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MELVIN LAX
1922–2002

A Biographical Memoir by

JOSEPH L. BIRMAN AND HERMAN Z. CUMMINS

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Mel Lax

MELVIN LAX

March 8, 1922–December 8, 2002

BY JOSEPH L. BIRMAN AND HERMAN Z. CUMMINS

MELVIN (MEL) LAX WAS A versatile and productive theoretical physicist who made major contributions in many areas of science, including acoustics, multiple scattering of waves, disordered media, coherence and fluctuations in classical and quantum systems, applications of group theory to solids, phonon production and optics, and high-power lasers. His classic 1951 *Reviews of Modern Physics* paper on multiple scattering theory has been used in many areas of physics. For example, it led to the coherent potential approximation for disordered systems. His 1958 analysis with J. C. Phillips of electron motion in disordered systems showed how impurities randomly placed in a semiconductor crystal, or with random variation of interaction strength, will affect the energy levels and hence the conduction properties of the medium. This analysis was crucial for the early understanding of impurity bands in semiconductors, a topic of central importance in semiconductor device applications.

Mel wrote another influential *Reviews of Modern Physics* paper on "Fluctuations from the Nonequilibrium Steady State" in 1960. The laser was first demonstrated that same year, leading Mel to study fluctuation phenomena in lasers. During the 1960s he wrote a series of papers on classical and quantum noise. Almost all of these pertain to fluctuation phenomena in lasers. The results obtained enabled the signal, which contains the relevant information, to be separated from the unwanted (uncontrollable) random noise and gave rise to the Lax-Onsager regression theorem. This work now underlies many aspects of the design of optical communications devices and was part of Mel's lifelong, deep interest in random processes. Most recently he worked in the area of inverse scattering techniques needed to extract information from noisy measurements, such as using light scattering to study clouds with lidar (light detection and ranging) techniques; searching for oil-bearing layers using acoustic backscattering; and detecting possible tumor nodules in the human breast using pulsed, noninvasive infrared light. These major directions of his work do not exhaust all of his significant contributions in physics, as we shall describe below. In his own resume Mel listed eight areas of physics where he had made significant scientific contributions: (1) multiple scattering of waves; (2) multiphonon processes in solids; (3) application of group theory to solids; (4) coherence and fluctuations in classical and quantum systems; (5) nonlinear interaction of light with sound and other excitations in solids; (6) high-power lasers; (7) phonon production and phonon optics; and (8) hot phonon interaction with electrons in semiconductor quantum wells and heterostructures. Mel also did early work on quantum transport theory.

Mel was an indefatigable worker who maintained and regularly used three offices: at City College, at Bell Labs, and at home, all crammed with piles of documents. Somehow he always seemed to know in which office he had placed any specific article. He had an inexhaustible curiosity and interest in nearly every branch of physics. More broadly he was deeply interested in any field of human endeavor that could be made quantitative. This included fields as diverse and as far from theoretical physics as finance (long before finance became a career objective of some of our brightest Ph.D. physicists), the law, traffic control, biology, and the philosophical underpinnings of quantum mechanics.

Computers were a particular fascination for him. When computers were first introduced, Mel quickly became expert in their use for specialized computations (splines and other esoterica) and ultimately contributed an article to a specialized journal on computer science, as well as a review article on "Wave Propagation and Conductivity in Random Media" in the 1973 proceedings of the Society for Industrial and Applied Mathematics and American Mathematical Society. He early realized the importance of computer typesetting of scientific manuscripts and served on a committee of the American Physical Society that explored the best way to have physics manuscripts prepared for electronic submission to the APS journals. As a result, APS initiated its Compuscript program, initially accepting manuscripts in TROFF (a document-processing system), opening the way for the now nearly universal practice of electronic journal submissions as TeX files.

Mel had a very broad but also very deep store of knowledge about the many areas of physics to which he contributed. Colleagues at all stages of his career who asked him a question were guaranteed to get a long and detailed answer and never a simple "yes" or "no." When Michael Lubell asked Mel why the UNIX system he had installed at City College was superior to the VMS Mike knew from Yale, Mel launched into a very long discussion of several hours duration, finally concluding by giving Michael some thick notebooks and manuals from his bookshelf and saying, "Look these over in the next couple of days and let me know if you have any questions." Lubell reported later to us: "Next couple of days? For Mel, perhaps. For me it was a year's work."

Mel was never satisfied with simple answers; he attacked any problem in physics with verve, enthusiasm, and confidence. He was sure he could solve it, because he was certain that he either had already mastered the needed mathematical skills or, if need be, could invent new ones. Eli Burstein reports an event from the 1950s. The work of T. S ("Ted") Berlin and J. S. Thomsen on the interaction of dipoles in simple lattices, using a sphericalization technique first introduced by Ellliot Montroll but assuming only nearest neighbor forces, was brought to Mel's attention by Montroll. Mel was confident that he could solve the spherical model, including long-range as well as short-range dipole-dipole interactions, and he ingeniously overcame the difficulties that are encountered in a straightforward generalization of the Berlin and Thomsen work. In his 1952 paper "Dipoles on a Lattice: The Spherical Model" he also proved that in the spherical model a permanent dipole lattice is equivalent to an induced dipole lattice with an effective polarizability, and he pointed out that the generality of his results is due to the fact that they have been expressed in terms of the eigenvalues rather than the interaction energies. Moreover, he noted that his treatment, including short- and long-range interactions, is also applicable to the spherical Ising problem. It was an impressive achievement. This interaction with Mel convinced Eli that optimism is always a valuable asset when tackling a challenging problem. Mel had an abundance of optimism and confidence about solving physics problems to which he directed his attention. He was never satisfied with writing a physics paper unless every single detail was under control and understood—at least by him!

This brings to mind Mel's generosity with his ideas. One striking example of this concerns the history of the coherent potential approximation, or CPA, which is now widely used for effective treatment of a system with random distribution of impurities. In his much earlier treatment of multiple-scattering theory, Mel realized that some effective or average potential could incorporate many-impurity effects in a self-consistent fashion. We will give more details below when discussing Mel's work at Bell Labs. Suffice it to say that the CPA is attributed to other physicists; but if one looks at the acknowledgements in the papers most cited as the original work, one sees (as P. W. Anderson put it) that "Mel was a prime mover behind this work. It is impressive to realize that no matter what you do in the study of disordered systems, you are following in the footsteps of Mel Lax, since he either invented or was crucial in the development of both of the major approaches to this problem." [1] Mel never complained about not getting proper credit for his pioneering steps here or in other cases like it.

Mel was not without idiosyncrasies. We both recall many years of City College colloquium dinners with Mel at Chinese restaurants and also one of us (J.L.B.) recalls a 1980 China trip with Mel that bring memories of one area where Mel had very profound and openly expressed strong opinions: He did not like spicy food! When our physics group would order some food of questionable pungency at a Chinese dinner, the server was always instructed to make the "Lax cut" (i.e., to separate all vestiges of the hot sauce for the rest of us) but give Mel the mildest version of the dish possible. Mel's family reports that whenever the family went out to dinner, be it Chinese, Indian, kosher, or other, the Lax cut was a necessity so that dinner could proceed. And, despite various family attempts to re-educate Mel to the pleasures of some spicy dishes, his preference was clear and unchangeable.

Mel was very deeply affected by three global events during his lifetime: the Great Depression of the 1930s, World War II, and the Shoa (Holocaust). We will comment later on the effect of the economic depression of the 1930s on his career choices. World War II occurred when Mel was in graduate school, and his work during that period for the Navy, concerning the loss of ships to submarine attacks, left in him a deep and largely unspoken "old-fashioned" patriotism, evident in his quick willingness to serve his country by giving his consulting services to scientific agencies of the United States. During his career he consulted for the Army Research Office in Durham, Aberdeen Proving Grounds, and various other Navy and Air Force offices of scientific research. As far as we know, all this work was classified, and we have no direct knowledge of specifics of the projects on which he worked. Yet there are evident echoes of this work in Mel's long interest in extracting signals from noisy data—for example, when laser radiation is scattered from turbid or partially opaque media, such as dust in the atmosphere. Interestingly, this work also later appeared when he began a long and fruitful collaboration with Robert R. Alfano at City College on extracting and interpreting signals from noise in the scattering of laser light from human tissue, for example, to distinguish healthy from morbid cancerous tissue.

Mel was in a very deep way an intellectual whose ethics were profoundly informed by his Judaism. He was a completely moral person in his dealings with other people. His word was his bond. He was a teacher par excellence in the sense of being an ethical role model in his dealings with students and colleagues. As a referee or editor for a scientific journal, he would often have to evaluate other scientists' work. He did this in a most scrupulous fashion. If he found some work incorrect or incomplete, he would write a report in a straightforward fashion, emphasizing how the author could improve the paper by making such and such changes. Often this meant totally redoing the analysis along the lines he indicated and of course rewriting the paper. He never asked credit for this, but he took a quiet satisfaction in knowing that, with his suggestions, at least that part of the scientific literature would be correct. He always thought it was his responsibility as a prominent physicist to be an educator-teacher in the broadest sense.

When Mel and the authors of this memoir were in Moscow after having organized a U.S.-U.S.S.R. symposium on "Laser Light Scattering," he joined American colleagues in visiting and supporting a group of *refusenik* physicists and mathematicians who were hoping to learn of the latest scientific developments in the West. Mel (and others) did not let them down. Later, when emigration from the former Soviet Union became possible, Mel sponsored new immigrants from the former U.S.S.R. (some of whom had been refuseniks) to work with him under the Program for Refugee Scientists. He later helped these scientists obtain permanent academic or other professional positions in the United States.

We will turn now to some chronological history of Mel's life and work.

THE EARLY YEARS

Mel Lax was born in New York City on March 8, 1922. His father, Morris Lax, owned a men's clothing store, Lax Haberdashers; his mother, Rose Hutterer, studied pharmacy. Morris and Rose placed tremendous emphasis on education and read the newspaper to their children every day. At an early age Mel was reportedly reading the *New York Times* by himself. In high school Mel excelled in math and science. He was president of the math club and editor of the student newspaper.

Growing up during the Great Depression left Mel deeply concerned with being financially secure. In high school, as he later recalled, he had some fine science and math teachers who were teaching there because they could not get jobs at universities at that time. He decided early on in high school that he would become a high school math teacher, a career that offered the security of permanent employment. His high school math teacher, however, urged him not to cap his ambitions at that level but to go on for advanced study, including graduate work. Fortunately, Mel took this advice, attended New York University as a full-scholarship Charles Hayden Scholar, and graduated with a B.A. degree (summa cum laude) in physics in 1942.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

After graduating from NYU, Mel was admitted to the graduate school of the Massachusetts Institute of Technology with a Fellowship in Applied Mathematics; later he was a teaching assistant and research associate in physics en route to his M.S. degree (1943) and Ph.D. (1947). In reflecting on this period of his studies he would often remark with pride that he was a teaching assistant to both P. M. Morse and H. Feshbach and that he had worked out solutions to every one of the problems in the well-known two-volume textbook of Morse and Feshbach, *Methods of Mathematical Physics*.

Mel's Ph.D. years at MIT during the Second World War included three years of research (1942-1945) at the MIT Underwater Sound Laboratory, under the direction of P. M. Morse, R. H. Bolt, and H. Feshbach. Mel worked with a group that developed devices to acoustically decoy torpedoes away from ships. These devices reduced the loss of ships transporting soldiers and military equipment to Europe.

When the war ended, he returned to finish his Ph.D. He proposed a thesis topic to Morse, the more senior professor. Morse told him the problem was too hard, so Mel switched to Feshbach as his advisor. In his Ph.D. thesis he calculated the cross-section for photoproduction and electron production of mesons. The technique he employed later came to be known as the impulse approximation. During this time Feshbach selected Mel with Arthur Wightman and Conrad Longmire to spend a summer at General Electric Research Laboratories in Schenectady, New York. At MIT Mel's roommate was Eli Burstein, who later joined the Naval Research Laboratory.

SYRACUSE

After completing his Ph.D. at MIT, Mel received several job offers, including a postdoctoral fellowship at the Institute for Advanced Study in Princeton. This was probably the best job in the country for a young physicist at that time, but it would last only two or three years and then would require looking for another job. Mel's concern with financial security led him to look for a job that would offer him tenure and permanent job security after two years. Syracuse University offered him a position with a guarantee of tenure in two years, which he accepted.

In his early years at Syracuse Mel worked in nuclear and acoustical physics. While he was at Syracuse, the field of solid-state physics (now condensed matter physics) was developing rapidly, stimulated by the invention of the transistor at Bell Labs in 1947. Mel became convinced that solid-state physics was an important emerging area and decided to move his research interests in that direction. As a first and quite decisive step, he announced a new physics lecture course on solid-state theory. Then and throughout his career Mel prepared and distributed extensive, detailed lecture notes for every new course that he taught, some of which later developed into books.

From his publications we can track Mel's shift of interest from scattering problems to meson physics, and then to topics in magnetism, such as his study of the spherical model for dipoles on a lattice (a problem that had engaged Elliott

Montroll and Mark Kac, among others), and then to his early studies on transport and capture of carriers by defects in crystals, then lattice dynamics (especially the density of phonon states and how to determine it from "inverse" methods). We will return to this topic later.

In 1951 Mel was invited to spend the summer as a consulting solid-state theorist at the Physics Section of the Crystal Branch, Naval Research Laboratory, which was headed by E. Burstein, his former roommate at the MIT Graduate House. The phenomena being investigated by Burstein and his group at that time involved radiative and nonradiative transitions of impurities in semiconductors. Mel extended the work of K. Huang and A. Rhys on the radiative and nonradiative transitions in F-centers that was restricted to the case of optical phonons. He included acoustic phonons and developed a new technique that, as he described it, "relied on delta-function tricks." Some years later he wrote, "If an optical experimenter does his work with lenses and mirrors, a theorist does it with delta functions and Green's functions." Aside from the new technical procedures that he introduced, the results that he obtained using a semiclassical approximation shed light on the Franck-Condon principle in solids. His 1952 paper, "The Franck-Condon Principle and Its Application to Crystals," became a citation classic (reported in "This Week's Citation Classic," *ISI Current Contents* No. 38, September 25, 1985). Mel found it amusing that his entry paper to solid-state theory became a citation classic and commented that perhaps this was because of its innovative approach to a long-standing problem.

Another topic that bridged his earliest to his most recent work concerned the simultaneous interplay between electronic and ion displacement or vibration in determining the absorption and emission of light and the electrical resistivity of materials. These subtle electron-phonon effects were meticulously analyzed by him in early papers on the Franck-Condon energy shift of emitted light compared with absorbed light in bulk crystals and then taken up again some 40 years later to explain how hot (out of equilibrium) electrons and hot phonons can interact to give negative carrier mobilities in modern quantum well or heterostructure systems. This explanation has important device applications and is a completely counter-intuitive result.

Based on work during this period he wrote a comprehensive paper with Eli Burstein in 1955 on the fundamentals of infrared radiation connected with the ionicity or homopolarity of crystals and how to understand and interpret the *reststrahlen* absorption of such crystals. This work carried further the pioneering studies of Max Born, T. von Karman, and the preceding generation into a fuller and more fundamental treatment.

In his early work on quantum transport theory Mel introduced a density matrix theory of linear response from equilibrium.[2] This method was also developed independently by Kubo[3] and others (e.g., Mori, Nakano, Feynman). This method is usually known as the Kubo approach and has also been referred to as the Kubo-Lax description of transport properties.[4]

Mel remained at Syracuse University from 1947 to 1955, advancing from assistant to full professor. His published work during that period on theories of magnetism, phonons, optical properties of solids, and multiple scattering brought him growing attention as a major young theoretical physicist in the rapidly developing solid-state physics community and led to his being recruited to join the new Theory Department at Bell Laboratories in Murray Hill, New Jersey.

BELL LABS

Before 1950 Bell Labs contained a group of experimental laboratories to which theorists were attached. Following the departure of John Bardeen, Bill Shockley, Charles Kittel, and Hal Lewis, Bell Labs created its first Theory Department (1111) around the remaining theorists. They recruited Mel as the first new full-time member. He served as a member of the technical staff from 1955 to 1972, as chairman of the Theoretical Physics Department from 1962 to 1964, and continued as a consultant to the Physics Research Laboratory until his death. By 1958, when Mel recruited John Hopfield, the department was fast becoming the preeminent condensed matter theory group in the world. The invention of the transistor was quickly recognized as a major breakthrough in the communication and telephone business of Bell Telephone that would lead to many other novel devices.

When Mel joined Bell Labs his first initiative was to suggest a problem to J. C. Phillips, who had been hired as a postdoc. The resultant paper on density of electron states in a disordered system was one of the first to explore the effect of disorder on the electronic spectrum of solids. Another important initiative of Mel's was to hire John Hopfield into the theory group. This was a magnificent beginning to what became a highly productive period in Mel's professional life. When Mel took over the reins as the chair of the theory group, further progress was assured.

Around 1960 the laser was invented, and this provided another huge stimulus to theoretical work. Mel rapidly grasped and investigated two main themes in laser physics: the effects of fluctuations, or noise, and the analogy of laser action to a phase transition in conventional crystalline solids. The output of Mel's work on noise was phenomenal: some six papers on classical noise and a baker's dozen on quantum noise. In short, Mel created this specialty in laser physics.

Much of Mel's work was stimulated by the steady outpouring of extraordinary experimental results on semiconductor physics at Bell Labs. One of the major directions this took was the study of optical properties of solids, for example, the investigation of the frequency dependence of the optical absorption coefficient in the infrared region of the spectrum, due to creation/emission of phonons. Another set of observations concerned the detailed mechanisms of optical absorption near the fundamental edge due to electronic transitions from valence (filled) to conduction (empty) states in the crystal. These studies, as well as more intricate ones involving the scattering of conduction electrons or holes by phonons that affected the electrical conduction of the semiconductor, and especially its temperature dependence, required a microscopic quantum mechanical picture and theory of the processes involved. One of the key ingredients needed here was the application of symmetry/group theory to develop selection rules for allowed/forbidden processes and for relating different processes to one another. Mel made important contributions here, using the subgroup methods that he developed. And at one stage three of the practitioners of this arcane topic (in alphabetical order: J. L Birman, M. Lax, and R. Loudon) came together to write a joint paper on the relevant electron-phonon intervalley scattering selection rules needed to interpret data on electrical conductivity in GaAs and related III-V semiconductors with cubic zincblende structure.

Additionally Mel made a significant contribution to the use of time reversal symmetry in further simplifying the calculations. Because of the importance of group theory in many branches of physics, including molecular and solid-state physics, Mel gave a series of tutorial lectures on the subject for a number of years at Bell Laboratories. He developed a subgroup technique to obtain symmetry-related selection rules governing the go and no-go alternatives for physical processes (for example, scattering or optical transitions) in crystalline solids. His lectures on this topic were published in his 1974 book *Symmetry Principles in Solid State and Molecular Physics*.

Another important direction of Mel's work in those years at Bell Laboratories was investigation of the crystal lattice normal modes or phonons for those crystals important in semiconductor studies, such as silicon, germanium, gallium arsenide, and related materials. Part of this work required doing the symmetry analysis, and the complementary part required detailed calculation of the dispersion of the phonon frequencies as a function of wavelength or wave vector of the phonon waves. Mel, with Joel Lebowitz, had initiated some work on phonon density of states when he was at Syracuse University studying the moment analysis of vibration spectra. His work at Bell Labs carried the analysis to a deeper level by studying several force-coefficient models, including shell and valence force models and applying the analysis to actual materials. Related to this were his work on microscopic and macroscopic theories of elasticity of crystals and ultimately his studies on damping and anharmonicity effects on phonons. This work was reported at the 1963 International Conference on Lattice Dynamics, where Mel's talks spanned the gamut from group theory methodology to concrete calculations of phonon frequencies using microscopic mechanisms and early many-body treatments of anharmonicity. This work on phonon physics led him to an investigation with Donald Nelson at Bell Labs of the photoelastic effect, to which we now turn.

The photoelastic properties of anisotropic media were investigated very thoroughly in the earliest days of the study of light passing through a crystal and being modified due to both natural birefringence and induced optical anisotropy caused by external fields like stress. A compendium of all possible optically anisotropic coefficients had been compiled in the late nineteenth century by F. Pockels, one of the pioneers of the subject, in his book *Lehrbuch der Kristalloptik.* But in some very careful experiments by Don Nelson at Bell Labs, discrepancies were discovered between Pockels's predictions and experiments.

Nelson's studies of the coupling of light waves and acoustic waves led him to initiate a collaboration with Mel in order to develop a fundamental formulation of optical phenomena, including optical harmonic generation, piezoelectric coupling, and the photoelastic effect. The papers they produced on this topic were exhaustive and covered the range from macroscopic measurable consequences of the new effects to microscopic, atomistic force models of the origin of these effects. Nelson realized that they had shown that the photoelastic effect was dependent on the displacement gradient (which is a sum of the long wavelength strain and long wavelength rotation), not on the strain alone as in the Pockels theory. This led him to measure the effect by Brillouin scattering experiments, first in rutile and then in calcite, resulting in the discovery of the discrepancies noted above, which were in dramatic agreement with the new predictions of their theory.

The rapidly growing interest in electrical response of semiconductors to high electric fields resulted in much new experimental information about nonlinear conductivity in such systems. This topic rapidly grew into a major subject of investigations: the effect of "hot electrons" on the nonlinear conductivity. With characteristic focus Mel carefully investigated analytical and numerical techniques for solving the coupled Boltzmann transport equations for the distribution functions of the hot electrons, holes, and acoustic and optic phonons.

Starting in the mid-1990s much work in semiconductors began on low dimensional systems. A typical example is the quantum well in which electronic carriers are confined to two-dimensional regions, such as thin layers or surface regions. Mel invented a way to deal with the interaction of three-dimensional phonons with the confined electrons. His key and novel idea was to introduce a wave packet of coherent phonons whose envelope function is determined by the confined electron wave function. This formalism enabled a realistic calculation showing that there is a reduction of one order of magnitude in the energy transfer from the electrons to the phonons when the phonon distribution has been "heated." A novel prediction of this theory, confirmed by time-dependent relaxation experiments when both electrons and holes are present, is that the system will exhibit negative mobility.

When Mel accepted a post at City College in 1971, he retained a position at Bell Labs as a consultant to the electronics division, where he collaborated with many experimental groups, particularly that of V. Narayanamurti on high field effects on semiconductor transport.

CCNY

We now turn to the period after Mel joined the City College (CCNY) of the City University of New York (CUNY) as Distinguished Professor of Physics. Since its founding in 1847, City College had been noted for excellence in teaching. Many outstanding physicists (as well as chemists, future physicians, and others) had passed through as undergraduates majoring in the sciences. Indeed, seven Nobel laureates are included in that group. However, by the 1960s it was clear that the Physics Department was in urgent need of moving forward to include Ph.D.-level work. And so in 1967 the Physics Department at the City College of New York, then chaired by Harry Lustig, won a competitive National Science Foundation departmental development grant to transform its undergraduate Physics Department into a research focused Ph.D.-level department, including the creation of three Distinguished Professorships. In 1970 CCNY President Robert Marshak recruited the first two City College Distinguished Professors (Mel Lax and Bunji Sakita), and Mel recruited the third (one of us: H.Z.C.). Mel served as Distinguished Professor of Physics at City College from 1971 until his death. Mel quickly set about recruiting other new faculty members in condensed matter theory and experiment, including the authors of this memoir, and Harry Swinney. This triple hire was code-named "the BCS package" at CCNY. Because of Mel's efforts and those of other faculty (some of whom, like Myriam Sarachik and Robert Alfanos, had joined CCNY earlier), the condensed matter physics activity at CCNY took a major step forward.

Mel quickly adapted to the academic life. He enthusiastically began teaching basic graduate physics courses, such as electrodynamics and quantum theory, and he also developed his own variety of specialized lectures while continuing his research programs, now with his students and postdoctoral research associates. Many of them have since gone on to major academic, industrial, and government laboratory careers in the United States and overseas.

At City College Mel taught and carried out theoretical research in condensed matter physics, laser physics, coherence and fluctuations in classical and quantum systems, and nonlinear interaction of light and sound in solids. And he developed a new direction for his investigations: foundations of quantum mechanics.

His City College colleagues considered Mel the complete and ideal colleague. He prepared his lectures with exceptional care and delivered them clearly to his students. In many of the advanced courses that he taught he prepared extensive and detailed notes, which he photocopied and distributed to the students. This was a considerable effort and was an enormous benefit to his students. He was always available to students, colleagues, and coworkers for lengthy discussions, including phone and e-mail exchanges, and he shared his ideas and insights freely and graciously. All this took a great amount of his time, which he cheerfully gave. He served on many departmental, college, and university committees, such as the University Committee on Research, where he chaired the All-University CUNY Physics Faculty Research Award Program for several years. He was a member and chair of many departmental promotion and tenure committees, including committees on promotion to distinguished professor of the university. He brought to this work the very highest standards, tempered with a deep understanding of the strengths and limitations of the candidates. When Mel supported appointing a new faculty member or awarding tenure or promotion, it was universally accepted that this action was well merited.

During his last years Mel worked in the area of inverse scattering techniques needed to extract information from noisy measurements. Applications included the use of light scattering to study clouds using lidar techniques, searching for oil-bearing layers using acoustic backscattering, and the detection of possible tumor nodules in the human breast using pulsed, noninvasive infrared light. In carrying out this research Mel and his colleagues reexamined the Boltzmann transport equation. Scientists had tried for decades to develop the analytical solution of the classic Boltzmann transport equation. Mel developed and extended the theory of light scattering and transmission through strongly turbid media.

He developed algorithms to extract meaningful signals that could enable differentiation of different constituents contributing to the scattered light. The objective was to determine different responses from malignant and healthy tissue. With R. R. Alfano, W. Cai, and Min Xu, Mel developed the analytical theory to the extent possible and then the algorithms and codes needed for detailed numerical analysis. Not surprisingly some of this work was an echo of his earlier work on light scattering in the dense atmosphere with inclusions of particulate matter. His new methods for the solution of Boltzman's equation by cumulant expansion was among the last projects he completed before his death.

At his death all his colleagues at City College shared the profound feeling of having lost a unique and irreplaceable colleague who played a key part in bringing the Physics Department at City College to national and international prominence during the years starting in the mid-1970s. Equally, his colleagues are deeply grateful to have had the opportunity to work with him during this exciting period in the life of the CCNY Physics Department.

PERSONALIA

Mel took deep pride in his family. Although he was relatively reticent about most domains of his life, he was quite outspoken with pride in the achievements of his wife, Judy, and their children and grandchildren. Mel was an enthusiastic tennis player and played regularly in the evenings. In December 2001, while driving home from a night tennis game, he suffered a massive stroke. By the following June he had recovered the ability to walk although he did not regain his full cognitive abilities. With his research associate, Wei Cai, and former students, Min Xu and Boris Yudanin, he was energetically trying to complete two monographs: *Random Processes in Physics and Finance,* and *Quantum*

Optics. At the time of writing this memoir (spring 2005) the first of these, *Random Processes in Physics and Finance* by Melvin Lax, Wei Cai, and Min Xu has been completed and will be published by Oxford University Press.

In the summer of 2002 Mel was found to have inoperable cancer, to which he succumbed peacefully on December 8, 2002.

Mel is survived by his wife, Judith; his daughters, Laurie and Naomi; his sons, David and Jonathan; and five grandchildren, Eric and Lena Lax, Hannah Kober, and Dahlia and Orli Katz.

SERVICE AND HONORS

Mel was always prepared to offer service to the physics community. His early work for the American Physical Society as chair of its Publications Committee was instrumental in creating the present system of electronic submission and processing of manuscripts, which is now practically universal. Mel served on the editorial boards of *Physical Review* and of *Quantum Optics*, as a member of the advisory board of World Scientific's *Modern Physics Letters B* and *International Journal of Modern Physics*, and as editor of *Advanced Series in Applied Physics.* He was a member of the Basic Research Advisory Committee of the National Academy of Sciences and provided scientific services to the Naval Research Laboratory, Los Alamos National Laboratory, the U.S. Army Research Office, and the U.S. Department of Energy.

Mel was elected to the National Academy of Sciences in 1983 in recognition of his many contributions to science. He served as secretary of Class III (Engineering and Applied Physical and Mathematical Sciences) 1989-1992 and 1995-1998. He was a Fellow of the American Academy of Arts and Sciences, the American Physical Society, the American Association for the Advancement of Science, and the Optical

Society of America. In 1999 he received the Willis Lamb Medal for Laser Science and Quantum Optics, together with Lorenzo Narducci and Herbert Walther. In addition to his long-term faculty appointments at Syracuse University and the City College of New York, Mel also taught at Princeton (spring 1961) and Oxford (1961-1962) and gave many lecture series around the world: in Vancouver, Tokyo, Trieste, Florida, Varenna, Israel, Kyoto, Beijing, Lausanne, and New Mexico.

In writing this memoir we drew extensively on autobiographical material in the National Academy of Sciences' files by Mel, as well as material by Mel and by P. W. Anderson collected in the volume *CCNY Physics Symposium: In celebration of Melvin Lax's Sixtieth Birthday.*[1] We also acknowledge contributions of material by Mel's family and colleagues, including Judy Lax, David Lax, Eric Lax, Eli Burstein, Wei Cai, Harry Frisch, Charles Henry, John Hopfield, Donald Nelson, Takashi Odagaki, and Michael Lubell.

NOTES

1. P. W. Anderson. Random lattices thirty years after. In *CCNY Physics Symposium: In Celebration of Melvin Lax's Sixtieth Birthday*, ed. H. Falk, pp 1-14. New York: City College of New York Physics Department, 1983.

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