques. To give an idea of the scope of this work, we list a few of the eleven chapter headings: the description of scattering processes; the two-body problem with central forces; introduction to dispersion theory; and scattering by systems of bound particles.

In addition to the topics we have discussed, Murph also did research, together with Gell-Mann and others, on applying Regge pole theory to relativistic particle physics.[18] Regge poles are singularities of scattering amplitudes in the complex angular momentum plane and represent an important generalization of the role of analyticity in the study of scattering amplitudes. They had been introduced by Tullio Regge in the context of non-relativistic quantum mechanics and soon became an important theme in S matrix theory. The combination of dispersion relations and Regge pole theory eventually led to the discovery of string theory around 1970. A second topic that was studied by Murph with Gell-Mann and others at this time was the problem of divergences in the theory of the weak interactions. In their 1969 publication, Murph and his collaborators gave a masterful statement of the problem, the importance to particle theory of finding a solution, and a survey of possible routes to a solution.[19] The eventual solution of the divergence problem, found by Steven Weinberg and Abdus Salam and by Gerard 't Hooft and Martinus Veltman was central to the establishment of the SM. These two examples demonstrate that Murph was a master of identifying problems whose solutions would lead to revolutions!

In summary, Murph had a distinguished and influential career in research in theoretical particle physics. In retrospect, it seems to us that with his insight and talent, he might have done even more had he not devoted a substantial fraction of his time to government service during his period of most intense scientific activity, the 1950s through the 1960s. This service, which will be discussed in the next section, was motivated by Murph's strong sense of patriotic duty and his belief that science had important contributions to make to national security.

Government Service

Murph's work on science in the defense of his country began with his military service in World War II. As mentioned earlier, his training in physics led him to be assigned (from 1943 to 1945) to the theoretical physics division of the Chicago Metallurgical Laboratory of the Manhattan Project. The Met Lab's mission was to establish the basic physics of nuclear reactors and then to design reactors for producing Pu-239 in quantities sufficient for making bombs. Future Nobel Prize winner Eugene Wigner led the team of scientists responsible for designing the Hanford production reactor, and Murph worked with that team during his time at the Met Lab (apparently studying the statistics of neutron diffusion in solids). Although working so closely with Wigner must have been a formative experience for a young theoretical physicist, we were, to our surprise, unable to find any reminiscences about Murph's Manhattan Project experience, and thus the details of this period in his scientific life remain obscure.

In the late 1950s, with the marriage of nuclear weapons with ballistic missiles bringing new aspects of physics into the national security arena, senior physicists who had had leading roles in the Manhattan Project became concerned that no mechanism existed for bringing the younger generation of physicists into contact with these important problems. Murph's Princeton colleagues Eugene Wigner and John Wheeler were among this group, and discussions that probably involved Murph led to the proposal to form a group of twenty or so outstanding younger physicists who would receive security clearances, be briefed in detail on classified technical issues, and then gather for an extended summer study to develop (hopefully) innovative solutions to these problems for presentation to the government sponsors who had briefed them. The trial version was a success and led to the formation of the JASON group of consultants to the Institute for Defense Analyses. The name was proposed by Mildred Goldberger, who saw an analogy with the Greek myth of Jason and the Argonauts: "Bright young men going out to save the world," as she said in a 2002 interview. Murph served as chair from 1960 to 1966 and remained an active member of JASON for several decades. The structure that Murph founded had remarkable staying power, remaining relevant to national needs and attractive to the largely academic scientists comprising its membership through many dramatic changes in geopolitics, technology, and U.S. politics.

During the period of Murph's chairmanship, JASON helped (quotes in the rest of this section are Murph's words in various interviews) to "shoot down a number of very ineffective and technically premature concepts on ballistic missile defense." A JASON idea that did come to fruition was an "extremely low radio frequency system for communicating with submarines." Murph's classified JASON work stimulated an unclassified paper (with Hal Lewis and Ken Watson) of general scientific interest.[20] The subject was "the notion of using a technique known as the Hanbury-Brown-Twiss effect of intensity correlation to measure the size of reentry vehicles—the warheads of ballistic missiles." This motivated a later paper "that showed how you could in principle solve the phase problem of X-ray diffraction by using the Hanbury-Brown-Twiss technique." Many years later, secret JASON work that had figured out how to remove atmospheric distortions from spy satellite observations was declassified and became the basis of the adaptive optics that is now used with great success to sharpen images in astronomical telescopes.

The JASON group became a subject of controversy when publication of portions of the "Pentagon Papers" (a highly classified history of the Vietnam war) by the *New York Times,* beginning in 1971, revealed a JASON proposal to create a system of land mines and microphones (an "electronic battlefield") in Vietnam. In fact, there were only about six or seven people from the true JASON group involved in it and they were, as Murph noted, "some of the real old warriors ... it was not a true JASON activity." After this a few members resigned, but most stayed on in JASON. According to Murph "most of them feel that they have done something for the country, with the possible exception of this Vietnam era." In another interview, Murph said that he had "become extremely disillusioned about the whole Vietnam operation." Displaying remarkable candor, he also said, "I'm ashamed of how long it took me to recognize this."[21]

In addition to JASON, Murph was called to serve on other groups of national security importance. The President's Science Advisory Committee (PSAC) was founded under Pres. Dwight D. Eisenhower to bring broad high-level scientific advice to the executive branch of the U.S. government. Murph joined PSAC's Strategic Military Panel in 1959, a panel that was primarily concerned with giving PSAC advice on ballistic missile defense. Murph became the chairman and a full member of PSAC itself in 1965 (serving until 1969). During Murph's tenure, PSAC was influential in creating the Office of the Director of Defense Research and Engineering in the Department of Defense, as well as the Arms Control and Disarmament Agency. PSAC also "did studies of the environment, of the oceans, of energy, health problems, all kinds of things that had nothing to do with defense." His engagement with the problem of ballistic missile defense was the context for another of Murph's signature wisecracks: summoned to testify to a Senate committee about the proposed Safeguard missile defense system, he expressed his opposition to the plan by saying, in public session, that "Safeguard is spherically senseless. It makes no sense no matter how you look at it."

His experiences as an advisor on defense technology gave Murph an intense interest in arms control and arms negotiations with nuclear peer nations, an interest he exercised in several ways as a private citizen. In his capacity as a member of the National Academy of Sciences, Murph served on the Academy's Committee on International Security and Arms Control both as chair (1980–86) and member (1987–93). He was a member of the United States-People's Republic of China Joint Commission on Scientific and Technological Cooperation, a connection that led him to be a member of the first Western scientific delegation to visit China after it opened to the outside world (a distinction of which he was extremely proud). He also served a term as chairman of the Federation of American Scientists, the leading scientific organization advocating for steps to reduce the risks of nuclear war.

We finish this section by recounting a forgotten incident that illustrates Murph's concern for science in society as well as his penchant for grand (and brash) gestures (we are grateful to John Hopfield for refreshing our memory). In 1973, Andrei Sakharov's outspoken advocacy of nuclear arms control had been muzzled by house arrest in the Soviet Union, and Murph felt that western scientists should somehow show strong support for him. As chair of the Princeton Department of Physics, his simple solution was to get his faculty to offer Sakharov a professorship of physics. This was duly done without asking the Princeton administration whether the department had such a position to offer. The administration, faced with a *fait accompli*, transmuted this into an offer of a one-year visiting professorship, which was communicated to Sakharov and, of course, the press. Sakharov accepted the offer and applied for an exit visa, which was never granted under conditions acceptable to him. Though in the end nothing came of this initiative, it was noted in the press and in the Soviet Union and achieved Murph's purpose of visibly demonstrating support for Sakharov. And it was a classic example of Murph's taste for the grand gesture and brash unconcern for bureaucratic niceties.

High Academic Administration

After a successful stint as the chairman of Princeton's Department of Physics, Murph was ready for bigger things: whereas most academic scientists only agree to manage their home department "under protest" and happily go back to their lab after doing their duty, Murph had clearly enjoyed the moving and shaking that go along with the job and began to think about the possibility of playing on a larger institutional stage. Fortuitously, at precisely this moment, the California Institute of Technology (Caltech) was looking for a new president (as previous president Harold Brown had been appointed Secretary of Defense by Pres. Jimmy Carter). Murph threw his hat into this ring and was in due course selected as Caltech's fifth president (and professor of theoretical physics) in 1978. Thus began another facet of Murph's professional life: that of leader of major academic scientific institutions.

During Murph's presidency, Caltech's endowment doubled, teaching standards were revised, the curriculum was restructured, and undergraduate houses were renovated. Although Caltech necessarily focuses on science and engineering, Murph encouraged a strengthening of its offerings in the humanities and social sciences. In addition to his "serious" contributions to Caltech as an educational institution, Murph also brought a sense of fun to the office of president with carefully chosen hijinks, such as riding an elephant through campus at the beginning of his tenure to launch a celebration of Albert Einstein's 100th birthday.

A fundraising highlight during Murph's presidency was a $70 million grant in 1985 from the W. M. Keck Foundation for the Keck Observatory, built on Mauna Kea in Hawaii. The observatory includes two 10-meter telescopes, which were the largest in the world for many years. Another fundraising success during that period was a $40 million gift from the Arnold and Mabel Beckman Foundation in 1987 to establish the Beckman Institute. According to its charter, "The mission of the Beckman Institute is to invent methods, instrumentation, and materials for fundamental research in the chemical and biological sciences, and to provide technological support for these efforts."

Perhaps the most consequential scientific initiative undertaken by Caltech in the Goldberger years was the launch of the LIGO project to detect gravitational waves from astrophysical sources. Before national funding for this ambitious project was available, Murph used his authority as president to commit roughly $1 million in Caltech resources to build a 40-meter prototype interferometer. This testbed played a major role in the initial demonstration of the technical feasibility of the suspended-mass interferometer concept and, over the years, in the development of further innovations critical to LIGO's success. In 1979, the National Science Foundation approved funding at Caltech and MIT for research and development of laser interferometric gravity wave detector technology, and over the next decade this evolved into national support for a gravitational-wave observatory. It took three decades to master the needed technologies, and Murph sadly passed away one year before the observatory that he had helped bring into being observed the first black-hole merger, opening a totally new way of viewing the Universe.

Murph stepped down from the Caltech presidency in 1987 after a decade of service. He then returned to Princeton, having been appointed as the sixth director of the IAS. During his tenure, the IAS continued its growth into a major research institution, and the campus expanded with the addition of a building for the School of Mathematics (Simonyi Hall) and a large lecture hall (Wolfensohn Hall). After four years at the IAS, Murph returned to California, serving as dean of the Division of Natural Sciences at the University of California, San Diego, until his retirement to private life in La Jolla in 1999. He died on November 26, 2014. His wife of sixty years, Mildred Goldberger, passed away in 2006, predeceasing Murph by eight years. They are survived by two sons, Joel and Sam, and three grandchildren.

Murph earned many awards and accolades throughout his life. He received the Dannie Heineman Prize for Mathematical Physics from the American Physical Society in 1961, and the citation reads, "For his utilization and extension of dispersion relations in the physics of strongly interacting elementary particles." He was awarded honorary degrees from Carnegie Mellon University, the University of Notre Dame, Hebrew Union College, the University of Judaism, and Occidental College. Also, he was elected to the National Academy of Sciences (1963), the American Philosophical Society (1980), and the American Academy of Arts and Sciences (1965).

Summing Up

Murph was an important contributor to the theoretical particle physics of the post-WWII era. In addition to his scientific activity, he embraced the opportunities for interaction with government and public policy that became available to physicists in the second half of the twentieth century. As a result, his influence on U.S. science went beyond the papers that he wrote for scientific journals and the Ph.D. students that he taught. Those of us who knew him well remember an engaged scientist, a warm and generous friend, a man who deeply enjoyed life and was always fun to be with.

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Nevertheless, its existence implies that it must be possible to incorporate it. Nowadays many theorists are trying to do this, mostly using string theory, the discovery of which grew out of the S-matrix approach.

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