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JULIAN SCHWINGER
1918—1994

A Biographical Memoir by

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Photograph courtesy of Clarice Schwinger.

Julian Schwinger

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February 12, 1918–July 16, 1994

BY PAUL C. MARTIN AND SHELDON L. GLASHOW

JULIAN SCHWINGER, WHO DIED ON July 16, 1994, at the age of 76, was a phenomenal theoretical physicist. Gentle but steadfastly independent, quiet but dramatically eloquent, self-taught and self-propelled, brilliant and prolific, Schwinger remained active and productive until his death. His ideas, discoveries, and techniques pervade all areas of physics.

Schwinger burst upon the scene meteorically in the late 1930s, and by the mid-20th century his reputation among physicists matched those of earlier giants. To a public vaguely conscious of relativity and quantum uncertainty but keenly aware of nuclear energy, the New York Times reported in 1948 that theorists regarded him as the heir apparent to Einstein's mantle and his work on the interaction of energy and matter as the most important development in the last 20 years. With the development of powerful new theoretical methods for describing physical problems, his influence grew. In the early 1950s the *Journal of Jocular Physics*, a publication of the Bohr Institute for Theoretical Physics in Copenhagen, included a template for articles by aspiring theorists. It began "According to Julian Schwinger" and invoked "the Green's function expression for …". References to unpublished Schwinger lecture notes and some classic Schwinger papers followed. The recipe elicited smiles, but it accurately portrayed his preeminence at that time. With this preeminence came stratospheric expectations, which he continually strove to fulfill.

Schwinger was born in upper Manhattan on February 12, 1918. He went to P.S. 186, to Townsend Harris High School (then New York City's leading public high school), and to the College of the City of New York, following brother Harold by six years. Harold was the outstanding student, the valedictorian, their mother would explain. Julian took the establishment of teachers, textbooks, and assignments less seriously. From some, most notably physics teacher Irving Lowen, he benefited greatly. But there were better things to do with the 11th edition of the *Encyclopaedia Britannica* and the books and journals in nearby libraries.

In 1926 when Werner Heisenberg and Paul Dirac were developing quantum mechanics, Schwinger was in the third grade. Eight years later, before completing high school, he had assimilated these ideas and in an unpublished paper extended Dirac's ideas to many-electron systems. By then, word of the wunderkind had spread among graduate students at City College, where he enrolled in the fall of 1934 and at Columbia University, to which—thanks to that institution's support and the subsequent intervention of I. I. Rabi—he was able to transfer in 1936.

In a remarkable letter dated July 10, 1935, from Hans Bethe to I. I. Rabi, Bethe describes his meeting with Schwinger:

> I entirely forgot that he [Schwinger] was a sophomore 17 years of age. . . His knowledge of quantum electrodynamics is certainly equal to my own, and I can hardly understand how he could acquire that knowledge in less than two years and almost all by himself." Bethe concludes that "Schwinger will develop into one of the world's foremost theoretical physicists if properly guided, i.e., if his curriculum is largely left to his own free choice.

Less than four years after he entered college Schwinger had completed both the requirements for his undergraduate and graduate degrees and the research for his doctoral thesis. During his sophomore year, with Otto Halpern, he predicted the polarization of electrons by double scattering and with Lloyd Metz he computed the lifetime of the neutron. On his own as a junior he computed how neutrons were polarized by double scattering from atomic electrons. That the electron current must be treated relativistically by the Dirac equation (that is, that the classical approximations made by Felix Bloch were inadequate) was noted *sotto voce.* Next, he calculated the influence of a rotating magnetic field on a spin of any magnitude j. His analysis for $j = 1/2$ remains the prototype for all discussions of transitions in two-level systems by "Rabi flipping."

During the spring of 1937, he and Edward Teller studied coherent neutron scattering by hydrogen molecules, showing how the spin-dependent, zero-energy, neutron-proton-scattering amplitudes could be determined from the experimental data. This topic was the theme of his doctoral thesis.

In the fall of 1937, with his undergraduate degree in hand, eight significant papers published, and his doctoral thesis virtually complete, Schwinger left New York, planning to spend the fall term at the University of Wisconsin with Gregory Breit and Eugene Wigner, and the spring term at the University of California, Berkeley, with J. Robert Oppenheimer. In Madison he took such great pleasure in working at night on problems of his own choosing that he stayed for the entire year. He would maintain this nocturnal regimen for most of his career.

Schwinger returned to Columbia for 1938-1939. As house theorist he worked with Hyman Henry Goldsmith, John Manley, Victor Cohen, and Morton Hammermesh on nuclear-energy-level widths and on the neutron-proton interaction and with Rabi and his associates on molecular beams. His doctoral degree under Rabi's supervision was awarded in 1939.

Schwinger spent the next two years at Berkeley working with Oppenheimer, students, and visitors (Herbert Corbett, Edward Gerjuoy, Herbert Nye, and William Rarita). With Rarita he determined definitively the effects of the tensor force on the deuteron's magnetic and quadrupole moments. He also examined the consequences of tensor and exchange forces between pairs of nucleons on the magnetic and quadrupole moments of light nuclei, nuclear pair emission, deuteron photodisintegration, and other phenomena.

The Rarita-Schwinger equation—one of the few of his many contributions that bear his name—was all but forgotten for many years. But this generalization of the Dirac equation to particles with spin 3/2, and the study of its invariances when the particles are massless, has been recalled by theorists who postulate a gravitino, a spin-3/2 fermion supersymmetric partner of the graviton.

Notwithstanding a ticker tape parade for Albert Einstein, theoretical physics held little fascination for the American public or major American universities prior to the Second World War. Even so, in 1941 the nation's great universities might have been expected to compete fiercely for an acknowledged young genius who lectured along with Wolfgang Pauli, Frederick Seitz, and Victor Weisskopf at the world-famous Michigan summer school for physics. They did not. In some cases, a long tradition of anti-Semitism may have been a factor. Schwinger was offered and accepted a lowly instructorship at Purdue University with just one concession to his preferred work schedule: His introductory physics section would start at noon.

Led by first-rank physicist Karl Lark-Horovitz, Purdue attracted able graduate students and postdoctoral fellows. Among them was Robert Sachs, who (as related by Sylvan Schweber in his book on QED) recalled that in February 1942, "We had to spend the whole time trying to cheer Julian up" at his 24th birthday party "because he had not yet made the great discovery expected of him."

Along with physicists at Cornell University and the University of Rochester and with colleagues at Purdue, Schwinger spent the first year and a half of World War II working on the properties of microwave cavities. The work was coordinated with and supported by MIT Radiation Laboratory research projects.

Invited by Oppenheimer to join the Manhattan Project, Schwinger spent the summer of 1943 at the University of Chicago's Metallurgical Laboratory, where John Wheeler, Eugene Wigner, and other scientists were designing the first Hanford reactor. As in Madison, Schwinger worked nights, and so Bernard Feld (who had worked with him at Columbia) decided to work an intermediate afternoon-evening shift so that he might help link Schwinger with those working normal hours.

After "a brief sojourn to see if I wanted to help develop the Bomb—I didn't," recalled Schwinger, "I spent the war years helping to develop microwave radar." Reluctance to follow others' agendas once again helped determine his course. Thus, in the fall of 1943 after most luminaries with nuclear expertise had left the MIT Rad Lab for Los Alamos, Schwinger arrived in Cambridge with little notion that he would remain in the area for more than a quarter century.

Many of Schwinger's colleagues during his three-year stint at the Rad Lab became his lifelong friends. Among them were Harold Levine from Cornell; Nathan Marcuvitz, an electrical engineer from Brooklyn College; and David

Saxon, an MIT graduate student. Schwinger's collaboration with Levine led to a series of papers that creatively used variational methods and Green's functions—two approaches central to so much of Schwinger's work—to obtain important new results on radiation and diffraction.

Schwinger and Marcuvitz appreciated the value of integral equation formulations of waveguide theory that incorporate the boundary conditions accompanying partial differential equation formulations and can be cast in the engineering language of transmission lines and networks. The isolation of complex internal properties of components and the characterization of these components through a small set of parameters provided valuable insights—insights that would later prove valuable in characterizing nuclear phenomena via effective range theory, scattering matrices, and new formal approaches to complex scattering processes.

At the Rad Lab Schwinger gave a series of lectures on microwave propagation for which David Saxon served as his Boswell. Many of the ideas and techniques in them recur in his later theoretical work on quantum mechanics, electrodynamics, nuclear physics, and statistical mechanics. A small volume, titled *Discontinuities in Waveguides*, containing some of these lectures, was published decades later. In the volume's introduction and 138 pages of text, Schwinger himself observed that the name "Green" or simply "G" (for Green's function) appeared more than 200 times. Some powerful relations imposed on scattering amplitudes by time reversibility and energy conservation can also be traced back to Schwinger's work at the time.

When the War ended, Schwinger's attention turned to the physics of high-energy accelerators and to the obstacles to producing them. It struck him that the energy loss of a highly relativistic electron accelerating in a circular orbit could be simply and straightforwardly deduced from the covariant expression for radiation damping, making the fourth power law for the radiated energy transparent. "Manifest covariance" would play an important role in Schwinger's work on quantum electrodynamics. During this period, Schwinger also designed a novel accelerator, later named the *minotron.*

In addition to work on other aspects of synchrotron radiations, notepads in his desk drawers at that time included studies of neutron scattering in a Coulomb field, and a group-theory-free approach to the properties of angular momentum that expresses angular momentum operators in terms of oscillator creation and annihilation operators. *On Angular Momentum*, a set of his notes that makes exhaustive use of this approach, circulated widely for 15 years prior to its publication in 1965.

Schwinger's long and diverse bibliography, with more than 200 publications, contains no publications over the period 1942 through 1946. However, the war produced sweeping changes in the social and intellectual values and mores of the public and the nation's premier universities. Thus, in February 1946, the month Schwinger turned 28, he was offered and accepted a tenured position at Harvard. Professorship offers from Columbia and Berkeley soon followed, but he turned them down.

Students attending topflight universities were also different before and after the war. Postwar students included mature veterans whose studies had been interrupted by the war and bright youth from a broader cross-section of the nation's preparatory schools. Doors were open, for example, to outstanding students from New York's select high schools (for example, Bronx Science, Brooklyn Tech, and Stuyvesant, the successors to Schwinger's alma mater, Townsend Harris).

Schwinger's first year at Harvard, 1946-1947, was a busy one. He offered courses on waveguides and theoretical nuclear physics, and accepted a number of graduate students whom he set to work on a wide range of problems. Among these early students were Bernard Lippmann who investigated integral equation formulations of scattering theory (Lippmann-Schwinger equations); Walter Kohn, who studied variational principles for scattering; Ben Mottelson, who worked on the properties of light nuclei; Bryce DeWitt, who explored gravitation and the interaction of gravitation with light; and Roy Glauber, who examined meson-nucleon interactions and mesonic decay. He and longtime friend Herman Feshbach pursued their studies of the internucleon potential.

When the academic year ended, Schwinger and 22 other physicists headed off to the Shelter Island conference on the foundations of quantum physics, where the electrodynamic origin of the spectral lineshift measured by Willis Lamb and Robert Retherford was discussed. Legend has it that Weisskopf and Schwinger proposed that in the Dirac theory compensating effects of electrons and positrons could lead to a cancellation of divergences, and that Hans Bethe—on his way home from the conference—recognized that the bulk of the effect could be estimated nonrelativistically.

Four days after the conference ended, Schwinger married Clarice Carroll, whom he had been courting for several years and with whom he would share the next 47 years.

Schwinger's lectures, from his early days at Harvard on, have been likened to concerts at which a virtuoso performs pieces brilliantly. Each lecture was an event. Speaking eloquently, without notes, and writing deftly with both hands, Schwinger would weave original examples and profound insights into beautiful patterns. Audiences would listen reverently seeking to discern the unheralded difficult cadenzas. As at a concert, interruptions to the flow were out of place.

Schwinger's masterly performances were not limited to the Harvard community. His audiences quickly grew to include faculty and students from throughout the Boston area. Notes taken by John Blatt, an MIT instructor, were shipped to a team of Princeton graduate students, who in swift relays copied them onto duplicator masters for reproduction. Underground notes in multiple handwritings, with some pages containing picturesque mistranscriptions (such as "military matrices" for "unitary matrices") spread quickly throughout the country and overseas.

Schwinger was never satisfied with his expositions. Each time he offered a course he carefully reworked and honed his ideas, methods, and examples, presenting them in a new way, a way that differed from his earlier versions circulating in others' articles and lecture notes, often without attribution. Significant portions of many classic texts on nuclear physics, atomic physics, optics, electromagnetism, statistical physics, quantum mechanics, and quantum field theory can be traced to one or another version of his lectures.

As noted, a few isolated gems—his work on microwaves and his notes on angular momentum—were eventually published. He was also stimulated in 1964 "to rescue from the quiet death of lecture notes" a beautiful discussion of Coulomb Green's functions "worked out to present to a quantum mechanics course given in the late 1940s." The bound-state momentum space wave functions are deftly and concisely constructed as four-dimensional spherical harmonics.

Notes for his early quantum mechanics courses also include elegant and revealing unpublished treatments of Coulomb scattering and of the unusual way that the Stark effect lifts hydrogenic degeneracies. These and other jewels may be found in the archives assembled by UCLA of lecture notes, chapters, and preliminary editions of books on quantum mechanics, field theory, and electromagnetism that failed to meet his exacting standards. A few appear in *Classical Electrodynamics*, published in 1998.

Not until September 1947 did Schwinger begin to work on the electrodynamic effects responsible for deviations of experimental observations from values predicted by the Dirac equation. Hyperfine structure measurements of hydrogen, deuterium, and tritium by John Nafe, Edward Nelson, and Rabi indicated a 0.12 percent error in the electron's magnetic moment, and measurements by Lamb and Retherford displayed a splitting of about 1050 megacycles between states of the hydrogen atom with degenerate Dirac energies. "By the end of November I had the results," Schwinger later recalled. He described them to a capacity audience at an American Physical Society meeting at Columbia University on a Saturday morning in January 1948, giving a command repeat performance to an overflow audience that afternoon. He discussed his calculations in fuller detail at the Pocono conference in the spring and in lectures at the University of Michigan summer school. Demonstrating his computational virtuosity, he published his reformulation of quantum electrodynamics in three long papers in *Physical Review,* Quantum Electrodynamics I (1948), II (1949), and III (1949). They include several of the results for which he, Richard Feynman, and Sin-Itiro Tomanaga were eventually awarded the 1965 Nobel Prize in Physics. To those who admire the eloquence of Schwinger's expositions, it seems ironic that these three uncharacteristically opaque papers should have helped secure his place in Nobel history.

In light of his many spectacular achievements, including his fundamental contributions to quantum electrodynamics, Schwinger was elected to the National Academy of Sciences at the exceptionally young age of 31.

By 1950 Schwinger recognized the need for a more systematic approach to quantum field theory utilizing a covariant quantum version of Hamilton's principle. In 1951 in a pair of brief papers in the Proceedings of the National Academy of Sciences, the techniques and concepts on which field theorists all rely made their appearance. Using "sources" as fundamental variables, Schwinger provided the functional differential equation version of what in integral form is now called functional integration. Of lasting importance, much of this material has been rediscovered by others. For theoretical students at Harvard at the time, Schwinger's techniques provided an Aladdin's lamp for parsing, analyzing, and solving problems. As a matter of principle, these papers noted,

> The temporal development of quantized fields is described by propagation functions, or Green's functions. The construction of these functions for coupled fields is usually considered from the viewpoint of perturbation theory. Although the latter may be resorted to for detailed calculations, the formal theory of Green's functions should not be based on the assumption of expandability in powers of the coupling constant.

After relating the outgoing wave boundary condition to the vacuum, the second paper defined functions (such as self-energies and effective interactions) that characterize exactly (that is, not as power series in the coupling constant) the propagation and interaction of quantum fields. This approach opened the way for major conceptual and computational advances in quantum electrodynamics. A series of papers called "Theory of Quantized Fields" followed.

Word appears to have circulated that the stress Schwinger placed on the properties of fields that transcended perturbation theory, and his personal dislike of diagrams disadvantaged those working for and with him in the 1950s. Hardly! His students and postdoctoral fellows were fully conversant and facile with the diagrammatic approaches of Feynman and Freeman Dyson and analytic approaches. With Schwinger's tools, they generated directly and succinctly the connected diagrams involving dressed propagators that describe various processes. With them they evaluated a large share of the quantum electrodynamic corrections to hydrogen and positronium bound states and a large share of the higher order corrections (for example, to the electron's magnetic moment) computed at that time.

Other aspects of Schwinger's routine can also mistakenly be cast in an unkindly light. It is true, for example, that students might wait a long time to see him during his lengthy office hours. He could have spent less time with each and he could have accepted fewer. In his first year at Harvard he accepted 10 graduate students, and in subsequent years no one recalls his ever turning down a prospective student whom the department certified as qualified. When requested, Schwinger posed problems to students, sometimes offering them and colleagues his notes. At the same time, he welcomed students who preferred to formulate their own thesis topics. If students told him they were stuck, he would offer suggestions and proposals on the spot and at subsequent meetings. Rare are the students who did not cherish their interactions with Schwinger in sessions that were often lengthy.

His late arrival for classes was not because he left gathering materials for his lecture to the last minute. Not only in the early years but also throughout his long career he insisted on remaining home the night before each lecture, staying up late to prepare exactly what he would say and how best to say it.

Among the giant figures in theoretical physics, his level of commitment to course lectures and to the supervision of large numbers of research students may be unmatched.

Schwinger's investigations of quantum field theory continued through the 1950s. Relativistic invariance and gauge invariance constrain the formally divergent expressions appearing in quantum electrodynamics calculations. Colleagues of Pauli, ignoring the consequences of gauge invariance, had recast and manipulated these expressions to predict a finite photon mass. Schwinger's 1951 paper on vacuum polarization and gauge invariance addressed some of these issues with a novel and elegant proper-time formalism. The nonperturbative properties of a Dirac field coupled to a prescribed external electromagnetic field, first derived in this paper, are still widely used and admired. Schwinger saw that many ambiguities associated with interacting quantum fields lay in the treatment of formal expressions for composite operators such as currents. Indeed, the "triangle anomalies" that play a major role in modern (post-1969) field theory were first identified here and studied further by Schwinger and Ken Johnson during the 1950s. Further studies of quantized fields led in 1958 to Schwinger's important series of papers on "Spin, Statistics, and the TCP Theorem."

During the 1950s, puzzles posed by elementary particle physics preoccupied Schwinger. What role could strange particles, whose properties were just being elucidated, play in the grand scheme of things? He was convinced that the answer had to do with their transformation properties under a generalization of isotopic-spin symmetry, which he took to be the four-dimensional rotation group. The group generators, under commutation, defined what would later become known as the "algebra of charges."

Schwinger gathered particle species together, both strange and nonstrange, into representations of his proposed group. In this manner the otherwise mysterious Gell-Mann-Nishijima formula—which relates charge, hypercharge, and isospin—had a natural explanation. It later turned out that Schwinger's intuition was correct, although his choice for the relevant transformation was not.

The approximate symmetries of mesons and baryons were not shared by the leptons. For these particles, Schwinger proposed a direct analog to isospin. Just such a group was later to become an integral part of today's successful electroweak theory. The known leptons—in Schwinger's perversely original interpretation—were to form a weak isospin triplet: $\{\mu^+, \nu, e^-\}$. An immediate consequence of this notion was the selection rule forbidding $\mu \rightarrow e + \gamma$ and the obligatory distinction between neutrinos associated with electrons and muons. "Is there a family of bosons that realizes the T=1 symmetry of [the lepton symmetry group]?" Schwinger asked. If so, the charged counterparts of the photon could mediate the weak interactions. Both the vectorial nature of the weak force and its apparent universality would arise as simple consequences of the underlying symmetry structure. He also suggested that vacuum expectation values of scalar fields could provide a way of breaking symmetries and giving fermions their masses.

Schwinger's 1957 paper on particle symmetries appeared at a time of rapid progress and great confusion, between the discoveries of parity violation and the V-A nature of the weak interactions. His ambitious paper concluded with the modest suggestion that "it can be of value if it provides a convenient frame of reference in seeking a more coherent account of natural phenomena." For some of the theorists who developed that coherent theory over the next 15 years, it did just that. Schwinger himself, however, turned to other problems.

A 1959 paper with Martin extended Schwinger's nonperturbative field theoretic concepts and methods for the vacuum state to material systems in equilibrium at nonvanishing densities and temperatures, and a 1961 paper, camouflaged by the title "Brownian Motion of a Quantum Oscillator" paved the way for the study of systems far from thermal equilibrium. Extended by K. T. Mahantappa, Pradip Bakshi, and Victor Korenman at Harvard, and rediscovered (independently) by Leonid Keldysh, Schwinger's "two-time" approach is now widely used in studies of cosmology, quark-gluon plasmas, and microelectronic devices.

As indicated above, Schwinger recognized in the early 1950s that the composite operators for observables must be treated with care. Naive manipulations with canonical commutation relations suggest that the space and time components of a current commute with each other. In 1959 Schwinger published an argument, dazzling in its simplicity, that moved this problem to the fore and identified a class of anomalies, now called "Schwinger terms." He followed it in papers directed toward the gravitational field with a study of the conditions imposed by consistency on stress tensor commutation relations. Today we recognize the key roles such terms play in particle physics and statistical mechanics.

In the late 1960s Schwinger directed much of his attention to his source theory. The motivation was clear. In spite of field theory's many triumphs, the prospects then seemed dim for predicting the results of experiments involving strongly interacting particles from a unified field theory. Prospects for a renormalizable theory of the electroweak interactions also seemed dim. Why not try to develop a theory that would progress in the same way as experiment—from lower to higher energies? Source theory provided a framework for pursuing this modest goal.

Soon thereafter these prospects brightened. Gauge field theories were shown to be renormalizable and consonant with an increasing number of phenomena. Quantum field theory, to which Schwinger had contributed so much, might describe all strong and electroweak phenomena. Schwinger demurred, remaining steadfastly committed to the source theory approach that he and his students were pursuing. The philosophical basis of divergence-free "anabatic" (going up) phenomenological source theory was, he maintained, immensely different from "the speculative approach of trickle-down" field theory. So too were its predictive powers. He espoused this contrarian position steadfastly.

During the 1960s, Schwinger's lifestyle expanded in other ways. He began playing tennis regularly, and he and Clarice spent time in distant places, including Paris and Tokyo. In 1971 the Schwingers left Harvard and their Belmont home for UCLA and the Bel Aire hills. In sunny southern California, with students, new collaborators, and longtime friends, Schwinger continued working on source theory ("source" appears in the title of more than 15 publications) and contributing significantly to a host of interesting physical problems not in vogue. With Lester DeRaad Jr. and Berthold-Georg Englert, he explored statistical models of the atom that extend the Fermi-Thomas approximation and, with Kimball Milton and DeRaad, various aspects of the Casimir effect. In his new surroundings he published more than 70 papers.

Reports of cold fusion whetted his contrarian appetite. The publicized experiments might be flawed, he would observe, but fundamental physical principles do not rigorously exclude the possibility that without tokamaks and high-temperature plasmas, somehow, in some way, in some material, the energy required for fusion might be coherently concentrated and transferred from atoms to nuclei.

One of Schwinger's last papers is a 1993 talk titled "The Greening of Quantum Field Theory: George and I, Lecture at Nottingham, July 14, 1993." It contains the count of references to Green in Discontinuities in Waveguides mentioned earlier and a recital of a multitude of the linkages with George Green of Schwinger's research on field and particle theory, statistical mechanics, through to work on the Casimir effect and sonoluminescence. Although Schwinger's genius was widely recognized immediately, and Green's very slowly. Schwinger concludes his talk by answering the question, "What then shall we say about George Green?" with "He is, in a manner of speaking, alive, well, and living among us." That, too, can be said for Schwinger.

Schwinger's legacy has also been greatly amplified by the 70 doctoral students and 20 postdoctoral fellows who worked with him. For their research they have innumerable major awards, including four Nobel prizes; nine of his students have been elected to the National Academy of Sciences.

Two features shared by Schwinger's professional offspring are striking: the diversity of their specialties and the consistently high regard and great debt they express for his mentorship. The group includes leaders in particle theory, nuclear physics, astrophysics, gravity, space physics, optics, atomic physics, condensed matter physics, electromagnetic phenomena, applied physics, mathematics, and biology. It also includes many who, like Schwinger, have worked in a variety of fields, mirroring Schwinger's own broad interests and his passion for seeking patterns and paradigms that put new facts in proper perspective.

Their recollections are remarkably uniform. While few former students considered him a close friend, almost all speak fondly of his kindness and generosity. He was considerate and willing to do his best to provide scientific advice when he thought help was needed. His insight and suggestions were often decisive.

By example he conveyed lofty aspirations: to approach every problem in a broad context, with as few assumptions as possible; to seek new and verifiable results and to present them as elegantly as possible; to avoid energy- and time-consuming political maneuvering; to understand, extend, unify, and generalize; and to reveal the hidden beauty of nature. Walter Kohn spoke for all of Schwinger's students in saying, We carried away the self-admonition to try and measure up to his high standards; to dig for the essential; to pay attention to the experimental facts; to try to say something precise and operationally meaningful, even if—as is usual—one cannot calculate everything a priori; not to be satisfied until ideas have been embedded in a coherent, logical and aesthetically satisfying structure.

Schwinger also had a remarkable knowledge of matters nonscientific and a gentle humor. While too reserved to savor media stardom, he enjoyed presenting relativity to a wide audience in a popular book and on BBC television. He was always willing to lend his name and support to worthy causes. Fond recollections of the hospitality, warmth, and interest displayed by both Julian and Clarice Schwinger abound.

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