Arthur von Hippel: The Scientist and the Man

Frank N. von Hippel

Abstract

"We will not be intimidated!" is one of the mottos Arthur R. von Hippel lived by. From refusing to salute Hitler to starting a unique interdisciplinary university laboratory—the Laboratory for Insulation Research at the Massachusetts Institute of Technology—von Hippel followed his principles, laying the foundations for modern materials research and distinguishing himself as a pioneering scientist, an inspirational mentor, and a devoted family man. This article shows the personal and professional contexts within which von Hippel—the namesake of the Materials Research Society's highest award—emerged as a scientific leader and role model of interdisciplinarity, as seen through the eyes of his son, Frank N. von Hippel, physicist, professor of public and international affairs, and co-director of the Program on Science & Global Security at Princeton University.

Keywords: *Arthur R. von Hippel, dielectrics, interdisciplinary, Massachusetts Institute of Technology, materials engineering, materials research, MIT.*

Introduction

Arthur R. von Hippel was born in Rostock, Germany, on November 19, 1898, and died in Newton, Mass., on December 31, 2003, at the age of 105. During his long life, he joined in Germany's pre–World War I youth rebellion against the social stratification of Victorian Germany; spent two years as a German artilleryman on the French border during World War I; opposed the Communists and then the Nazis before leaving Germany in 1933 to teach in Istanbul and then to perform research in Niels Bohr's institute in Copenhagen; and joined the faculty of the Massachusetts Institute of Technology in 1936, where he built the Laboratory for Insulation Research, developed dielectrics for radar and other World War II applications, and laid the foundations for modern interdisciplinary materials science and engineering. All this with half a lifetime still before him.

His pioneering role in materials research inspired the Materials Research Society to name its highest honor after him and to make him the first recipient of the Von Hippel Award in 1976. Since 1978, MRS has annually recognized a distinguished materials researcher for those qualities most prized by scientists and engineers: brilliance combined with a vision that transcended the boundaries of conventional scientific disciplines.

Arthur R. von Hippel: The Man

Wandervögel

My father was always interested in fostering the careers and well-being of his co-workers, whom he considered his friends rather than his subordinates. This was a departure from the Victorian "upstairs–downstairs" culture into which he was born and the German tradition that deemed the professor lord of his institute.

The development of this enlightened attitude may have started when von Hippel and his two older brothers joined Germany's pre–World War I youth movement, the self-styled *Wandervögel* ("birds of passage"). Groups of teenagers from upper-crust families wandered the country, sleeping in barns and helping with farm chores before they left in the morning. In 1913, when von Hippel was 14 years old, the *Wandervögel* met in a large conclave on a mountainside near Göttingen and joined in an oath that captured their reformed version of the Victorian ideal: In addition to premarital chastity, it included social responsibility and mutual helpfulness. Von Hippel tried throughout his life to live up to these ideals. Later on, James Franck (who was to become von Hippel's father-in-law) and Niels Bohr served as models for the young von Hippel of nonhierarchical academic leaders and socially responsible scientists.[1] Another model for him was MIT president Karl Taylor Compton, whom von Hippel considered to be the ideal administrator:

> Full of human understanding, modesty, and scientific curiosity, he walked through M.I.T. in order to learn what was going on and where help or criticism was needed. He enjoyed new insights, was not afraid to ask "foolish questions," and tried to keep the faculty responsible for its own affairs. As a result, the administration of M.I.T. remained small, funds could be made available as seed money for new initiatives, and his door was always open for people in distress. When he died in 1954, we cried.[2]

As university students, von Hippel, his brothers, and some of their friends organized what they called the *Akademische Gilde* as an alternative to the singing-drinking-dueling student fraternities of the time. In addition to creating a positive social environment and lifelong friendships for themselves, they also tried to enrich the lives of working-class children, who in those days completed only six or nine years of schooling. Von Hippel and his friends put together a horse-and-buggy "bookmobile" and also set up a book stall in the town square, from which they sold books at low prices to families that otherwise would not have bought them.

While pondering his career alternatives, von Hippel considered social work, among other possibilities. One of his closest friends, Curt Bondy, did pursue a career in social work and later played a leadership role in helping Jewish boys and girls escape Nazi Germany by training them in agriculture so that they could take advantage of unfilled immigration quotas in countries that needed farm labor, such as the United States. Von Hippel's sister, Olga, also went into social work and after World War II gathered 40 wandering orphan children into an abandoned army barracks where she raised them. Following the Second World War, von Hippel and his wife, Dagmar, spent every available dollar sending care packages of food and other essentials to tens of families of

relatives and friends in Germany until conditions there became less desperate. Throughout his life, von Hippel had great difficulty saying "no" to anyone in need, and he depended on others—especially his wife—to bail him out when requests for help became overwhelming.

Von Hippel was also very conscious of the family as a unit offering mutual support (see Figure 1). When asked by a son why he had had five children, von Hippel answered, "We were starting in a new country and I wanted you to have relatives."

His wife, Dagmar, had another answer: "We had four boys and I wanted a girl!"

Von Hippel lived up to the motto that he inculcated in his children, "We shall not be intimidated!" He was both anti-Communist (requisitioning an artillery battery to help put down a local Communist uprising during the post–World War I revolutionary period in Germany) and openly anti-Nazi after the Nazis came to power (including a personal confrontation in which he refused to salute Hitler). And, despite the disapproval of some of his family (who apologized later), he married a Jewish woman in Germany in 1930.

While many people live by the "kiss up and kick down" ethic of hierarchical organizations, von Hippel tended to do the opposite. As a professor, he was fierce in his defense of students when they appeared to be mistreated, and he was direct in telling senior administrators when he thought that they were getting in the way of progress. At one point, he became so disgusted that he resigned from MIT with the intention of building an independent institute. He joked that this institute would have sensors embedded in the walls that would blow it up when the first administrator moved in. He returned to MIT, however, after the company that had promised to fund the new institute suddenly went bankrupt.

Not surprisingly, given his inclination to "tell truth to power," von Hippel was not showered with as many honors by the science and engineering establishment as some of his scientific peers. This irritated him during his career, but later he understood it as the price of his independence and joked, when he was elected to the National Academy of Engineering in 1977, "My friends have outlived my enemies!" In fact, his *students* had outlived his enemies. Their beloved "Prof" had also by then been uniquely honored by the Materials Research Society, which named its highest award after him.

Importance of Visual Imagination

Before turning to science, von Hippel spent some time studying Renaissance art in Munich after he left the German army in 1919. Later, in his scientific work, von Hippel drew on his art training to visualize atomic and molecular structures, as an aid to understanding how they worked. Abstract math was not his strength. He spent long hours in his study at home constructing stick-and-ball models of crystal structures (Figure 2) and pondering the influence of these structures on dielectric properties. John Mara's beautiful diagrams in von Hippel's books and articles conveyed the resulting physical understanding clearly and elegantly (Figure 3). Mara was the draftsman at the Laboratory for Insulation Research.

In 1960, when a colleague gave him a copy of M.C. Escher's first book, *Grafiek en Tekeningen*, von Hippel was "thunderstruck by his wonderful mastery and originality" in an art form that he felt was similar to his own efforts to represent three-dimensional crystal structures in two.[3] He arranged Escher's first visit to the United States, for a lecture at MIT, and received from him a woodcut, *The Thinker* (Figure 4), which he felt captured his struggle to visualize crystal structures.[4]

Throughout his career, von Hippel also enjoyed the dendritic beauty of Lichtenberg figures (Figure 5). Georg Christoph Lichtenberg was a professor of astronomy in Göttingen and a scientist and philosopher in the 18th century who, by accident, discovered in the dust of his laboratory the pattern created by an electrical discharge. These illustrations became known as Lichtenberg figures, and a selection of photographs of Lichtenberg figures, made in von Hippel's laboratory with Fred Merrill, appeared in the same volume as von Hippel's memoirs under the title *Lightning Strokes in Other Worlds*.[5] These spectacular images have become quite popular. One is displayed on the wall of MIT's Kendall Square subway station. Recently, some have even been exhibited in an art museum.[6]

Von Hippel was concerned that his students and children have careers that they would find as meaningful and enjoyable as he had his own, and he encouraged them with remarkable effectiveness to

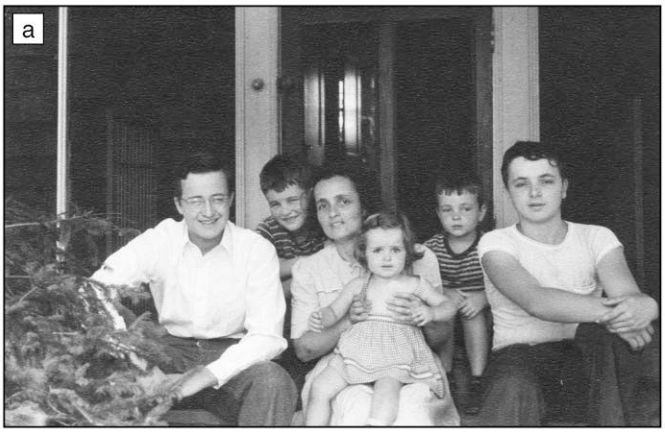

Figure 1. (a) Arthur von Hippel's wife Dagmar with their five children on the front steps of the house where they lived from 1938 to 2003, circa 1947. Left to right: Peter (now a professor of molecular biology at the University of Oregon), Frank (now a professor of public and international affairs at Princeton University and author of this article), Dagmar with Maianna on her lap (now a social worker and novelist), Eric (now a professor of innovation in the Sloan School at MIT), and Arndt (now a retired chest surgeon in Alaska). Photo by Arthur von Hippel. (b) Arthur von Hippel on his 95th birthday celebration in 1993 with his children. Back row, left to right: Frank, Arthur von Hippel, Eric, and Peter. Front row, left to right: Arndt and Maianna.

pursue interests that he felt matched their talents. He correctly pointed out to two of his boys that molecular biology and astrophysics were on the threshold of exciting revolutions such as he had lived through in physics. Although he was a third-generation professor, he saw nonacademic careers as equally valuable. He saw the possibilities for creativity and adventure in virtually all professions. His reaction to a grandchild going into a profession that no other family member had tried was "Wonderful! It is high time someone in the family did that!"

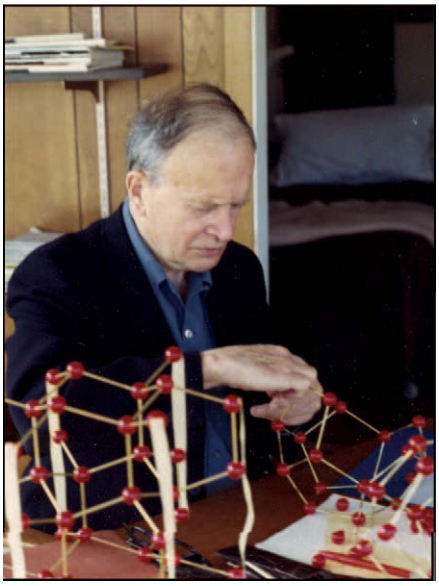

Figure 2. Arthur von Hippel working with a stick-and-ball model, which he used to help himself visualize crystal behavior. (circa 1970). Photo by Dagmar von Hippel.

Love of the Wilderness

Von Hippel's reading as a youth of James Fenimore Cooper's *Leatherstocking Tales*[7] in German translation imprinted him with a love for the American wilderness. He realized a dream when, after World War II, he had his own log cabin built on the bank of the Swift River at the edge of the White Mountains National Forest in New Hampshire (Figures 6 and 7). Cliff Pratt, a jack-of-all-trades with a 6th grade education, built the cabin. Pratt lived with his wife, Mabel, in their own log cabin a few miles away and was for von Hippel the personification of the self-reliant, pioneering spirit that he most admired.

Von Hippel's preference for leaving the beaten path led to a number of near-fatal incidents on mountains and glaciers—as well as scratches on colleagues who found that a walk in the woods behind his house sometimes included a scramble through a bramble patch. His last narrow escape occurred in 1975 at the age of 76, when he fell through the ice while skiing on the Swift River. He enjoyed that adventure more than did the son who hauled him out, and the excitement of it pulled him out of a depression over the loss of his wife earlier that year.

The neighborhood children and grandchildren adopted von Hippel as their beloved grandfather—as did a neighbor's cocker spaniel, who spent his days underfoot in the house and on the walks in the woods (Figure 8).[8]

After his official retirement from MIT in 1964, von Hippel regularly visited his far-flung children and grandchildren and his sister in Germany. He especially enjoyed visiting his son Arndt in Anchorage, Alaska. Arndt owned a small plane, and together father and son flew low and fast, taking in the beauty of the surrounding mountains and bays. Later, when traveling became more difficult for him, von Hippel's children and grandchildren visited him in the house in which he and Dagmar had raised their family and where he continued to live with a house-

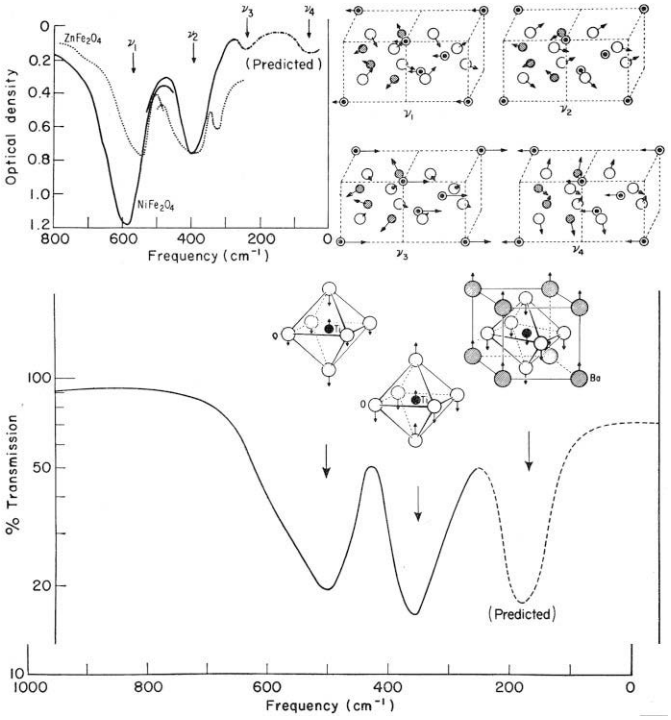

Figure 3. Arthur von Hippel's efforts to visualize atomic crystal structure were aided by the elegant illustrations of John Mara, the draftsman at the MIT Laboratory for Insulation Research. Shown here is a diagram drawn for von Hippel by Mara, describing atomic vibrations associated with different absorption bands in $BaTiO_3$ and Fe_3O_4.[22]

Figure 4. M.C. Escher's The Thinker, *which Escher presented to Arthur von Hippel for arranging his first visit to the United States for a lecture at MIT. Von Hippel felt the woodcut captured his struggle to visualize crystal structures.*[4]

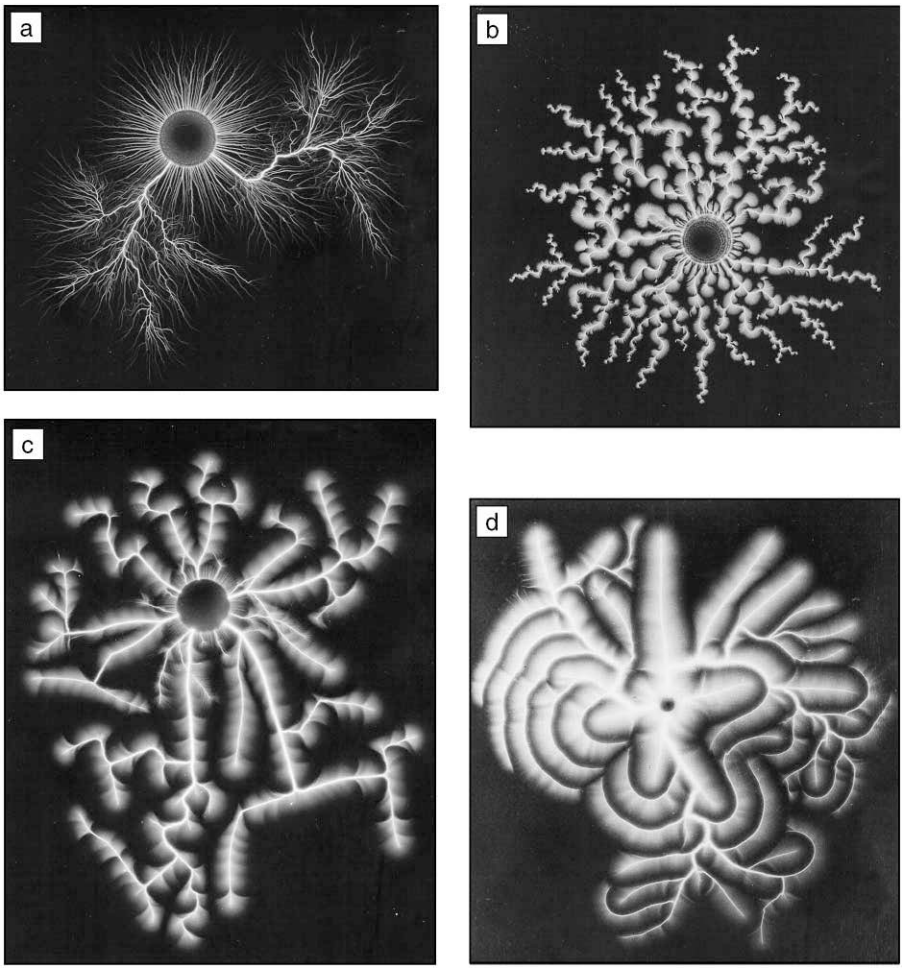

Figure 5. (a)–(d) Examples of Lichtenberg figures, made in Arthur von Hippel's laboratory with Fred Merrill.[5]

keeper–caregiver, Margaret Kavanaugh, until his death.

The Scientist

Early Years

After rejecting social work, law, medicine, and art as potential career fields, von Hippel decided upon science. His thesis research was carried out in the Institute of Applied Electricity in his hometown of Göttingen, where his father was a professor of law and his grandfather and uncle had been professors of ophthalmology.[9] With the broadcasting age just beginning, von Hippel chose as his thesis problem the invention and theoretical description of a new, more inertia-free "thermo-microphone" that would allow the transmission of radio broadcasts with as little frequency distortion as possible. Using the Institute's machine shop and the many odds and ends collected from the war, he built a frequency sensor of a nearly invisible meshwork of thin Wollaston wires, measured and analyzed its frequency response, developed its theory, and obtained a patent on the device.[10]

After receiving his PhD degree in 1924, von Hippel joined Max Wien's institute in Jena, where he researched cathodic sputtering and established that the metal was being released in the form of atoms. He then received a Rockefeller Foundation fellowship to spend a year (1927–1928) at a U.S. university. He chose the University of California at Berkeley so that he would be able to see the wonders of the United States and Canada in two cross-country trips.

At UC–Berkeley, he measured the ionization cross section of atomic mercury as a function of electron energy, firing a beam of electrons perpendicularly at a beam of mercury atoms. He also was befriended by James Franck, then a visiting professor who had just been awarded the 1926 Nobel Prize in physics with Gustaf Hertz. When von Hippel returned to Germany, he joined Franck's physics institute in Göttingen. In 1930, he married Franck's daughter, Dagmar.

Von Hippel's research while in Franck's institute laid the foundations for the understanding of electrical breakdown in gases, liquids, and solids. In the course of this work, he learned how to record and interpret the physics behind the shapes created by the branching electron cascades that developed during breakdown. This is when he developed his lifelong fascination with Lichtenberg figures.[5]

In 1933, after the Nazis seized power in Germany, von Hippel left the country with his family—now including two boys (Peter and Arndt)—first for a teaching position in Istanbul and then, in 1935, for a research position in Bohr's institute in Copenhagen. There, he continued his research on phenomena associated with electrical breakdown.

Dielectric Properties of Materials

In 1936, von Hippel returned to the United States and joined MIT as an assistant professor of electrical engineering. A year later, with a start-up grant from then MIT president Compton, von Hippel established the Laboratory for Insulation Research (LIR).[11] His area of research quickly broadened beyond breakdown phenomena into an effort to understand the electric properties of materials more generally.

He began to explore with collaborators the propagation of electrons in crystal structures as a wave phenomenon. His first PhD student, Julius Molnar, studied the color centers of alkali halide crystals and discovered the M bands that are named after him.

The approach of World War II drew von Hippel into applied research, starting with a consulting contract with International Telephone and Telegraph that resulted in the invention of an electrolytic process for producing selenium rectifiers and the invention of the selenium photocell.

A group within LIR, later led by William B. Westphal, began to develop techniques to measure the dielectric properties of materials from dc to microwave frequencies, research that led to the development of the MIT Coax Instrument[12] and whose results were summarized in the LIR's "Tables of Dielectric Materials." The tables were later declassified and published—approximately 150 pages' worth—in *Dielectric Materials and Applications*.[13] This work was stimulated by and found widespread application in the U.S. radar development program, which was also based at MIT.

The interdisciplinary nature of the work at LIR attracted physicists, chemists, and

Figure 6. The von Hippel log cabin, built on the bank of the Swift River at the edge of the White Mountains National Forest in New Hampshire, circa 1948.

ceramists as well as electrical engineers. By the end of World War II, the LIR was home to about 40 researchers. Von Hippel built platforms in the crowded rooms that LIR occupied in MIT's original high-ceilinged building so that research could be carried out on two levels.

Measuring dielectric properties led naturally to the search for materials with desired properties and also to serendipitous discoveries. For example, the development of high-dielectric-constant ceramics for capacitors and delay lines led to the discovery and exploitation of the ferroelectric and piezoelectric properties of barium titanate.[14]

By the end of World War II, the contributions of the LIR were so valued by the U.S. military that the laboratory received the first three-service (Army–Navy–Air Force) contract to enable it to continue its operations. Von Hippel received the U.S. President's Certificate of Merit from President Truman in 1948.

Figure 7. Arthur von Hippel with a caulking gun, working on the cabin, circa 1948.

Figure 8. Arthur von Hippel at 98, walking in the woods with a neighbor's granddaughter and cocker spaniel.

Materials Science and Engineering

Having discovered the power in the combination of physical insight and interdisciplinary research in the designing of materials with specific desired properties, von Hippel dedicated his two post–World War II decades at MIT to developing and promoting "the molecular designing of materials and devices."[2] With continuing support from the U.S. military—now engaged in a technology race with the Soviet Union—the number of researchers in the LIR grew to about 80, including refugee scientists from Eastern Europe and visitors and students from Western Europe and Japan. Alexander Smakula, another PhD graduate from Göttingen (1927), was among those who came and stayed, as the LIR expert on growing pure crystals.[15] Under von Hippel's leadership, the laboratory systematically developed a fundamental understanding of the structural determinants of the dielectric properties of crystals, glasses, polymers, and the special couplings that result in ferroelectric and ferromagnetic properties.

To communicate this evolving understanding in a systematic way, von Hippel wrote a textbook, *Dielectrics and Waves* (1954),[16] copiously illustrated with elegant diagrams produced by Mara. This book was translated into a number of languages, including Russian.[17] It is a testimonial to the book's lucidity that, 50 years later, it is still in print.

Von Hippel also organized three summer symposia to examine the range of applications of the molecular design of materials and edited the presentations into books: *Dielectric Materials and Applications* (1954), *Molecular Science and Molecular Engineering* (1959), and *The Molecular Designing of Materials and Devices* (1965).[4,13,18] Two of these books—*Dielectric Materials and Applications* and *The Molecular Designing of Materials and Devices*—are also still in print.

LIR helped populate the new field of materials research. In addition to the many postdoctoral fellows who joined in the interdisciplinary work there, about 60 PhD and 48 master's theses were completed in the LIR, as well as a very large number of bachelor's theses. Many of the LIR alumni went on to become leaders in materials research. A number of these alumni remained at MIT, which, with the support of the Department of Defense's Advanced Research Projects Agency, built a large Center for Materials Science and Engineering with 40 professors and their research groups.[19] Six of the LIR research groups joined the new Center in 1963, when von Hippel reached MIT's retirement age.

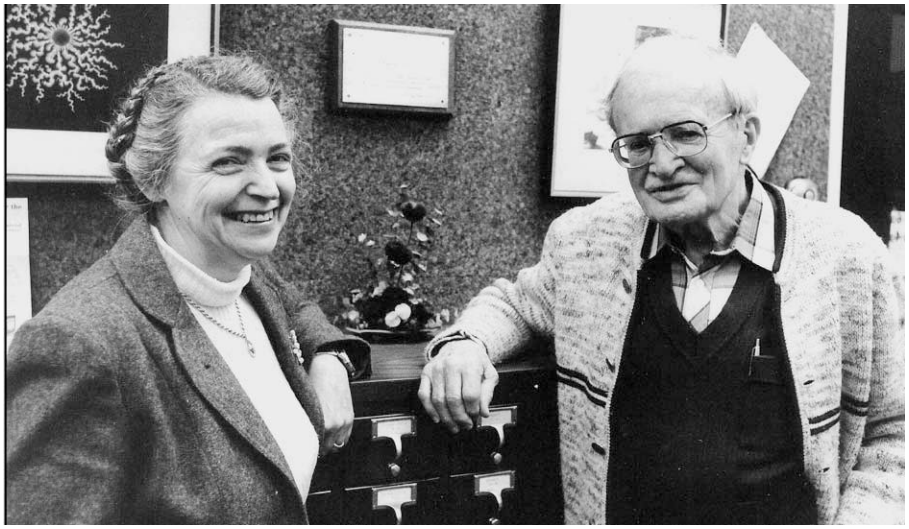

Figure 9. Mildred S. Dresselhaus, then director of the Center for Materials Science and Engineering at MIT, with Arthur von Hippel in the Arthur von Hippel Reading Room dedicated in his honor (circa 1982). Note the framed Lichtenberg figure from Figure 2b on the wall above Dresselhaus.

From Atoms to Living Systems

After becoming an MIT Institute Professor in 1962 and "retiring" in 1964, von Hippel kept one of his research groups and started a new line of study that he continued until 1980. That research reflected his desire—shared with a number of other physicists—to help build a physical foundation for the new biology. In his own case, he decided to try to understand the dielectric properties of water that make it a medium in which the molecular reactions of life can take place. His last scientific paper, published in 1979, was titled "From Atoms toward Living Systems."[20]

Up until 1984, von Hippel participated in the Von Hippel Award presentations at MRS's Fall Meetings, in which he gave a short address, often reflecting on the interdisciplinary nature of materials research. In 1992, *Ferroelectrics* (vol. 135) published a special issue with a series of articles paying tribute to von Hippel's life and work. Earlier, when the Center for Materials Science and Engineering was established at MIT, it dedicated the Arthur von Hippel Reading Room in his honor (Figure 9).

Von Hippel remained active, intellectually and physically, until very near the end of his long, productive life. He wrote two memoirs, one subtitled "A Scientific Autobiography" (*Materials Design and Molecular Understanding: A Scientific Autobiography*, 1980) and the other a highly readable and detailed personal history, *Life in Times of Turbulent Transitions* (1988). Both works are accessible on the MRS Web site dedicated to the memory of von Hippel.[21]

The indomitable spirit that gave rise to his motto "We will not be intimidated!" remained unquenched throughout my father's life. He continued to walk or ski twice a day in the town forest behind his house in Weston, Mass., until he was well over 100. When told on his 100th birthday of the Chinese saying that if one walks 100 paces each day after dinner, one will live to 100, he asked, with a twinkle in his eye, "What if I walk 200?"

Notes and References

1. James Franck, who was Jewish, resigned his position as professor (a government appointment in Germany) when Hitler came to power but did not leave Germany until he had been able to place his Jewish assistants and von Hippel, who had married his daughter, Dagmar, safely abroad. Both Franck and Niels Bohr joined the secret U.S. nuclear weapons development program during World War II and separately tried to influence U.S. policy in a direction that they hoped would prevent a postwar nuclear arms race with the Soviet Union. Von Hippel's book *Dielectrics and Waves* was dedicated to Franck and Bohr, and his first U.S.-born child, the author of this article, was named after them.
2. A.R. von Hippel, *Materials Design and Molecular Understanding: A Scientific Autobiography* (© 1980 Arthur R. von Hippel), http://vonhippel.mrs.org/ (accessed October 2005).
3. A.R. von Hippel, *Life in Times of Turbulent Transitions* (© 1988 Arthur R. von Hippel), http://vonhippel.mrs.org/ (accessed October 2005).
4. A.R. von Hippel, ed., *The Molecular Designing of Materials and Devices* (MIT Press, Cambridge, Mass., 1965) p. 1.

5. A.R. von Hippel, *Lightning Strokes in Other Worlds* (© 1982 Arthur R. von Hippel) http://vonhippel.mrs.org/ (accessed October 2005).
6. M. Kemp, *Nature* **435** (2005) p. 888.
7. A series of novels by James Fenimore Cooper named after their hero, Natty Bumppo, who also was known as "Leatherstocking" and "Hawkeye": *The Pioneers* (1823), *The Last of the Mohicans* (1826), *The Prairie* (1827), *The Pathfinder* (1840), and *The Deerslayer* (1841).
8. P.T. von Hippel, "A Man of Habit," in *Life in Times of Turbulent Transitions* (© 1988 Arthur R. von Hippel) p. 145, http://vonhippel.mrs.org/ (accessed October 2005).
9. Von Hippel's father, Robert, is still well known in German jurisprudence as a pioneer in introducing the idea that prisons should be used for reforming as well as punishing criminals. His uncle, Eugen von Hippel, was co-discoverer of von Hippel–Lindau disease.
10. A. von Hippel, *Ann. Phys.* **75** (4) (1924) p. 521; A. von Hippel, *Ann. Phys.* **76** (4) (1925) p. 590.
11. K.L. Wildes and N.A. Lindgren, eds., *A Century of Electrical Engineering and Computer Science at MIT, 1882–1982* (MIT Press, Cambridge, Mass., 1986) p. 166.
12. The MIT Coax Instrument measured dielectric constants as a function of frequency by filling a section of a cylindrical standing-wave cavity with the material of interest and measuring the effects on the standing wave, first when the material was placed against the metal conductor at the closed end of the cavity and then a quarter wavelength in front of it. See A.R. von Hippel, *Dielectrics and Waves* (John Wiley and Sons, New York, 1954) p. 74.
13. A.R. von Hippel, ed., *Dielectric Materials and Applications* (Technology Press of MIT, Cambridge, Mass., 1954, reissued by Artech House, Norwood, Mass., 1995).
14. A.R. von Hippel, *Rev. Mod. Phys.* **22** (1950) p. 221.
15. "[I]n the early 1950s, manufacturers of transistors were having problems in producing pure crystals of germanium and silicon. It was at this time (1952) that von Hippel brought Alexander Smakula . . . into LIR. Smakula . . . contributed to solving the problem. (Incidentally, Smakula had been the inventor of the antireflection coating for optical lenses so widely used today in camera lenses.)." K.L. Wildes and N.A. Lindgren, eds., *A Century of Electrical Engineering and Computer Science at MIT, 1882–1982* (MIT Press, Cambridge, Mass., 1986) p. 172.
16. A.R. von Hippel, *Dielectrics and Waves* (John Wiley & Sons, New York, 1954).
17. "Two books written by Professor von Hippel were translated and published in the Soviet Union shortly after the Second World War. These excellent books were popular among students in their final years, postgraduate students, and specialists in the fields of electrical engineering, physics, and dielectric materials." Lev A. Shuvalov, "A Tribute to Professor Arthur von Hippel," *Ferroelectrics* **135** (1992) p. 19.
18. A.R. von Hippel, ed., *Molecular Science and Molecular Engineering* (Technology Press of MIT and John Wiley & Sons, New York, 1959).
19. K.L. Wildes and N.A. Lindgren, eds., *A Century of Electrical Engineering and Computer Science at MIT, 1882–1982* (MIT Press, Cambridge, Mass., 1986) p. 177.
20. A.R. von Hippel, *Mat. Res. Bull.* **14** (1979) p. 273.
21. "In Memoriam: Arthur Robert von Hippel (1898–2003)" Web site, http://vonhippel.mrs.org/ (accessed October 2005).
22. A.R. von Hippel, ed., *Molecular Science and Molecular Engineering* (Technology Press of MIT and John Wiley & Sons, New York, 1959) p. 273. □