Paul C. Martin

1931-2016

BIOGRAPHICAL *Memoirs*

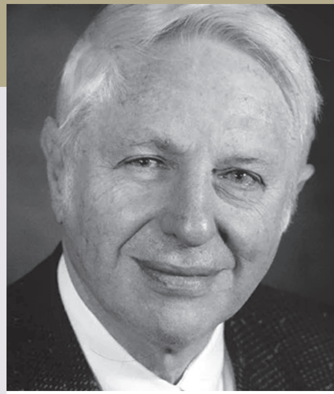
A Biographical Memoir by
by Tom Lubensky

NATIONAL ACADEMY OF SCIENCES

PAUL CECIL **MARTIN**

January 31, 1931–June 19, 2016

Elected to the NAS, 1979



By Tom Lubensky

Paul C. Martin was born in Brooklyn, New York, on January 31, 1931. Paul's father is believed to have come from Austria-Hungary, arriving in the United States in time to enlist as a soldier to fight in World War I. His mother was from Russia. Family lore has it that the last name Martin was taken from Martin's Toy Store, which Paul's parents purchased and ran. Paul's mother, who is reputed to have announced that baby Paul would be going Harvard, was the eldest of a large family. In spite of her academic promise, she had to quit school to take care of her many siblings, all of whom (including the girls) she put through college. Paul attended Stuyvesant High School, graduating as valedictorian in 1948. While there, he was active in the Junior Astronomy Club and was one of forty winners of the Westinghouse Science Talent Search, who were then invited to Washington. Paul entered Harvard in the fall of 1948 at the age of 17, beginning what would be sixty-eight years of almost continuous association with the institution. He graduated summa cum laude in 1951, having been selected as one of eight students for membership in Phi Beta Kappa in their junior year. He entered graduate school at Harvard the same year and obtained his Ph.D. only three years later, under the supervision of Julian Schwinger. While in graduate school, Paul met his future wife, Ann Bradley, who was also the first in her family to go to college.

While working on his thesis and shortly thereafter, Paul published several papers with Robert Karplus, Margaret Kivelson, Thomas Fulton, and Roy Glauber, but none with Schwinger. After completing his degree, he spent a year at the University of Birmingham in England and at the Niels Bohr Institute in Copenhagen, where he met the French physicist Cyrano De Dominicis, with whom he established a lifelong and collaborative friendship that was kept active by Paul's frequent visits to France.

Paul and Cyrano worked on the nuclear many-body problem, following the work of Keith Brueckner. At that time, Murray Gell Mann and Brueckner were investigating the properties of the quantum electron plasma, calculating in particular its ground-state energy as a function of electron density. Additionally, Bardeen, Cooper, and Schrieffer's investigation of superconductivity was beginning to bear fruit. Paul and others recognized that the nuclear many-body problem, interacting electrons, and superconductivity have much in common and that they and other condensed-matter systems could benefit from the language and techniques introduced by Schwinger for the study of relativistic fields. Upon his return to Harvard as an assistant professor, Paul managed to enlist Schwinger's aid in developing a general framework for a field-theory description of non-relativistic equilibrium condensed matter systems, from superfluids, to periodic solids, to magnets, and more. The result was their famous and influential 1959 joint paper, "Theory of Many-particle Systems I." In a talk at a conference honoring Schwinger's sixtieth birthday, Paul highlighted what he saw as the advantages of the Schwinger formalism over the approaches taken by contemporaries Takuo Matusbara in Japan and Dmitry Zubarev in the Soviet Union. He noted, based on perturbative expansions:

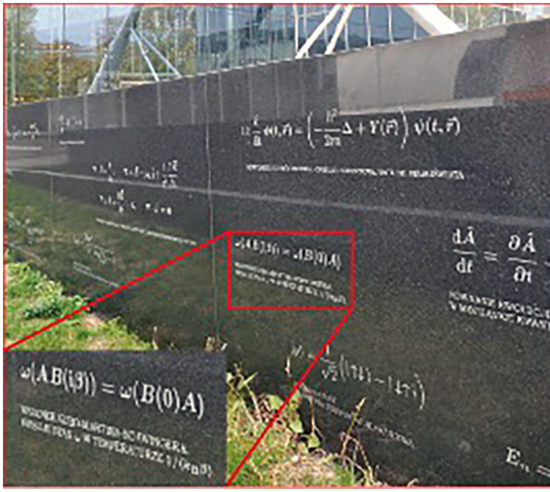


Figure 1: KMS boundary condition memorialized in a plaque that the Warsaw University's Centre of New Technologies along with Maxwell's and Schroedinger's equations and other significant contributions to physics. (Photo courtesy of David Nelson.)

> *It makes no 'adiabatic' perturbative assumption and thus allows naturally for self-consistent solutions.*
>
> *At no stage does it entail unphysical 'unlinked diagrams.' Their absence does not rest on a 'Wick theorem' (which does not hold for operators that do not satisfy canonical commutation relations).*

Paul further noted that to discuss systems in thermal equilibrium, it is necessary "to introduce a periodic boundary condition in imaginary time, which is tantamount to the fluctuation-dissipation theorem," now often referred to as the KMS conditions in honor of the contributions of Ryogo Kubo as well as Martin and Schwinger (Fig. 1).

Essentially all of Paul's subsequent research dealt with many-particle systems, and much of it was heavily influenced by the Martin-Schwinger paper. With his student Leo Kadanoff, he applied the techniques of that paper along with the formalism introduced by Yoichiro Nambu to superconductors, paying particular attention to the development of gauge-invariant approximations. Leo P. Kadanoff and Gordon Baym later extended ideas from this work to develop many-body approximations that guarantee that conservation laws are obeyed. Also, with Kadanoff, he established a general formalism for calculating quantum response and correlation functions associated with hydrodynamic equations of spin diffusion and of normal fluids, which was later presented in his popular lectures at the 1967 Les Houches Summer School. The work with Kadonoff provided fodder for a string of subsequent graduate students on problems related to superfluid helium (Pierre Hohenberg), ultrasonic attenuation and second sound in insulators (P. C. Kwok), ferromagnetism (H. S. Bennet and T. C. Lubensky), and itinerant antiferromagnetism (P. A. Fedders).

After the above work on quantum systems, Paul became interested in purely classical systems, exploring (with grad student Dieter Forster and with Sidney Yip of Columbia University) topics like moment methods for calculating the viscosity of simple liquids and approximation methods, which are very much in the spirit of those he developed for quantum systems with Schwinger, to treat the kinetic theory of weakly coupled fluids. In 1973, Paul, along with students Eric Siggia and Harvey Rose, published a groundbreaking paper that presented a path-integral formalism for calculating properties of interacting classical systems that introduced auxiliary fields to enforce classical equations of motion in a field-theoretic representation. This formalism, which applies to both systems that possess a well-defined thermal equilibrium and those that do not, is now the favorite one for calculating dynamic correlations not only of microscopic classical systems but also of phenomenological models for dynamical critical phenomena and generalized hydrodynamics.

In the late 1960s and early 1970s, largely through the influence of Nobelist Pierre-Giles de Gennes, physicists discovered liquid crystals, the remarkable phases of matter that generally flow like fluids but possess properties, such as rotational anisotropy or spatial periodicity, that are normally associated with solids. The simplest of these phases is the nematic phase in which rod-like molecules align along a common direction but still diffuse freely as they do in the "disordered" isotropic fluid phase. Like superfluid helium or ferromagnets, this is a phase with a spontaneously broken continuous symmetry, and it necessarily has dynamical modes, involving the rotation of the anisotropy axis, whose frequency vanishes at long wavelength. In collaboration with Dieter Foster, Peter Pershan, Jack Swift, and Tom Lubensky, Paul developed a purely hydrodynamic theory for the nematic liquid crystals that did not suffer from the existence of a rapidly decaying non-hydrodynamic mode that previous theories at the time did. In a magisterial follow-up to this work, Paul, along with O. Parodi and Peter Pershan developed a general theory for the hydrodynamics of broken symmetry systems including not only all of the intermediate-symmetry liquid-crystal systems but crystalline solids as well. The fundamental result is that the there is a first-order-in-time differential equation for each conserved and broken-symmetry variable and, as a result, the number of hydrodynamical modes is equal to the number of conserved plus the number of broken-symmetry variables. Thus, an isotropic fluid with conservation laws for mass, energy, and the three components of momentum, has five hydrodynamic modes (two-longitudinal sound that are forward and backward travelling, two diffusive transverse momentum, and one energy diffusion). A nematic liquid crystal with five conservation laws and two broken-symmetry variables has two diffusive orientational modes in addition to the five modes of an isotropic fluid for a total of seven hydrodynamic modes. A crystalline solid has three broken-symmetry translations and eight modes: one heat diffusion, six sound, and a vacancy or interstitial diffusion mode, the latter of which is really a "permeation" mode in which mass diffuses relative to the periodic lattice.

In the 1970s and early 1980s, apart from a brief foray with graduate students Bruce Patton and Andres Tremblay into non-linear current fluctuations in metallic resistors and long-lived modes in low-temperature superconductors, Paul continued his exploration of mostly classical systems with a greater focus on non-linear and chaotic properties. With John McLaughlin and De Dominicis, he studied turbulence in statically stressed and randomly stirred fluids and with students Boris Shraiman and Clarence E. Wayne investigated period-doubling transitions to chaos. With student George F. Carnevale, he applied the methods he developed with Siggia and Rose to statistical fluid dynamics and nonlinear wave mechanics of relevance to geophysics, and with his last student Scott Milner, he calculated critical slowing down of chemical reactions near a second-order demixion transition and divergent viscosities in the fluctuating hydrodynamics of layered (smectic) liquid crystals, the latter using the Martin-Siggia-Rose formalism. Paul's seminal scientific contributions were developed for the broader physics community in several influential books. Kadanoff and Gordon Baym (*Quantum Statistical Mechanics*, 1962), by Sandy Fetter and Dirk Walecka (*Quantum Theory of Many Body Systems*, 1971), by Dieter Forster (*Hydrodynamic Fluctuations, Broken Symmetry and Correlation Func-*

tions, 1975), and by Paul Chaikin and Tom Lubensky (*Principles of Condensed Matter Physics*, 1995) as well as his own 1968 book on *Measurement and Correlation Functions*.

In parallel with these scientific contributions, Paul played a pivotal role in training the post-Sputnik generation of condensed matter theoretical physicists. Paul's students and associates are a veritable "Who's Who" of the leading figures in diverse areas of science, including not only condensed matter, but also applied mathematics, chemical engineering, and quantitative biology. Six are members of the National Academy of Sciences.

Teaching

Paul taught graduate courses in quantum mechanics, electromagnetism, and many-body theory. He had his own approach to all of these, presenting in lectures what was often impossible to find anywhere else (other than perhaps in his publications), such as, for example, a microscopic expression for the conserved energy current. His standards were high, and it is unclear that it ever occurred to him that students might not have the background to understand the concepts he taught. His teaching style did change, however. His earliest students recall that he lectured without notes and worked everything from scratch at the blackboard. The experience, his student David Mermin notes, was like "watching Sisyphus pushing his rock up the hill—except that every now and then Paul actually managed to get it to the top." Another of his students, Pierre Hohenberg, remembered trying to reconstruct all the mathematical machinery Paul had used to elevate one rock and confessed, at the beginning of the next class, that he couldn't understand how Paul had gotten it across some gap. After thinking silently, Paul announced, "You're right. It's all wrong." The rock rolled down to the bottom, and Paul began, in class, to push it up again. He sometimes talked so rapidly that a half-expressed idea needed revision before it was finished. His insistence on precision, his colleague from college days Margaret Kivelson said, "led him to interrupt his own sentences to specify limitations or add interpretation, so that one wondered whether he would be able to complete the sentence before the lecture came to an end."

At some point, Paul realized the troubles students had following his lectures without the aid of some kind of study material. When I took quantum mechanics and many-body theory from him in 1964 and 1965, he prepared detailed notes that were provided to us in the primitive reproduction method of the time: mimeographed with typed or handwritten text and handwritten equations, of which there were many. These notes, a page of which is reproduced below, were exhaustive yet efficient to the extreme. I marveled at how he managed to get most of the machinery of diagrammatic field theory, derived

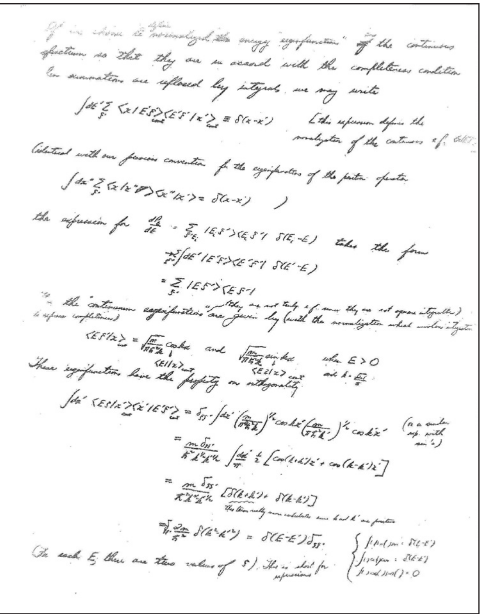


Figure 2: A page of Paul's hand-written notes on quantum mechanics.
(Handout to T. Lubensky.)

using functional derivatives, into only 10 pages. The homework problems in both courses would have been Ph.D. theses under almost any other teacher. The amazing thing in my mind is the extent to which what Paul taught us has stayed with me and has served me throughout my career.

Service to Harvard

Paul became chairman of the Department of Physics in 1972 and served until 1975. This was a surprise to me at least. He seemed to be the quintessential academic theorist who would avoid administrative duty if possible. This was, of course, not the case. He was devoted to Harvard, and he was intent on doing all that he could do towards its benefit. His outstanding job as department chair led to his greater recognition around campus and to his appointment in 1977 as chair of a committee to study undergraduate concentrations. His report made a compelling case that students should not have to go through a second admission process to study what they wanted and that individual departments should not be allowed to pick which students are admitted to their programs. In that same year, Paul was appointed Dean of the Division of Engineering and Applied Sciences (rebranded the John A. Paulson School of Engineering and Applied Sciences in 2007), a post he held for twenty years. His appointment followed a review of the division in 1975 that set a grand agenda for applied sciences at Harvard. Paul immediately set about pushing this agenda and lifting applied sciences to the central role it plays Harvard today.

The year 1977 was a turning point in history: Apple introduced the Apple II computer, Radio Shack the TRS-80, and Commodore its PET. Also, Digital Research released CP/M, the 8-bit operating system that provided the template for MS/DOS. Computers were readying for the masses, and computer science entered a whole new world. As dean, Paul introduced the first stand-alone concentration in computer science and recruited key computer science faculty, against the desires of some of the engineering faculty. In the 1980s, he worked with university officials to implement strategies for Harvard to embrace the digital world. He labored tirelessly to ensure that every faculty member in the Graduate School of Arts and Sciences (GSAS) had access to broadband internet at a time when it was not yet obvious that such access would be very useful.

Paul was something of a micro-manager who seemed to do everything himself. He had one assistant, rather than an army of them. He personally compiled Harvard's first email directory and tracked every detail when the Harvard campus was networked. He worked long hours in evenings and on weekends, expecting those working with him to do the same. In the view of many of his faculty, he lacked "the superficial smoothness and diplomacy" that should characterize a dean, and he often ruffled feathers, but he was effective and respected.

During his tenure as dean, Paul created the Department of Earth, Atmospheric, and Ocean Science (now the Department of Earth and Planetary Sciences) and an undergraduate concentration in science and public policy. He also oversaw construction of the Maxwell Dworkin Laboratory, made possible by donations from Microsoft's Bill Gates and Steven Ballmer, and the development of new laboratories for research in applied physics and applied bioscience. In addition, from 1981 onwards, he also served as associate dean of the Faculty of Arts and Sciences, the chief scientific advisor to the dean of GSAS. He stressed interdepartmental and interdisciplinary collaboration over the empire-building ambitions that emerged occasionally. He returned to teaching and research in 1997 and retired in 2009, when he was granted emeritus status.

Honors and Community Service

Paul was elected to the National Academy of Sciences in 1979. He was also a Fellow of the American Academy of Arts and Sciences (1963), the American Physical Society (1968), and the American Association for the Advancement of Science (AAAS) (1981). He served on editorial boards of the *Journal of Mathematical Physics, Annals of Physics, Journal of Statistical Physics,* and *Transport Theory and Statistical Physics*.

Paul's commitment to the larger physics community was embodied in his service on numerous committees and boards, including chair of the Advisory Committee of the Institute of Theoretical Physics in Santa Barbara (1979–80), chair of the Physics Section of the American Association for the Advancement of Science (1986–87), chair of the New England Consortium for Undergraduate Education (1988–2016), and chair of the (1996–2019) board of trustees of Associated Universities, Inc., which managed the Brookhaven National Laboratory. He also served on the boards of several national organizations. He also played a key role, through his students and by organizing various topical conferences, in fostering interest on the part of the U.S. Physics community in unsolved problems in nonlinear dynamics, fluid mechanics, and turbulence.

Paul died at home in Belmont, Massachusetts, on June 19, 2016, and was survived by Ann, his wife of fifty-nine years, his brother Robert, his three children Peter, Daniel, and Stephanie Martin Glennon, and his nine grandchildren.

ACKNOWLEDGMENTS

I wish to thank David R. Nelson and Bertrand Halperin of Harvard for providing information and stories about Paul's tenure at Harvard and for constant encouragement for me to write this memoir. I am particularly grateful to Paul's daughter, Stephanie Martin Glennon, for sharing background and anecdotes about the Martin family.[1]

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