The Contributions of Arthur Robert von Hippel to Electrical Insulation Research

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ABSTRACT

The life and career of Prof. Arthur Robert von Hippel, Institute Professor Emeritus at M.I.T., is reviewed. His European schooling and early professional life put him in association with major achievers in physics including Bohr, Sommerfeld, Heisenberg, Wien, Courant, Debye, Born, Franck, Hertz, and Pauli, and in America, Loeb and Oppenheimer. His participation in the scientific revolution of the early twentieth century, together with the upheavals of World Wars I and II, make von Hippel's life an inspiring story. He founded the Laboratory for Insulation Research at M.I.T. in 1940, pioneering in materials research, measurements, and instrumentation evolving to the present-day M.I.T. Center of Materials Science and Engineering and to the M.I.T. Laboratory for Electromagnetic and Electronic Systems. His theme was of molecular engineering for the 'making of materials to order'. If atoms are relatively well understood, they can be used as building blocks for design purposes with physicist as architect using the hundred-odd atoms of the Periodic System. His research activities cover a broad area, and his publication list is extensive, as can be seen in this Issue.

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INTRODUCTION

PROFESSOR Arthur Robert von Hippel, now Institute Professor Emeritus (since 1962) in the Department of Electrical Engineering at the Massachusetts Institute of Technology, is widely recognized for his outstanding research in dielectrics, molecular science, and molecular engineering. He founded the M.I.T. Laboratory for Insulation Research (L.I.R.) in 1940 and served as its Head for almost thirty years. His work has included ferroelectrics and ferromagnetics; electric breakdown; dielectric polarization, rectifiers, and photocells; gas discharges; and solid-state physics. He is distinguished for his pioneering research in the field of molecular science and molecular engineering, which he has described as a 'broad new discipline ... comprising the structure, formation, and properties of atoms, molecules, and ions; of gases, liquids, solids and their interfaces; the designing of materials and properties on the basis of this molecular understanding; and their imaginative application for devices'. The Material Research Society's highest award, the Von Hippel Award, is an international hallmark of excellence in the field of materials research. Von Hippel was the first recipient of this award in 1977, thereafter named for him. The Society notes that L.I.R. pioneered the collaborative, interdisciplinary research that subsequently has taken the identity of 'materials science'. The Award recognizes those qualities most prized by materials scientists–brilliance and originality of intellect, combined with vision that transcends conventional scientific disciplines. Nominees must have outstanding scientific credentials, their scientific work must have had a real impact on materials research, and they must have demonstrated an interdisciplinary approach to materials research.

I met with Prof. von Hippel on March 10, 1987 to reminisce about important events in his life. Even at age 88, he continues to lead a vigorous outdoors life, snow-skiing on his property twice a day when snow is on the ground. He complained to me that being towards the end of winter, the snow was too icy for good skiing. He also uses a rowing machine in his bedroom to continue to keep fit. It was a pleasure for me to talk with Prof. von Hippel, both about technical issues and about his personal history. In 1969–70 I was a student in Prof. von Hippel's two-term course at M.I.T., 'From Atoms to Living Systems'. As part of the course work, I used to meet weekly with von Hippel to discuss physics. His long-time secretary Aina Sils served cookies and tea. His lectures included many slides about the subject currently being studied. Occasionally a slide of personal history would slip in, such as a picnic scene with a dignitary such as Albert Einstein. Then Prof. von Hippel would tell us some anecdote about the famous people in the slide.

In this biographical review I will first summarize von Hippel's achievements as obtained from his M.I.T. resume and from a published summary of his credentials when he was selected to deliver a lecture at the 140th Electrochemical Society Meeting in 1971 entitled 'Molecular Understanding of Electrochemical Processes by Ice Research' [1–4]. However, my main purpose is to go beyond just a listing of his many achievements and to give a more personal account with anecdotes of the human side of his distinguished career with the information partially obtained from my conversations with von Hippel and a colleague of many years, William B. Westphal, but more fully from his draft of memoirs written in 1981 for his family entitled 'Life in Times of Turbulent Transitions'. Von Hippel's life is an inspiring story because he was involved in both World Wars, having to leave Hitler's Germany because of a Jewish wife, yet knowing many of the major scientific achievers of the twentieth century, as student and colleague.

CAREER SUMMARY

ARTHUR R. von Hippel was born in Rostock, Germany in 1898. He was an artillery officer in World War I, 'trying not to kill myself in mountain warfare'. He studied at the University of Göttingen where he received his Ph.D. in 1924. He spent three years in research at the University of Jena, and after a year as a Rockefeller Fellow in Physics at the University of California, returned to Jena for a year as Privat-Dozent (assistant professor). From 1929 to 1933 he was Privat-Dozent at the University of Göttingen. After a year as professor at the University of Istanbul, he went to the University of Copenhagen where he worked with Professor Niels Bohr, distinguished Nobel Prize winner.

In 1936 Dr. von Hippel went to M.I.T. as assistant professor of electrical engineering; he became associate professor in 1940 and professor in 1947. In 1940 he founded the Laboratory for Insulation Research (L.I.R.), which he directed until his retirement in 1964. During World War II he was also engaged as a staff member of the M.I.T. Radiation Laboratory and member of its Coordination Committee, as a member-at-large of the Office of Scientific Research and Development (O.S.R.D.), and as an O.S.R.D. representative on the War Committee for Dielectrics (a joint committee of the Army, Navy, War Production Board, and O.S.R.D., which acted as

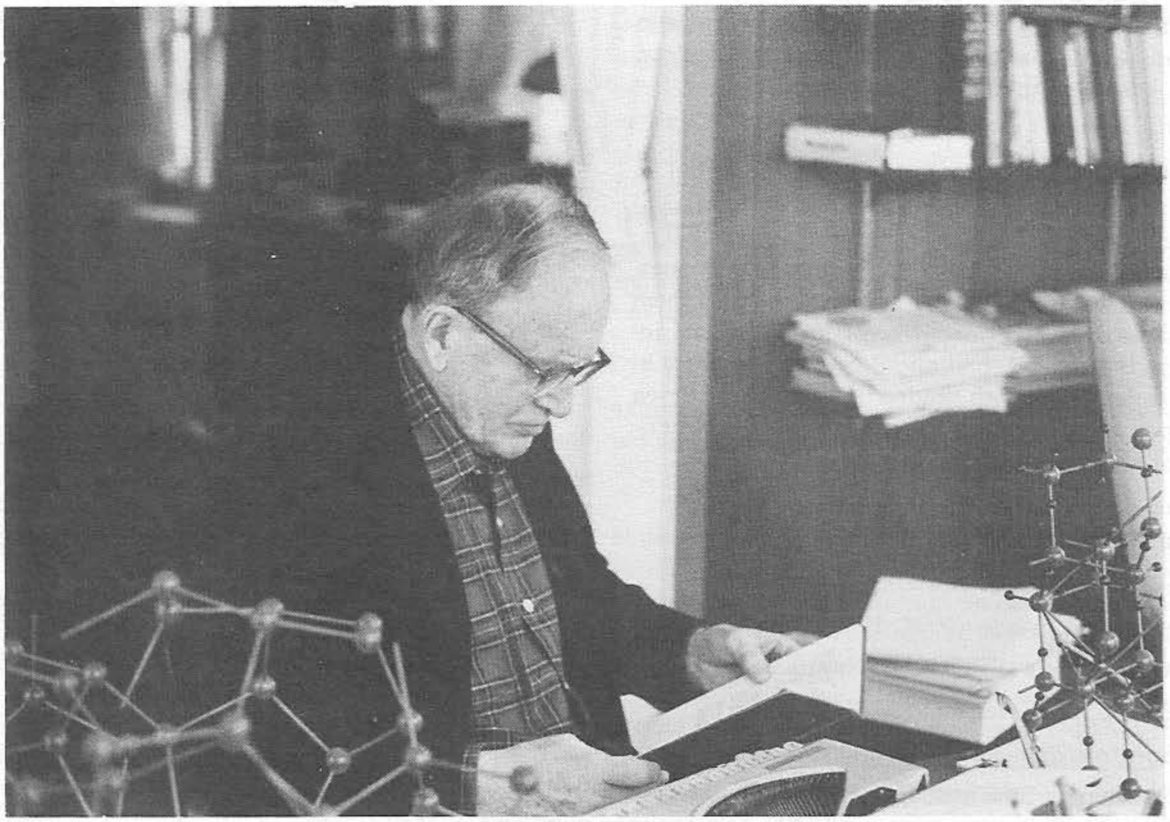

Figure 1. Professor von Hippel in his office

advisory board on service and supply problems). Professor von Hippel and his wife became naturalized American citizens in 1942. In recognition of 'outstanding services to his country', he was awarded the President's Certificate of Merit, the second highest civilian award, in October 1948.

Professor von Hippel married Dagmar Franck, a daughter of the German physicist James Franck, in 1930, and he and his wife became naturalized American citizens on April 21, 1942. They had five children: Peter Hans (1931), Arndt Robert (1932), Frank Niels (1937), Eric Arthur (1941), and Marianne Margaret (1945).

Professor von Hippel has been particularly concerned with the immediate future of material science and with the establishment of laboratories to promote its study among those in industry as well as university students.

He is author and editor of several books on modern materials research: *Dielectrics and Waves*, 1954 [5]; *Dielectric Materials and Applications*, ed., 1954 [6]; *Molecular Science and Molecular Engineering*, ed., 1959 [7]; *The Molecular Designing of Materials and Devices*, ed., 1965 [8].

Professor von Hippel is a fellow of the American Academy of Arts and Sciences, the American Physical Society, the American Association for the Advancement of Science, the New York Academy of Sciences, and the Washington Academy of Sciences, and a member of Sigma Xi, the American Chemical Society, and the American Institute of Electrical Engineers.

In 1952 he was appointed chairman of the Conference on Electrical Insulation and Dielectric Phenomena of the National Research Council, and was J. B. Whitehead Memorial Lecturer at the 1960 Conference. From 1964 to 1965 he served as scientific advisor for the Office of Naval Research, Washington, D.C. and received the

Superior Civilian Service Award from the Department of the Navy on October 27, 1965. He was elected to the National Academy of Engineering in 1977 and also received an award from the Materials Research Society, thereafter known as the Von Hippel Award.

The Laboratory for Insulation Research at M.I.T. educated about sixty doctorate students, two Electrical Engineering degrees, forty-seven Master degree theses, a large number of bachelor theses, and numerous post-doctorate workers from all over the world, many of them later renowned. At the time of von Hippel's official retirement in 1964, L.I.R. had about seventy members in eight research groups, each headed by a professor. Seven of these groups helped form the new Center for Materials Science and Engineering:

1. Crystal Physics (Prof. A. Smakula)
2. Magnetics (Prof. D. J. Epstein)
3. Magnetic Spectroscopy (Prof. P. A. Miles)
4. Structure Analysis (Prof. R. E. Newnham)
5. Photoconductor Systems (Prof. F. Chernow)
6. Mass Spectroscopy (Prof. C. K. Crawford)
7. Magnon-Phenom Spectroscopy (Prof. R. F. Morgenthaler).

As recognition today the Center has a von Hippel reading room.

In addition to his large number of journal publications, extensive details of L.I.R. research were published in a Technical Report Series for Research supported by the Navy Department (Office of Naval Research), the Army Signal Corps, and the Air Force. The Final Report, Technical Report 204 dated November, 1965 [9], provides a chronological list of all L.I.R. publications; see p. 841 of this issue for an updated bibliography [10].

A two-day Conference on the Structure and Properties of Dielectric Materials was held at M.I.T. in June 16–17, 1964 to honor Prof. von Hippel upon his retirement. However, von Hippel still kept on teaching and performing research, resulting in a second Technical Report series of seventeen reports until June, 1976, directed to applying materials science to biological systems. This work was first supported by O.N.R. and later by the National Institutes of Health. These reports are also listed in this issue [10].

EARLY PERSONAL HISTORY

FAMILY

The recorded history of the von Hippel family goes back to the 14th century and includes family members prominent in their times. While many relatives were large land-holders or in the military service, von Hippel's grandfather Arthur was one of the first professors of ophthalmology and his father Robert was a professor of criminal law at the University of Göttingen. Von Hippel had two older brothers, Ernst and Fritz, and a younger sister, Olga.

After grammar school he went for nine years to the 'humanistische Gymnasium' in Göttingen, obtaining a good classical education with nine years of Latin and six years of Greek in addition to French and English, with excellent science and mathematics. He feels that it is a great mistake that American schools today do not teach languages to the extent of his European education.

A teacher introduced von Hippel to the 'Youth Movement', which was a reaction to the 'class state' with special privileges for the upper class, slightly balanced by some social obligations. Upper and lower classes lived essentially separate lives without much intermingling and understanding, and the industrial age led to appalling exploitation, especially of child labor. Social services were minimal and beggars abounded.

As part of the reaction to this state, the youth group 'Wandervogel' (migrant birds) was formed which hiked through Germany and neighboring countries, sleeping in barns, helping with farm chores, rediscovering and collecting old folksongs, cooking outdoors, playing instruments, and making friends everywhere. Abandoned houses and later even old castles were fixed up as homes for transient groups. While the normal size of a hiking group ranged from five to ten boys, thousands might come for special fests. The ethical code of the youth movement was very strict. A solemn pledge was given to live a life of purity, responsibility, and mutual helpfulness. This promise guided von Hippel all his life.

The first large scale test of this oath came during World War I. People of the youth movement wore an identifying colored string on their uniform which made immediate friends independent of rank. The youth movement lost more than half its men, about 10,000, in combat during World War I. Von Hippel concludes that if they had lived, World War II and the assumption of power by the Nazis might never have occurred.

Von Hippel was the only child in the family with experimental inclinations, allowing him to install a private lighting system in his room for late night reading. However, a carbide lamp developed for after-dark bicycle-riding resulted in a 'bomb' that severely cut his left thumb.

WORLD WAR I

WORLD War I broke out in the summer of 1914. Being yet too young for military service, von Hippel was drafted for home defense. With older friends shipped out to war, von Hippel found himself one of the oldest members of the youth movement group and had to assume local leadership.

School and life were now serious business, with a morning assembly reading of the names of old friends who had died in battle. Food rationing began. Time passed fast and the war seemed an endless slaughter. By 1916 many of von Hippel's friends had been killed in battle, and patriotism gave way to quiet and hungry endurance. Terminating his high school education a half-year early, he joined the army as a buck private in the field artillery.

He lived in a world of ideals and was rudely shaken under military rule. Slowly he toughened and after five months was ready to be shipped to France. He was sent to the most southern part of the Western front, the mountain zone of Alsace-Lorraine. After an officers' course he became a lieutenant. He points out that his friend was a much better soldier but stayed a sergeant because he did not have a high school diploma. On furloughs to Göttingen, there was a sad accounting of friends killed. By the end of the war, 50% of his class were dead.

By November, 1918 the armistice went into effect. However, instead of the peace of human understanding came the peace of revenge. Germany was starved for years and loaded with intolerable reparations. These conditions led directly to Hitler and World War II.

UNIVERSITY EDUCATION

WHEN he joined the Army in 1916, his father, then Rector of the University of Göttingen, expected him to be a student of law. An uncle who was director of a big coal-mining concern tried to make him a mining engineer, but after the war with remembrance of traveling to a deep mine, he realized that fresh air had become a necessity of life after living outdoors during the war years.

He considered medicine and went to the Anatomical Institute but 'the dead babies in pickle-jars did not appeal to me'. An old teacher encouraged him to become a physicist, and so he enrolled in the famous 'Naturwissenschaftliche Fakultät' of the Georgia Augusta University at Göttingen. His teachers included Hilbert on classical mechanics, Hilbert's assistant Courant, Pohl for physics, and Debye who taught theoretical physics. On Debye, von Hippel writes that 'Everything seemed glass-clear, while you sat in front of him; but when you went afterwards down the stairs, you stared into the unknown'.

Continuing the 'Youth Movement' ideals of joyful exuberance, friendship, and outdoors activities, von Hippel and friends founded the 'Akademische Gilde'.

Contrary to the 'peace of brotherhood' promised at the end of WWI, Germany was blockaded and the von Hippel family with the rest of Germany lived on a starvation diet with minimal home heating. Galloping inflation devastated money. Soon, von Hippel's father and other professors had their salary paid in cash every day, standing in line. Immediately after the money was received, the whole family spread throughout the town to purchase whatever food and necessities could be had, before the value of the German Mark dropped further. Anyone who had relied on savings, mortgages, or other investments based on currency values was wiped out. Von Hippel showed me an old worthless 100000 Mark note and told me that he had a 1-million Mark note somewhere.

The breakdown of the economy inflamed the revolutionary climate, and communist governments formed in various regions of Germany. Von Hippel and friends organized a small nationalist counterforce as part of a house-defense team.

With order temporarily restored, von Hippel returned to his studies, not sure he was cut out to be a scientist. He ran with friends for the office of 'National Representative' in an All-German student election which won, and von Hippel found himself 'cultural representative' of the German students. He escaped for the summer term of 1921 to Munich to live in a climate of theater, music, and artistic life before becoming a 'professional'. After this carefree life he found himself broke. The message from his father: 'Out of money; complete studies in science or starve'.

Göttingen in the early twentieth century was a 'Center of the Scientific Revolution' from classical physics to quantum mechanics. Max Born had succeeded Debye and attracted a brilliant group of young theoretical physicists. James Franck taught experimental science. Franck and Gustav Hertz had done the famous Franck-Hertz experiment demonstrating that electrons colliding with the atoms of mercury vapor lose kinetic energy in discrete quanta and that the excited mercury atoms reemit that energy as discrete photons with energy $h\nu$.

EARLY PROFESSIONAL WORK

Niels Bohr came in 1922 to present his new theory of the Periodic System at the Institute of Theoretical Physics. With von Hippel as student in the audience, Sommerfeld with his student Heisenberg in tow disagreed with Bohr's theory. Then Born with student Pauli also disagreed with Bohr. This was a turning point in von Hippel's life. Convinced that theoretical physics was a calling reserved for geniuses, he then enlisted as a Ph.D. student in the Institute for Applied Electricity. He finished his thesis in early spring 1924, *summa cum laude*, designing and building a new type of thermo-microphone which allowed transmission of radio broadcasts as free as possible of frequency distortion. Vacationing in Italy before taking a final professional decision, he realized that he could enjoy art deeply but not produce it, so he returned home to an assistant position at the Physics Institute in Jena of Prof. Max Wien, who was the inventor of the quenched spark gap, necessary for wireless communication before the advent of electronic tubes. Wien used his spark-gap technique to study the conductivity in liquids at very high field strengths, discovering true deviations from Ohm's law now known as the first and second Wien effects.

Von Hippel's next two years concerned studying the sputtering of metals where he demonstrated that the metal was released as atoms from the cathode by positive ion bombardment.

Von Hippel's assistant years in Jena from the fall of 1924 to the summer of 1927 were full of scientific work and happy friendships. He helped in preparing lecture demonstrations, advising Ph.D. students, and in giving seminars.

In the spring of 1927 von Hippel became engaged to Marianne von Ritter, a pupil of his aunt. He also was offered a one-year Rockefeller fellowship and went alone to Berkeley to measure the ionization characteristic of mercury atoms by electron impact. He found time to hike and drive around California and he was friendly with Prof. Leonard Loeb, specialist in gas discharges, and Robert Oppenheimer from Cal. Tech who also lectured at Berkeley. The American interlude provided adventure and new friends, and he had been offered assistant professorships at three universities and tentatively completed a difficult experimental study. However, he returned to Germany to marry Marianne von Ritter. Sadly, she soon died in January, 1929, a victim of a flu epidemic.

To stay near the von Ritter family, von Hippel took a position at the Physikalische Institute in Göttingen and soon married James Franck's daughter Dagmar in 1930. With the rising tide of anti-semitism and the coming of the Nazis, marrying a Jew was risky, but von Hippel had taken a stand as an anti-Nazi and had written a counter-declaration for the Gilde and youth movements.

Scientifically, this last period in Göttingen was fruitful. Von Hippel developed a basic understanding of electric breakdown in gases and single crystals, and of the meaning of Lichtenberg figures.

The crisis in Germany was approaching its climax: the University Rector, an ardent Nazi, called a meeting of the faculty and abolished the university constitution. Nazi stormtroopers were present to break any resistance. Old 'friends' no longer kept contact.

PROFESSORSHIPS

At this time a new European-type university was being founded in Istanbul and about thirty European professors were hired to staff it, including von Hippel who established a Laboratory of Electrophysics in an old palace. However, jealousies of the old Turkish faculty, misunderstandings, and being in a strange culture made life unpleasant here, so after one year the von Hippel family left Turkey. After first vacationing in the summer of 1934 in Greece, Palestine, and Asia Minor, von Hippel accepted an invitation from Niels Bohr to lecture at the Technical University in Copenhagen as a guest professor from January 1935–1936. On the way to Denmark they spent Christmas in Göttingen, but the atmosphere was depressing because most people had become Nazi followers.

In those days all scientific equipment had to be built. Von Hippel had the shop build a spectrograph and studied the detailed steps of electric breakdown in gases and the alkali-halide crystals. Niels Bohr enticed von Hippel to plan a High Voltage Laboratory of 1–2 million volts for nuclear excitation and disintegration experiments. The van de Graaff and Cockcroft-Walton machines were just on the horizon and quite untried. Von Hippel suggested a cascaded transformer arrangement just being developed in Dresden, Germany, allowing von Hippel a chance for a last look at Hitler's Germany where he found many of his friends had become Nazis.

M.I.T. AND THE LABORATORY FOR INSULATION RESEARCH

PRE-WAR YEARS

Von Hippel received an offer from Prof. Karl Compton to join the M.I.T. faculty and become 'the physicist of the Electrical Engineering Department'. His starting salary was about $3500 per year, so small that when his three boys were in the hospital with infections, he had to sell his Handbook of Physics to pay the bills. His first assignment was to teach with E. Guillemin the introductory course, 'Circuits and Fields'. The subject was new to him and he had little time to prepare. However, because his children got scarlet fever and the whole family was quarantined for thirty days, he had ample time to prepare. Even at M.I.T. there were professional jealousies, and he had to have his students testify that he did not mistreat them. He also had to give a colloquium to demonstrate that his pronunciation was understandable. His first Ph.D. student, Mr. Molnar, worked on the color center in alkali-halide crystals and found the M-bands named after him. Molnar was eventually scheduled to become president of the Bell Laboratories except for his premature death.

During this time von Hippel continued his love of the outdoors by exploring New Hampshire and Maine, and eventually purchasing land and building a log cabin vacation home in Passaconway, New Hampshire.

In 1939 with a grant of $5000 von Hippel founded the Laboratory for Insulation Research, breaking away from classical engineering concepts and departmental constrictions. The name was chosen to justify having a group of physicists and chemists in an electrical engineering department, as insulation is of obvious concern to electrical engineering and also avoided offending other people's interests, but this name later proved to be much too narrow. The Laboratory became internationally known in the field of modern materials research.

Before WWII, sources of support were industrial contracts. An especially challenging problem arose from Colonel Behne, founder of IT&T, for the manufacture of selenium rectifiers, up to that time manufactured in his German plant. The war in Europe had cut off this source of supply and the knowledge of how to make them. A New York factory only had a 5% yield of good rectifiers that had an acceptable ac to dc rectification characteristic. Von Hippel became a consultant to IT&T and accepted a research contract for his laboratory. After achieving good rectifiers in the normal three-day heating cycle, the laboratory developed an electroplating process that produced rectifiers in twenty minutes, resulting in a number of M.I.T. patents, including selenium photo cells by electro-plating.

WORLD WAR II RESEARCH

With the US entrance into WWII, there were rumors of von Hippel as a spy, but this was quickly dispelled with his US citizenship in 1942, the earliest possible allowed date because of his involvement in radar dielectrics.

Radar development was concentrated in the M.I.T. Radiation Laboratory with the Laboratory for Insulation Research responsible for the development, measurement, commercial manufacture, and technical applications of radar dielectrics. Von Hippel was a member of both laboratories. L.I.R. had to create standard measurement techniques and equipment to determine the dielectric properties of many materials as a function of temperature from dc to microwave frequencies. The decimeter and centimeter wavelength ranges at that time were virtually unexplored, and L.I.R. had to develop new precision instruments for commercial manufacture and distribution to government and industry laboratories in the US and Allied countries.

Polymers such as polystyrene and polyethylene were upgraded as extremely low-loss dielectrics and their useful temperature range extended with additives to allow the Navy to pull radar cables through battleship boiler rooms. Dielectric properties of plastics, rubbers, ceramics, and glasses were measured by the newly-formed Dielectric Measurements Group under the supervision of Bill Westphal. Results were published in the classified 'Tables of Dielectric Materials'.

The development of new materials required setting up of inorganic and organic chemistry laboratories, x-ray and electron diffraction facilities, and electric and optical spectroscopy measurements. In producing high dielectric constant ceramics, L.I.R. discovered the ferroelectricity of barium titanate and made high voltage capacitors and ceramic delay lines. Previous experience with selenium photocells involved L.I.R. in infrared photocells of the thallous-sulfide type. Dielectric studies also led to dielectric heating for rapid wood-curing.

Through all these activities L.I.R. grew large and crowded so that (with the outwitting of fire codes) the M.I.T. Building 4 laboratory with a high ceiling required the building of a balcony. In addition, there were laboratories in Buildings 10 and the Radiation Lab Building 24 with a large shop in the basement. This scattering over widely separated buildings aggravated the problem of unified action.

To have a close liaison between L.I.R. and government agencies responsible for procurement and applications of dielectric materials, the War Committee on Dielectrics was formed with the Army, Navy, and War Production Board.

As the end of the European War approached in 1945, von Hippel volunteered to go at armistice time to Germany, in order to help with his knowledge of the country and people, as well as to find family and friends. He was offered the rank of Army colonel for this purpose but because he was greatly overworked he wound up in the hospital for a thyroid operation and did not go to post-war Europe until 1952.

POST-WAR YEARS

By this time von Hippel realized his challenge, to transform the field of materials research into the molecular designing of materials and devices. Because of the wartime performance of the L.I.R., they received the first Army-Navy-Air Force contract for peacetime work. Co-workers from many nations joined L.I.R., and von Hippel's first book, *Dielectrics and Waves*, (dedicated to Niels Bohr and James Franck) was written and was published in 1954 simultaneously with the book *Dielectric Materials and Applications* (dedicated to Karl Taylor Compton) which grew out of a 1952 M.I.T. summer session course trying to teach scientists, engineers, manufacturers, and users of dielectrics to speak each other's languages and appreciate mutual problems, failures, and advances. For the first book von Hippel considers 'dielectrics' as the usual insulators, but also any nonmetal, and even metals as a limiting case. 'Waves' is in the title of the first book to represent electromagnetic waves, probability waves of quantum mechanics, and the elastic waves of crystal lattices. Focus was on polarization, magnetization, and conduction trying to bring together physicist, chemist, and electrical engineer. The latter book contained as an Appendix an unclassified edition of the Tables of Dielectric Materials and hoped to establish alliances between research worker, development engineer, manufacturer, field engineer, and actual user of 'nonmetals'. In 1956 another summer session on Molecular Engineering resulted in the 1959 book, *Molecular Science and Molecular Engineering*. Finally, the 1963 summer course on 'The Molecular Designing of Materials and Devices' was published in 1965. Since the participants came from a gamut of professions, chaos was avoided by insisting that every lecturer express concepts in graphic language before mathematical formulation clouded the issues. Von Hippel had a friendship with M. C. Escher because he felt a relationship with Escher's art and molecular designing. Escher made a woodcut, 'The Thinker', for this last book, showing a man in a foolscap contemplating a 'screwy' model in puzzled confusion.

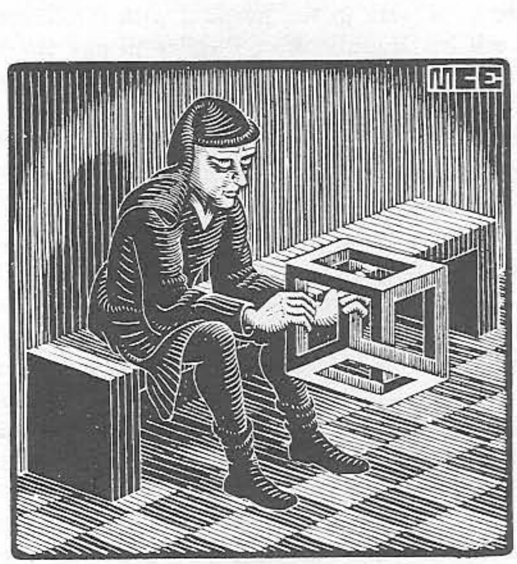

Figure 2.
Thinker, woodcut by Maurits Cornelis Escher (1898–1972), Dutch artist and friend of Arthur von Hippel and the Laboratory for Insulation Research. (Compare with Figure 1).

At one time von Hippel was going to take L.I.R. out of M.I.T. when a successful industrialist offered him a directorship and a chance to create a research laboratory. Fortunately, the industrialist went bankrupt before the deed was done, and M.I.T. was glad to keep von Hippel and L.I.R.

Throughout its existence, L.I.R. strove for a synthesis of knowledge, drawing research students in with unofficial agreement from the M.I.T. departments of physics, chemistry, electrical engineering, metallurgy, etc. A joint education in 'molecular science' and 'molecular engineering' made firm allies of the scientists searching for a deepening understanding and the engineers striving for intelligent applications.

Von Hippel laments that 'the securing of funds for the creation and maintenance of facilities as well as for the salaries of staff and students falls also to the unhappy lot of the research professor in charge'. Expenses were large. For example, the first single crystals of magnetite ever grown were produced in L.I.R. and cost $20000 each. The cost of one Ph.D. student from baccalaureate to doctoral thesis cost $40000, and L.I.R. educated sixty.

POST RETIREMENT

By retirement there was still uncompleted work of major importance: dielectric spectroscopy, electric strength of materials, and other unpublished material. To avoid loss of this backlog of important knowledge, von Hippel continued writing, teaching, and research as a small residual L.I.R. He became taken with the question: How does Nature proceed with its design in creating living systems? Following the theme 'from atoms to living systems', he studied electrobiology through better understanding of molecular electrochemistry of liquids and solids. This resulted in seventeen further Technical Reports (new series) focusing on the polarization and conduction of pure water and perfect ice single crystals and the three main properties of H_2O molecules–hydrogen bonding, dipolar action, and ion formation. However, he realizes that any premature optimism about our intelligence is squashed when the spotlight turns to biology. He acknowledges that to study biology today you must be a real biologist equipped with all modern tools–and not only a friend of biology and medicine by osmosis. Still, he felt that his ideas, approaches, and findings might prove useful for the next generation. His last publication, 'From Atoms Toward Living Systems', was published in the Materials Research Bulletin, V. 14, pp. 273–299, in 1979. His last student, Keith W. Karvate, received a Sc.D. in Electrical Engineering and Computer Science from M.I.T. in 1979 with the thesis 'Electrical Surface Studies on Hexagonal Ice and Their Interpretation'.

Von Hippel notes how ingeniously Nature uses water as a solvent, reactant, and structuring agent and that industrial pollution of water is a crime against life on earth. Knowledge automatically confers responsibility for a balanced utilization and preservation of this planet's resources. He feels that the molecular designer of nonliving materials has proven a keen inventor but at times a public menace because of the design of non-decomposable throw-away materials without regard to Nature.

In 1982 L.I.R. was partially resurrected in the new M.I.T. Laboratory for Electromagnetic and Electronic Systems (L.E.E.S.) of which this author is a member. This new laboratory combined the Electric Power Systems Engineering Laboratory, the High Voltage Research Laboratory, and the Continuum Mechanics Laboratory, for all of which many activities are directed to insulation research. This includes continuing dielectric measurements using the L.I.R. bridges and microwave lines by Bill Westphal even past his official retirement, as well as electrical breakdown studies, electric power equipment and systems, and applications to living systems.

REFERENCES

[1] "Molecular Understanding of Electrochemical Processes by Ice Research", A. von Hippel, J. Electrochem. Soc. Vol. 119, No. 2, pp. 45C–54C, 1972.

[2] "The Dielectric Relaxation Spectra of Water, Ice, and Aqueous Solutions, and their Interpretation. 1. Critical Survey of the Status-quo for Water", IEEE Transactions on Electrical Insulation, Vol. 23, pp. 801–816, 1988 (this issue).

[3] "The Dielectric Relaxation Spectra of Water, Ice, and Aqueous Solutions, and their Interpretation. 2. Tentative Interpretation of the Relaxation Spectrum of Water in the Time and Frequency Domain", IEEE Transactions on Electrical Insulation, Vol. 23, pp. 817–823, 1988 (this issue).

[4] "The Dielectric Relaxation Spectra of Water, Ice, and Aqueous Solutions, and their Interpretation. 3. Proton Organization and Proton Transfer in Ice", IEEE Transactions on Electrical Insulation, Vol. 23, pp. 825–840, 1988 (this issue).

[5] A. von Hippel, *Dielectrics and Waves*, John Wiley and Sons, New York, 1954.

[6] A. von Hippel, Ed., *Dielectric Materials and Applications*, The Technology Press and John Wiley and Sons, New York, 1954.

[7] A. von Hippel, *Molecular Engineering*, Tech. Rep. 101, Oct. 1955; Science Vol. 123, p. 315, 1956.

[8] A. von Hippel, Ed., *The Molecular Designing of Materials and Devices*, M.I.T. Press, Cambridge, Mass., 1965.

[9] "Final Report, Laboratory for Insulation Research, Massachusetts Institute of Technology", Tech. Rep. 204, Contract Nonr-1841(10), November 1965.

[10] "Laboratory for Insulation Research Publications", IEEE Transactions on Electrical Insulation, Vol. 23, pp. 841–859, 1988

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