Benjamin Lax

1915–2015

BIOGRAPHICAL *Memoirs*

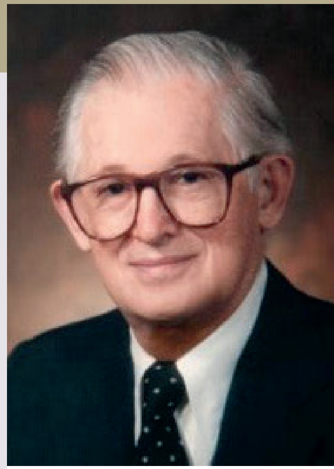
A Biographical Memoir by
Roshan L. Aggarwal
and Marion B. Reine

NATIONAL ACADEMY OF SCIENCES

BENJAMIN **LAX**

December 29, 1915–April 21, 2015

Elected to the NAS, 1969



Benjamin Lax

By Roshan L. Aggarwal[1]
and Marion B. Reine[2]

Benjamin Lax made significant and lasting contributions to solid-state physics and engineering. He innovated new resonance phenomena, including cyclotron resonance, to determine the basic band structure of semiconductors. He pioneered the field of magneto-optics and made important theoretical contributions that led to the demonstration of the first semiconductor GaAs diode laser. His seminal basic and applied research on semiconductor physics and engineering, which included solid-state plasmas and quantum electronics, provided a foundation for the development of semiconductor technology.

The locus of Ben's sixty-year career was the Massachusetts Institute of Technology (MIT). His career began during World War II at the MIT Radiation Laboratory on the MIT campus in Cambridge, Massachusetts. After the war, in 1951, he joined the recently formed MIT Lincoln Laboratory in Lexington, Massachusetts, where in 1958 he became the head of the Solid State Division and in 1964 the associate director of the Lincoln Laboratory. He championed and secured funding for the Francis Bitter National Magnet Laboratory located on the MIT campus, and in 1960 he became the founding director of that laboratory. In 1965, he became a professor in the MIT Department of Physics, where he supervised thirty-six MIT doctoral students over a thirty-year period.

Ben received the Oliver E. Buckley Prize for Condensed Matter Physics from the American Physical Society in 1960 for "his fundamental contributions in microwave and infrared spectroscopy of semiconductors." He was elected to the National Academy of Sciences in 1969. He is the author or coauthor of over three hundred journal articles and a coauthor of the classic book *Microwave Ferrites and Ferromagnetics* (McGraw-Hill, 1962).

1 MIT Lincoln Laboratory, Lexington, MA 02420

2 Consultant on Infrared Detectors, Cambridge, MA 02138

He became director emeritus of the National Magnet Laboratory in 1981 and professor emeritus in the MIT Department of Physics in 1986. Ben remained an active, enthusiastic, and valued consultant to MIT Lincoln Laboratory until 2006.

Early years

Ben was born in Miskolc, a town in northeastern Hungary, on December 29, 1915, the fourth of six children born to Amelia and Louis Lax. As a young boy, he was strong-willed, resilient, intelligent, resourceful, and he exhibited a natural athleticism. He was also a whiz at mathematics.

In 1924, Ben's father immigrated to the United States. In August 1926, after a weeklong trans-Atlantic crossing in steerage, ten-year-old Ben along with his mother and siblings arrived at Ellis Island and were welcomed there by his father.

The Lax family settled in Brooklyn, New York. Ben's father was a very religious man and wanted Ben to be a rabbi. Ben's interests, however, were firmly rooted in science and engineering. His natural talent for mathematics was evident early on. To stave off boredom while in temple, Ben would solve mathematics problems in his head, visualizing the formulae and their solutions. By the end of his junior year in high school, he had taught himself integral and differential calculus by reading William Granville's classic textbook.

Ben graduated from Boys High School in Brooklyn in 1936 with awards in mathematics, science, and languages.

During the academic year 1936–1937, Ben attended Brooklyn College, where he received first prizes in two mathematics competitions. In 1937, he entered Cooper Union Institute of Technology in New York City, where he held the Schweinburg Scholarship for four years. In 1941, he graduated *cum laude* with a bachelor's degree in mechanical engineering and honors in mathematics.

He married Blossom Cohen in New York City on February 11, 1942.

The war years

Ben began graduate work at Brown University in mathematics in 1942, but was drafted into the US Army that year. After a rapid series of assignments, which included taking accelerated war-time electronics and radar classes at Harvard University and MIT, he was assigned to the MIT Radiation Laboratory in 1943. Demonstrating an infectious enthu-

First Lieutenant Benjamin Lax, *circa* 1944.
(Photo courtesy Daniel R. Lax.)

siasm and keen initiative, he led a small group in a crash program to put together a new radar system named "Li'l Abner" (AN/TPS-10), an X-band height finder, which was successfully field tested and actually deployed.

After the war, in 1946, he entered graduate school at MIT. He first approached John C. Slater (1900–1976), a professor of physics, as his potential thesis advisor. Stuart Leslie in his 1993 book The Cold War and American Science relates this anecdote from an interview he conducted with Ben in 1988:

He intended to do a theoretical dissertation and collaborated with Slater for a time on magnetron theory. But Slater suggested that, at 31, Lax might be too old for a theoretical career. (Twenty years later, with the advantage of hindsight, Slater suggested that perhaps Lax was not yet quite old enough!)

Ben earned his PhD in plasma physics three years later, in 1949, with Professor Sandborn C. Brown as his advisor. His thesis research was part experimental and part theoretical, and was done in the Microwave Gas Discharge Laboratory within the MIT Research Laboratory for Electronics. His thesis research, titled "The Effect of Magnetic Field on the Breakdown of Gases at High Frequencies," served as a foundation for the rest of his highly productive research career.

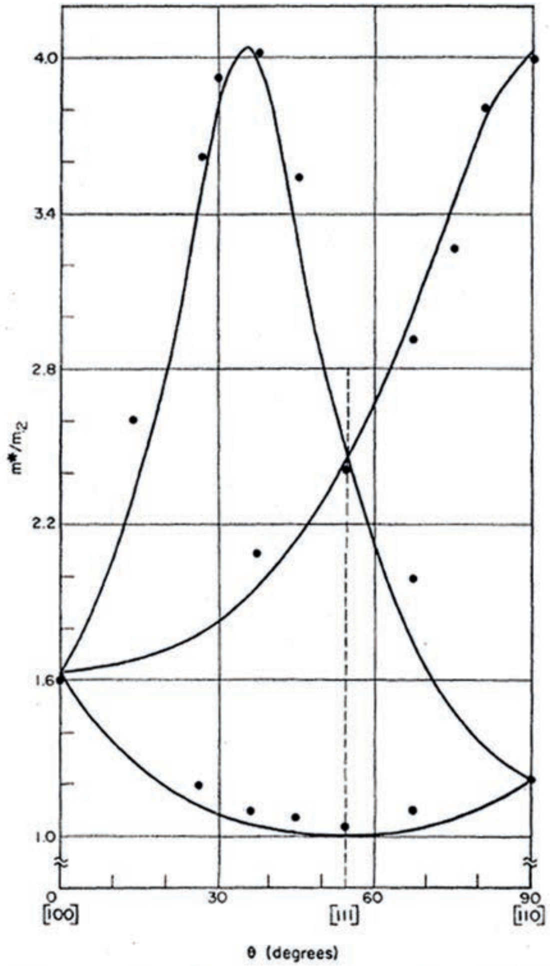


FIG. 2. Variation of the effective electronic mass m^* in a (110) plane as a function of θ. m^* is rationalized by the transverse mass $m_2 = 0.08\ m_0$. The solid lines are theoretical curves. The dots are experimental points.

Determination of the antisotropic electron effective mass in germanium from cyclotron resonance in germanium experiments performed at MIT Lincoln Laboratory. From: B. Lax, H. J. Zeigler, R. N. Dexter, and E. S. Rosenbluh, Directional properties of the cyclotron in germanium. *Phys. Rev.* 93:1418-1420. (1954)

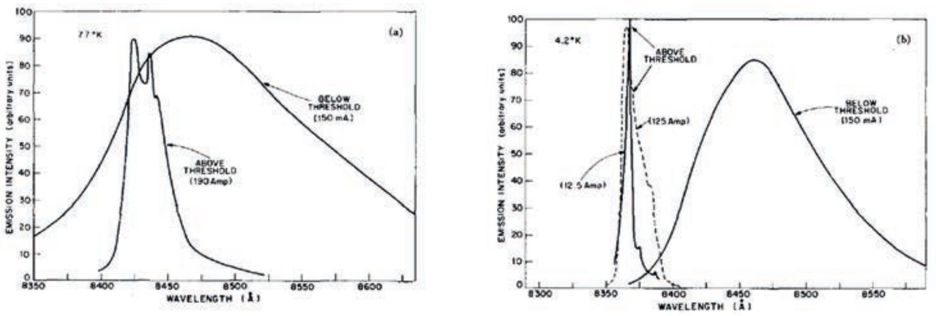


Fig. 2. **Spectrum of emitted radiation before and after threshold, both for 77°K (*a*) and 4.2°K (*b*). The resolution of grating spectrometer is 4 Å. The emission intensity scale is different from curve to curve.**

The first semiconductor diode laser at MIT Lincoln Laboratory. From: T. M. Quist, R. H. Rediker, R. J. Keys, W. E. Krag, B. Lax, A. L. McWhorter, and H. J. Zeigler. Semiconductor maser of GaAs. *Appl. Phys. Letters* 1:91-92. (1962)

MIT Lincoln Laboratory

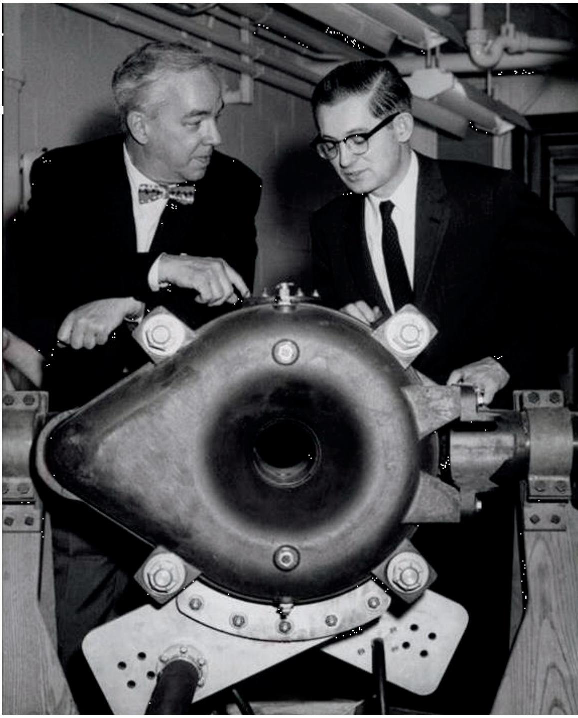
Ben joined MIT Lincoln Laboratory in Lexington, Massachusetts, in 1951. Early on, he exhibited strong technical and leadership abilities, both of which had been recognized and exploited by his commanders in the Army during the war. This combination of abilities—together with his sense of urgency, passion for getting things done, and determined persistence in overcoming obstacles and adversity, both man-made and technical—would shape his entire career. They also propelled his rapid advancement at Lincoln Laboratory. He became leader of the Ferrites Group in 1953, leader of the Solid State Group in 1955, associate head of the Communications Division in 1957, head of the Solid State Division in 1958, and associate director of Lincoln Laboratory in 1964.

Motivated by the spectacular success of semiconductors as materials that would enable a new generation of solid-state devices such as transistors, solar cells, and photodetectors, he soon initiated and participated in a broad array of programs in the physics and materials science of semiconductors and semiconductor devices. These programs would firmly establish Lincoln Laboratory as a major leader in semiconductor physics, materials science, and devices for the next decades and continuing up to the present.

In 1965, he resigned his position as associate director of Lincoln Laboratory to assume full-time duties as the founding director of the National Magnet Laboratory and professor in the MIT Physics Department.

Frances Bitter National Magnet Laboratory at MIT

MIT Physics Professor Francis Bitter had founded a small magnet laboratory in 1938 in the basement of Building 4 on the MIT campus. There, Bitter revolutionized high-field electromagnet technology with a unique design for a water-cooled solenoid configuration, which soon came to be called the Bitter magnet design.

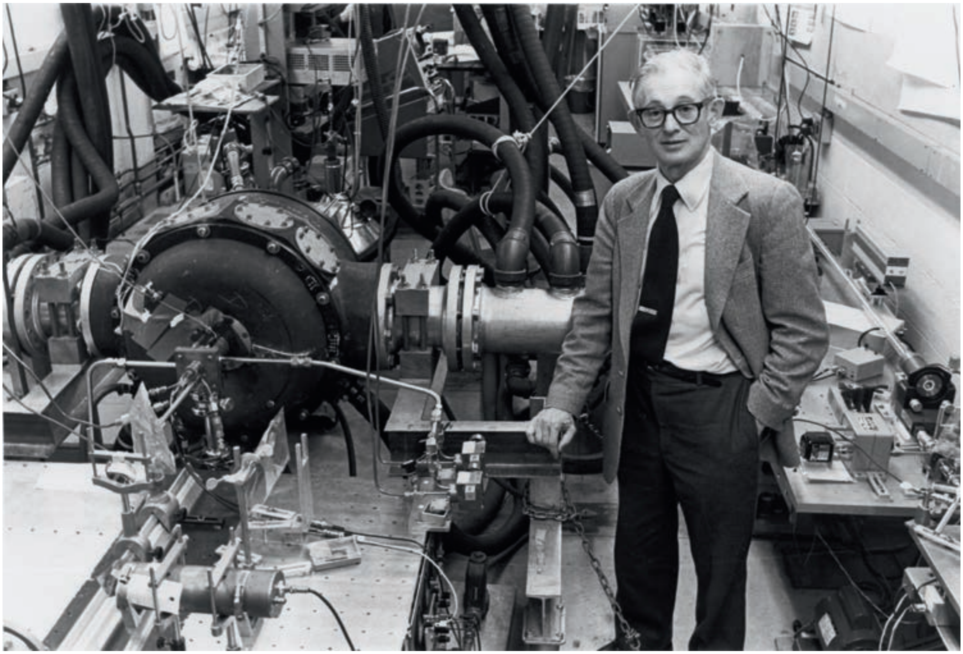


Ben is seen here with Prof. Francis Bitter, reviewing features of Bitter's design for water-cooled solenoid electromagnet. This photograph was **(probably) taken in Prof. Bitter's magnet laboratory in the basement of Building 4 on the MIT campus, *circa* 1957.** (The MIT Museum Collections.)

Ben's Solid State Division at Lincoln Laboratory had pioneering success in using the magnets in Bitter's MIT laboratory to do cyclotron resonance and magneto-optical experiments at moderately higher magnetic fields than were available at Lincoln Laboratory.

In 1957, recognizing the need for significantly higher magnetic field strengths to realize new phenomena and achieve higher resolution in magneto-optics and other semiconductor and semimetal characterization techniques, Ben conceived and set about generating interest for a new type of magnet laboratory. It would be a unique national facility, and would be devoted to the design, development, operation, and utilization of improved magnets. The goal was achieving a magnetic field strength of 250 kG, a factor of 2.5 higher than had been achieved in Bitter's laboratory.

Ben championed the successful proposal and secured the necessary financial support from the Air Force Office of Scientific Research for the establishment of the MIT National Magnet Laboratory in Cambridge, Massachusetts. He was the founding director of that laboratory for twenty-one years, from 1960 through 1981.



At the Francis Bitter National Magnet Laboratory at MIT, in one of the ten similar-size magnet “cells.” A Bitter electromagnet is on the left, with its bore oriented horizontally. The semi-flexible dark rubber hoses provide cooling water to and from the core of the magnet at a rate of 10,000 gallons per minute.

The mission of the new National Magnet Laboratory was to advance the art of generating intense magnetic fields, to make intense magnetic fields available for research, and to investigate the properties of matter in intense magnetic fields.

The National Magnet Laboratory was renamed the Francis Bitter National Magnet Laboratory on November 21, 1967 in honor of Professor Bitter (1902–1967), as recognition for his efforts in bringing the National Magnet Laboratory into existence and for his original design of the high-field “Bitter” water-cooled solenoid electromagnets.

Initially, Ben wanted the new National Magnet Laboratory to be located at Lincoln Laboratory in Lexington, Massachusetts, which is about fifteen miles west of the MIT campus in Cambridge. But the magnets’ need for a good supply of cooling water dictated that the new laboratory be located on the MIT main campus, nearly adjacent to the

Charles River. Two four-foot-diameter pipes were run beneath the MIT campus to connect the Charles River with the Magnet Laboratory, providing cooling water to the magnets at rates of up to ten thousand gallons per minute.

Under Ben's direction and leadership, the National Magnet Laboratory at MIT rapidly became an internationally preeminent center for basic research in a number of interrelated fields utilizing high magnetic fields, including magneto-optical studies of the physics of important semiconductors such as Si, Ge, PbTe, InAs, InSb, and HgCdTe. Other research areas included nuclear magnetic resonance, Zeeman splitting of fluorescence and absorption lines of paramagnetic ions in nonmagnetic host crystals, original observation in semiconductors of interband Faraday rotation and the interband Voigt effect, the Mossbauer effect, determination of the critical internal field in antiferromagnetic materials, de Haas-van Alphen experiments in ferromagnetic metals, magneto-optical and magneto-acoustical studies in bismuth and semimetals, magneto-tunneling in semiconductors, biomagnetism studies of the brain, laser-plasma interactions and plasma diagnostics, thermomagnetic effects in bismuth alloys, cyclotron resonance in diamond, and studies of high-field superconductivity.

The National Magnet Laboratory maintained its own internal research and operational staff of well-known scientists and engineers, which was supplemented by a steady stream of visiting scientists, postdoctoral fellows, and faculty members from around the world. Many of them were recruited by Ben. There was ample technician, machine shop, and electronic instrumentation support available. And there were always a goodly number of Ben's graduate students from the MIT Physics Department roaming around the Magnet Laboratory, each indentured to various permanent and visiting scientists who assisted Ben in supervising their thesis research.

As testimony to the excellence of the research facility that Ben established, staffed, and led, the fractional quantum Hall effect was discovered by Professor Horst L. Störmer of Columbia University and Prof. Daniel C. Tsui of Princeton University on October 7, 1981, in experiments conducted as visiting scientists at the National Magnet Laboratory with a 23 Tesla magnet. For this work, they and Professor Robert B. Laughlin of Stanford University received the 1998 Nobel Prize for Physics "for their discovery of a new form of quantum fluid with fractionally charged excitations."

Whenever Ben returned from a physics meeting, his briefcase would bulge with manuscripts, preprints and, most important, precious samples of rare semiconductor materials that would form the basis for a thesis or two. At a rapid series of hastily assembled

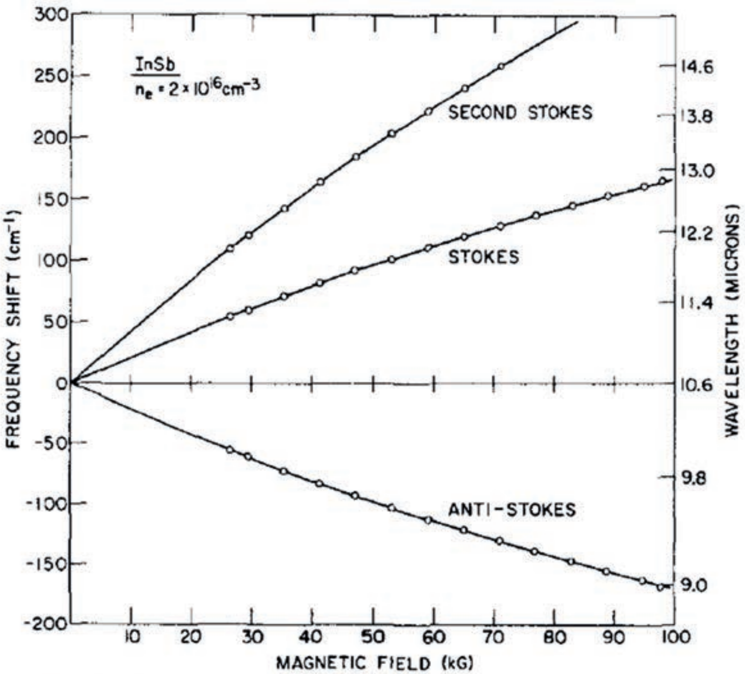


FIG. 3. Tuning curves for anti-Stokes, Stokes, and second Stokes components of the stimulated spin-flip Raman scattered radiation from InSb ($n_e = 2 \times 10^{16}$ cm^{-3}) pumped with 10.6-μ radiation from a high-pressure CO_2 laser.

Magnetic-field tuning of stimulated spin-flip Raman scattering in experiments performed at the Francis Bitter National Magnet Laboratory.
From: R. L. Aggarwal, B. Lax, C. E. Chase, C. R. Pidgeon, D. Limbert, and F. Brown. High-intensity tunable InSb spin-flip Raman laser. *App. Phys. Letters* 18:383-385. (1971)

meetings in Ben's office at the National Magnet Laboratory, he would staff-out news and samples, as well as ideas and directions for new experiments to be done posthaste. His competitive nature was on full display, urging that the experiments be done as soon as physically or humanly possible, or even sooner.

In 1981, he was appointed director emeritus and physicist of the National Magnet Laboratory. On June 15, 1981, an all-day symposium was held at MIT in honor of Ben's achievements as founding director of the National Magnet Laboratory. Papers were presented by Professor Nicolaas Bloembergen of Harvard, who received the Nobel Prize

Benjamin Lax with Herman Feshbach, Francis E. Low, and Roshan L. Aggarwal at the Lax symposium organized by the MIT Physics Department on 15 June 1981.
(The MIT Museum Collections.)

in Physics that same year for his work in laser spectroscopy; by Dr. C. K. N. Patel of Bell Laboratories, who invented the CO_2 laser; and by other notable physicists whose work was related to the research activities of the National Magnet Laboratory.

MIT Department of Physics

Ben was appointed to the faculty of the Department of Physics at MIT in 1965. He supervised fifty-one MIT theses, including thirty-six PhD theses, over the thirty-year period from 1962 to 1991.

He thoroughly enjoyed being a professor. He had thrived and excelled in academics throughout his entire life, and now he was a professor in one of the finest physics departments in the world. Through this position, he facilitated collaborations with the National Magnet Laboratory, both within the Department of Physics and with other MIT departments such as Materials Science and Electrical Engineering and Computer Science. His professorship also afforded him access to a regular stream of outstanding graduate students who conducted their research at the Magnet Laboratory.

Ben found time to teach courses every semester, including both undergraduate recitation sections and a graduate-level course, Special Topics in Solid State Physics, as well as other special topics courses. He would on occasion teach a course on a topic that was related to the concurrent thesis research of his graduate students.

In 1960, Ben received the Oliver E. Buckley Prize for Condensed Matter Physics from the American Physical Society for "his fundamental contributions in microwave and infrared spectroscopy of semiconductors." This award acknowledged Ben's leadership in establishing cyclotron resonance and magneto-optics for elucidating the energy band structure of semiconductors.

Ben was elected to the American Academy of Arts and Sciences in 1962 and to the National Academy of Sciences in 1969. He was a Fellow of the American Physical Society (APS), a member of the APS Council, and a member of the Executive Committee of the APS Solid State Division. He was awarded an honorary doctor of science degree from Yeshiva University in June 1975. In 1981, he was named a fellow of the American Association for the Advancement of Science and was awarded a Guggenheim Fellowship in Mathematics. In 1986, he became professor emeritus in the MIT Department of Physics.

Ben served as the chairman of the organizing committee for the 10th International Conference on the Physics of Semiconductors, which was held in Cambridge, Massachusetts, on August 17–21, 1970. He also served as the associate editor for *Physical Review*, *Journal of Applied Physics*, and *Microwave Journal*.

Final thoughts

Ben passed away on April 21, 2015, predeceased by his wife Blossom (1923–2007). He is survived by two sons, Daniel R. Lax (b. 1948) of Atlanta, Georgia, and Robert M. Lax (b. 1950) of Newton, Massachusetts; and a granddaughter, Rachael Lax Day.

Ben exercised his natural athletic abilities throughout his life. He was often seen in action on one of the MIT squash courts, in heated contests with a student or colleague. He started downhill skiing at the age of fifty-seven and continued skiing into his eighties.

Ben's life and career influenced the lives and careers of countless students, colleagues, faculty, and research staff, both within the MIT community and beyond. Ben gave of himself to foster the success of others. He was always able to recruit a loyal and collaborative cadre of talented scientists whom he would motivate with his visionary ideas that were rooted in sound physics; they, in turn, would use those ideas as starting points for promising research efforts. Ben did much to increase the presence of women in physics. He hired Mildred S. Dresselhaus (MIT Professor of Physics, Emerita Professor of Electrical Engineering, and Emerita Institute Professor) in 1960 at Lincoln Laboratory. Among other women physicists that Ben encouraged and mentored are Laura M. Roth, Margaret H. Weiler, Sunny Y. Auyang, and Aviva Brecher.

Ben was passionate and competitive about physics and research. He was devoted to his family, loyal to his staff and colleagues, and supportive of his graduate students. He had an innate ability in mathematics and a strong intuitive grasp of physics. He was a leader and a visionary who acted quickly, overcame obstacles and adversity, and brought seminal theories and marvelous new experimental physics facilities into being. He launched the careers of thirty-six MIT doctoral students into a diverse range of successful directions.

> *"He who controls magnetism will control the universe."*
> *—Paraphrased from a Dick Tracy cartoon, 1932.*

> *"He who masters magnetism can bring enormous blessings to mankind."*
> *—Benjamin Lax, "Science and Magnetism," University of Utah Frontiers of Science Lecture, December 16, 1969.*

Enduring Contributions to Science and Engineering

Ben's major contributions to solid-state physics and engineering are both technical and organizational:

Ben was instrumental in the establishment of the Solid State Division in 1958 at Lincoln Laboratory. He was its first division head from 1958 to 1964.

Ben made a significant contribution to cyclotron resonance in semiconductors for the measurement of electron and hole "effective" masses.

Ben played an important leadership role in the development of the first semiconductor diode laser at Lincoln Laboratory

Ben was responsible for convincing the Air Force Office of Scientific Research to set up the National Magnet Laboratory at MIT in Cambridge in 1960.

Ben supported the initial effort for the development of the high-field Tokomak for plasma fusion research at the Francis Bitter National Magnet Laboratory. Later this research was the focus of the MIT Plasma Fusion Center.

Ben made important contributions to high-field magneto-optical studies at Lincoln Laboratory and at the Francis Bitter National Magnet Laboratory.

ACKNOWLEDGMENTS

We thank Dr. Daniel R. Cohn, Daniel R. Lax, and Dr. Donald T. Stevenson for their contributions to this memoir. We thank Rajesh Aggarwal for finding the book by Stuart W. Leslie, *The Cold War and American Science.* We also thank Vicky Metternich and Tran Tan-Quy of the MIT Physics Department, Rachael Robinson of the MIT Museum, and Myles Crowley of the MIT Archives for additional biographical material.

CAREER SUMMARY

Born	29 December 1915 (Miskolc, Hungary)
Died	21 April 2015 (Newton, Massachusetts)
Education	
1941	Bachelor of science in mechanical engineering, Cooper Union
1941	1st Lieutenant, Officers Candidate School, Fort Monmouth, New Jersey
1949	PhD in physics, Massachusetts Institute of Technology (MIT)
Positions	
1944–1946	MIT Radiation Laboratory, Radar Officer
1946–1951	US Air Force Cambridge Research Center, Staff Member
1951–1953	MIT Lincoln Laboratory, Staff Member
1953–1955	MIT Lincoln Laboratory, Head of the Ferrites Group
1955–1957	MIT, Head of the Solid State Group, Lincoln Laboratory
1957–1958	MIT, Associate Head of the Communications Division, Lincoln Laboratory
1958–1964	MIT, Head of the Solid State Division, Lincoln Laboratory
1960–1981	MIT, Director of the Francis Bitter Magnet Laboratory
1964–1965	MIT, Associate Director of the Lincoln Laboratory
1965–1986	MIT, Professor of Physics
1981–2015	MIT, Director Emeritus and Physicist, Francis Bitter Magnet Laboratory
1986–2015	MIT, Professor Emeritus of Physics
Selected Participation	
1957–1959	Associate Editor, *Journal of Applied Physics*
1960–1963	Associate Editor, *Physical Review*; Associate Editor, *Microwave Journal*
1963–1967	Council member of the American Physical Society and Member of the Executive Committee for the American Physical Society Solid State Division
1964–1981	Member, IEEE-APS-OSA Joint Council on Quantum Electronics
1966–1968	Chair, IEEE-APS-OSA Joint Council on Quantum Electronics
1970	Chair, Organizing Committee, 10th International Conference on the Physics of Semiconductors, Cambridge, Massachusetts, August 17–21, 1970
1970–1981	Member, Solid State Science Panel, National Research Council

HONORS AND AWARDS

1957 Fellow, American Physical Society

1960 Oliver E. Buckley Condensed Matter Physics Prize, American Physical Society

1962 Member, American Academy of Arts and Sciences

1964 Cooper Union Distinguished Professional Achievement Award

1965 Citation for Outstanding Achievement, US Air Force Systems Command

1969 Member, National Academy of Sciences

1969 Gano Dunn Medal, Cooper Union Alumni Association

1970 Office of Aerospace Research Outstanding Achievement Award

1975 Honorary Doctor of Science degree from Yeshiva University

1981 Guggenheim Fellowship in Mathematics

1981 Fellow, American Association for the Advancement of Science

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Benjamin Lax, an oral history conducted on June 13, 1991, by Frederik Nebeker, IEEE History Center, Hoboken, NJ, USA. http://ethw.org/Oral-History:Benjamin_Lax. Nebeker was a senior research historian at the IEEE History Center at Rutgers University. His interview covers Ben's experiences in the Army and at the MIT Radiation Laboratory during the years 1942 to 1949. This readable and informative interview brings out the characteristics that Ben honed in his brief but productive military career and that served him well throughout the rest of his career—the abilities to navigate a system and make it work for you, to take initiative, to assemble a team, to motivate others to carry out projects on deadline. Here is Nebeker's abstract:

"Lax got his degree in mechanical engineering from Cooper Union, was starting a PhD in applied math at Brown in 1942, when he got drafted into the Army. A self-directive individual, he managed to get himself into the Signal Corps, into radio school, into OCS to qualify as a military math teacher, into radar school, and finally assigned on extended detached duty. He worked there from March 1944, essentially on the L'il Abner radar, AN/TPS-10, an X-band height-finder. He went from building a breadboard model to integrating the various parts and demonstrating it for the military. L'il Abner was in production by Nov. 1944 and in the field in time for Okinawa. Essentially he acted as a civilian scientist in uniform. After the war he got his PhD in Physics from MIT, and went on to a career largely in solid-state physics."

Stuart W. Leslie (1993). *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press), pages 195–201 contain a brief history of the MIT National Magnet Laboratory.

Eva C. Freeman, ed. (1995). MIT Lincoln Laboratory: Technology in the National Interest, (Lexington: MIT Lincoln Laboratory). Pages 194–199 contain a history of the of the early days of solid-state physics and device research between 1954 and 1963, written by Ben Lax and covering ferrites, cyclotron resonance, and magneto-optical spectroscopy.

Interviews with Benjamin Lax conducted by Donald T. Stevenson, 1998–2000, unpublished. Original tapes are with the American Institute of Physics (AIP) Center for the History of Physics.

Dan Cohn (April 27, 2015). “Professor Emeritus Benjamin Lax dies at 99: Pioneer in semiconductors created MIT’s magnet laboratory and served as associate director of the MIT Lincoln Laboratory,” *MIT News.*

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