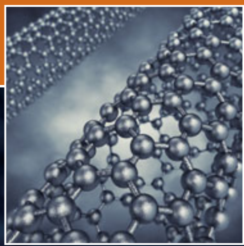

Memories of Arthur von Hippel, 1898–2003

Mildred Dresselhaus

This article is based on a presentation given by Mildred Dresselhaus for the Von Hippel Award on December 4, 2013, at the Materials Research Society Fall Meeting in Boston. Dresselhaus received the award "for her pioneering contributions to the fundamental science of carbon-based and other low electron density materials, her leadership in energy and science policy, and her exemplary mentoring of young scientists."

In my Von Hippel Award talk, I emphasized my connection to Arthur von Hippel since our meeting in 1960, when Arthur von Hippel was 62 years of age, but still spanning the last 40 years of his life. He was a Renaissance man with many broad interests. I also spoke about the work that was cited in my award and our overlapping activities. Professor von Hippel was a mentor to me in my early career, and he worked to advance my career behind the scenes. Even after his passing a decade before my selection for the Von Hippel Award, I continue to be influenced by his teachings about science, as well as about his enjoyment of the practice of science and the life of a scientist. Professor von Hippel's views on the foundations of materials research have strongly influenced the Materials Research Society, and this viewpoint is also emphasized in my article and by my own research career, which has been recognized by the Von Hippel Award.

Introduction

The Materials Research Society (MRS) has conferred the Von Hippel Award annually since 1976, in honor of its first recipient, Professor Arthur R. von Hippel, who had an important impact on international materials research as we know it today. He received this award that bears his name at the age of 79, at a time when he was still active in materials research and discovery. I am the 38th winner of the Von Hippel Award, and my citation was for pioneering contributions to the fundamental science of carbon-based and other low-electron-density materials, leadership in energy and science policy, and for exemplary mentoring of young scientists. My oral presentation also focused on these topics, and also included my own "Memories of Arthur von Hippel (1898–2003)," since I was his close friend for the last 40 years of his life, and one of the few winners of this award who knew him personally.

About Arthur R. von Hippel

I start with my memories of stories Arthur von Hippel told me in casual conversations about himself. He joined the MIT (Massachusetts Institute of Technology) faculty in 1936 after leaving Germany and a professorship in Göttingen because of the uncomfortable political situation that was developing in Germany in the 1930s. Arthur von Hippel was in particular jeopardy when the Nazis came to power in 1933, because he had publicly written statements against the Nazi party and against Hitler, and because his wife was Jewish. In his autobiography, he writes extensively about his life before 1934 when he fled from Europe with his family. He had been brought up in Europe and had prepared himself for a career in Europe, and remained European on a personal level all his life.

I got to know Arthur von Hippel because he was hired by the MIT Electrical Engineering Department. They hired him because they appreciated his broad view of materials research as a highly quantitative science that could someday have an increasingly strong impact on society.

It was not long after he arrived at MIT that World War II broke out in Europe. During World War II, Arthur von Hippel was the leader of a large group engaged in the research and development of new materials to meet US needs for radar development for potential defense applications. During this period, he trained many young people in the fundamental principles of materials research as well as in the development of interesting new materials and devices. MIT was an exciting place to be during the World War II period, and Professor von Hippel was happy to contribute strongly to the US war effort against Nazi Germany.

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Mildred Dresselhaus delivering the von Hippel Award Presentation at the 2013 MRS Fall Meeting.

He remained at MIT in the Electrical Engineering Department after World War II was over as the leader for developing new materials for electronics applications. He also was interested in enhancing the properties of known materials for meeting the ever-increasing performance demands of the electronics industry, which was growing rapidly in the 1940s and beyond. His research interests were very broad, and he could get excited about any kind of material that had the potential for contributing to the rapidly growing electronics industry after the invention of the transistor in 1947. His idea was to develop research and education hand in hand, keeping in mind both civilian and defense applications based on his own experience up through the 1930s and 1940s. He gathered many colleagues and students at the undergraduate and graduate levels into his laboratory, and by the 1950s, the materials component of the Electrical Engineering Department was a very large and strong activity at MIT.

Although his own background was in applied physics, and his interest was in materials research, he would often say to me and to others how his research spanned several academic departments, but people in these other academic departments did not always listen to his views. He often spoke highly of the connectivity between scientific disciplines and their interdependence in research and teaching. From his perspective, the faculty in the Department of Metallurgy, the forerunner of the present Department of Materials Science and Engineering, at that time were not much interested in new materials with specific functionalities, but rather in metals and alloys and their mechanical properties, such as strain, fracture, corrosion, and lifetime performance. Arthur von Hippel found them to have little concern with the electronic, optical, or magnetic properties of materials that interested him. He also liked to think about special properties that might be useful for a potential application and how to "engineer" any given material to optimize such properties. In other words, he felt himself to be more interested in the science behind material properties than were faculty members of the Metallurgy Department at MIT, which had many highly distinguished scientists and engineers working on metallurgy.

He also did not find the MIT Physics Department able to provide him with a welcoming home. The members of the MIT Physics Department were strongly focused on advancing nuclear physics and the forerunners of particle and high-energy physics, and they focused their energy and resources on building and strengthening those areas. As he used to tell me, the MIT Electrical Engineering Department was expanding rapidly in the 1930s and 1940s because of the rapid pace of discovery both in the electronics industry and in the leading industrial and government laboratory sectors. Research leaders were pushing developments of radar and electronics for the defense and communication industries, and once the United States entered World War II in 1941, the demand for professionals trained in these research areas increased even more rapidly. Thus the US government was pouring money and encouragement into university research laboratories to train students and military personnel and to accelerate technical progress and capability in the United States in applied physics research fields. All this helped Professor von Hippel to set up his laboratory at MIT. Here he worked with graduate students, undergraduates, and some permanent staff developing new materials, spearheading new directions for materials research, and enjoying himself thoroughly in his hard work. But he always found time in the day for tea and for personal exercise, following his European heritage.

I first met Arthur von Hippel in 1960 shortly after I joined the MIT Lincoln Laboratory, starting my own independent career. In those years, I studied the magneto-optics of materials. Such studies were enabled by the availability of high magnetic fields, which allowed me to study interesting new science. At that time, Professor von Hippel was 62 years old and close to retirement age for most MIT faculty members, but he was still at the peak of his career, and was intensely interested in perovskite-based materials. In fact, any kind of new material with fascinating properties interested him. However, our first face-to-face meeting in 1960 occurred not through science but through music.

Not only did Professor von Hippel have a passion for science, he was generally a very scholarly person in the European tradition. He came from a family of scholars, with a high density of professors in science and medicine. Not only was scholarship part of his own family background, but he also married into the James Franck family, which was another famous family of scholars, with his father-in-law a Nobel laureate for his discovery of the Franck-Condon Principle. The von Hippel family and the Franck family were deeply into the European culture of the early 20th century, and their environment was filled with music, art, and literature. The young von Hippels brought these interests and values with them to the New World when they emigrated to the United States in the 1930s. In fact, Arthur von Hippel's research group had a string quartet, and these players provided background music for social events.

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The time we first met, his string quartet needed a viola player, and I was soon enlisted for this assignment through Joe Stein, the cellist in the von Hippel quartet who also managed the publications of the von Hippel research group during the day while making music at the Stein home in Belmont every night. Stein was an avid and accomplished cellist, and also a refugee to the United States because of the brewing unrest in Europe. Stein is still remembered in the music world for his involvement in the Amateur Chamber Music Players association, which was known and operated internationally. I have memories of his Electrical Engineering Department String Quartet in which Stein was the cellist and intellectual leader, John Gelatis was first violinist and an engineer at Lincoln Laboratory, I played viola, and an Electrical Engineering student normally played second violin. These musicians enjoyed themselves, provided background music for laboratory parties and social events, and were involved with a brief performance of some classical string quartet musical composition for the Arthur von Hippel annual birthday party in the laboratory. I particularly recall his 75th birthday party, the last party that I remember where his wife Dagmar was present. I also remember his 90th birthday party, which was a big event for the Electrical Engineering Department as a whole.

Not only did Professor von Hippel have a long life, 105 years, spanning three centuries, but he remained active in research until 88 years of age, when he wrote his last (or nearly last) research paper. He also supervised graduate students actively well into his 80s. He closed down his active laboratory when he was about 88 years old, and some of his laboratory mementos were collected and placed in the von Hippel Room in the Center for Materials Science and Engineering at MIT, with many other items going into the MIT Museum and archives.

In my interactions with him, he was very interested in the work of young people going into new directions for materials research. For example, he was quite interested in my early work in the 1960s when I was trying to understand the electronic properties of graphite. At that time, there was very little research ongoing on the topic of carbon-based materials, which have a highly novel electronic structure. I found this materials system to have great scientific interest because carbon-based materials are so different from other materials systems, and Professor von Hippel was interested in my research for that reason. In the 1960s, people were largely interested in silicon and germanium, with some minor interest perhaps developing for III and V compounds. Professor von Hippel was interested in perovskites and ferroelectric materials, which were active areas in the 1960s, in part, because of the ongoing research in the von Hippel group.

Professor von Hippel was always telling me that new and interesting high-impact ideas are most likely to come from adventurous young people. His appreciation of these revolutionary and innovative ideas was one of his long-term impacts on me and others in my age group who attended his lectures. This idea has, in fact, been borne out in scientific developments historically and in studies of scientific innovation by social scientists. Professor von Hippel was a role model to me in mentoring young people and in encouraging them to develop their own ideas. He was also a role model for many young people in the latter years of his career, after his formal retirement from MIT in 1962. He remained active as a role model for the next 25 years, and has been a role model to many, including myself, on how to keep happy, healthy, and productive after formal retirement.

My own research during the von Hippel period

I received the MRS Von Hippel Award for my research on carbon-based and other low-electron-density materials, my leadership in energy and science policy, and for mentoring young students. As I said previously, Arthur Von Hippel was especially interested in my research because it was different from what others were doing, and it seemed quite fundamental to him in keeping with my comments about him as a person. He was especially fond of research with experimental and theoretical components, and my own research and his both required experiment and theory working together.

In the 1960s when we first met, I was working on the electronic structure of semimetals like bismuth and graphite and narrow-gap semiconductors like indium antimonide, all having low carrier densities and very high mobility carriers, because such materials could be very effectively studied in high magnetic fields. Such experiments could be carried out at MIT especially well because of the special facilities uniquely available in the laboratory of Professor Francis Bitter. In the early 1960s, the users of the facility were trained by Professor Bitter's graduate students; others, like myself, who were thus trained signed up for magnet time when the magnets were not being used by members of Professor Bitter's group. Young researchers from all over the world came to MIT to use the Bitter laboratory. Bitter was the designer of the "Bitter magnets," which provided high magnetic fields reliably, in a friendly environment. One benefit of working in this facility was the other users we met there. These researchers normally worked at the facility when they could schedule magnet time. Some of these researchers learned how to build such a facility in their home countries, and several of them did exactly that.

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In fact, a much larger version of the Bitter laboratory was built at MIT in 1964 to accommodate the increasing demands for magnet time. I personally found this facility a very attractive way to do frontier science conveniently and inexpensively and was very active in high-magnetic-field research from 1960 to 1990, which is the period when I had the most active scientific discussions with Professor von Hippel.

In the 1960s, I worked with a series of students and a few international collaborators on high-magnetic-field studies of the electronic and phonon properties of interesting narrow-gap high-mobility materials such as bismuth, BiSb alloys with low Sb concentrations (<15 at.%), where we focused on the electronic properties of anisotropic materials. In this time frame, we also did extensive work in studying the electronic structure of graphite. Both graphite and bismuth-antimony were becoming popular, and these topics had high-impact international conferences. At that time, international travel was rare, unusual, and expensive. But in 1970, I managed to go to a conference on narrow-gap semiconductors and semimetals in Dallas, Texas, where I met Jean-Paul Issi. Our common interests in bismuth-antimony brought us together, and we coauthored many papers, shared many graduate students, and strongly influenced each other's work. In 1980, I attended a conference in Provincetown, Massachusetts, where I met Morinobu Endo from Shinshu University in Japan, and we established a close working relation on nanocarbons. This collaborator has also had a long-term impact on my career for the past 30 years in expanding my knowledge of carbon nanomaterials and device applications.

Not only did Professor von Hippel have an appreciation for scientific studies for advancing the frontiers of science, but he also appreciated science for the benefit of society. He had good memories of his own efforts in contributing to the materials components of the development of radar for communications during World War II. Being a refugee from Europe, he emphasized internationalism and had people in his laboratory from many countries. He was in strong agreement with the Dean of Engineering at MIT, Gordon Brown, who thought that engineers needed to increase their knowledge of science so that they could learn the very rapid scientific advances that were made during World War II and could use the advances in physics and chemistry in the past two decades to develop transformative new devices and device concepts. Like Brown, von Hippel felt that the engineers trained in the United States in the 1930s did not have the scientific knowledge base to lead many of the World War II weapons development and defense development projects, which were consequently led by people coming from physics and chemistry working with engineers. von Hippel therefore advocated having students study both science and engineering concurrently, emphasizing the overlap between the two. The von Hippel laboratory therefore had a range of researchers of all ages who came from many countries, including people with science and engineering backgrounds, to work and learn from each other. Having an active scientific career spanning about 70 years, he was constantly learning new things together with young people until about age 88, when we started seeing less of him at MIT on a daily basis.

Mildred Dresselhaus and Arthur von Hippel in November 1988.

In his later years, after his 90th birthday party, I often had the chance to visit him at his home in Weston, Massachusetts. He and his caretaker gave visitors a warm welcome, simple refreshments, and a long walk in the woods close to his home. von Hippel had a one-hour walk in the woods twice a day to keep himself in good physical and mental shape. These walks took place independent of weather or season. Being systematic in life, as in science, is how I remember him. He believed that his organized lifestyle was responsible for his well-being, mental acuity, and physical longevity. Arthur von Hippel was not only a role model for materials research enthusiasts but for young people enjoying their work and their families.

I should also mention that Arthur von Hippel was very devoted to his family. He and his wife Dagmar (Daggie) raised five children (four sons and a daughter), and most of his children went into active careers contributing to science and engineering, but were located far from his home. I therefore had almost no contact with his family members, though I visited him often.

Arthur von Hippel as a mentor

Arthur von Hippel was my mentor, and he taught me the importance of mentoring young people. As my mentor, he took an interest in my research and helped my career to advance at MIT in ways unknown to me. Since he was the one person in the Electrical Engineering Department closest to me from a scientific standpoint, he took responsibility as my mentor and advisor. The broad training I received at the University of Chicago under the Fermi "system" enabled me to change fields readily when I started my independent career at the MIT Lincoln Laboratory, where I was strongly encouraged to work in a different research field of interest to the laboratory and different from what I had done before, which

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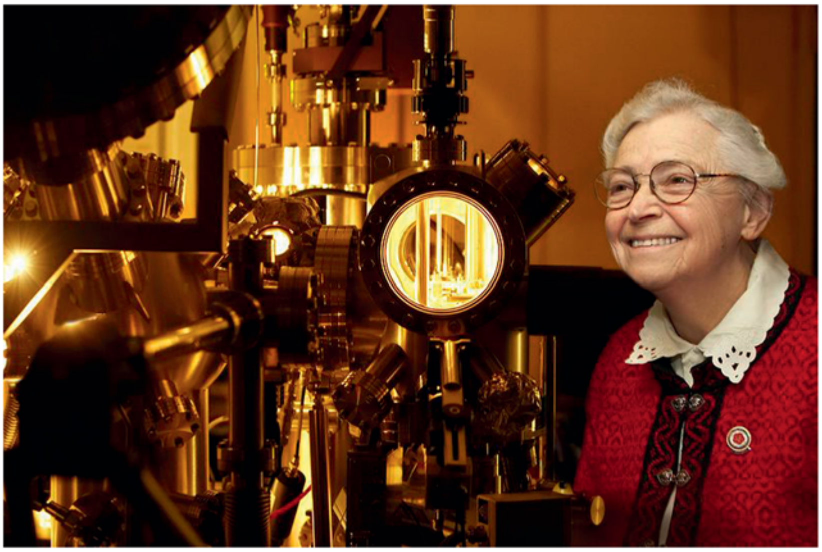
was on superconductivity in small-diameter wires in a magnetic field at microwave frequencies.

I chose magneto-optics, which was a relatively new research area at that time (1960) and was of great interest to Dr. Benjamin Lax, who was the head of the Lincoln Laboratory Division called "Solid State Physics." The high-magnetic-field research specialty attracted me as being a wide open field, and there was considerable expertise available in high-magnetic-field technology, optical techniques, and materials preparation at Lincoln Laboratory. I therefore saw this as a good learning opportunity. The field change from superconductivity to magneto-optics turned out to be highly advantageous for me. In fact, I worked happily with many graduate students in the magneto-optics field for the next 30 years. Once I became familiar with the new research field, I chose to differentiate myself from others already in the field by studying magneto-optic effects in semimetals and narrow gap semiconductors, where there was little activity at that time. Through my research in high magnetic fields, I was appointed in 1973 as the Abby Rockefeller Mauzé Professor at MIT. This endowed professorship gave me some additional funds with freedom in the choice of research topic and encouragement to mentor students, especially women, at both the undergraduate and graduate levels.

The year 1990 turned out to be a turning point for Professor von Hippel and also for my career. For the Professor, as we called him, he was at the end of his active career at the age of 91. I was also undergoing a career change because a US NSF advisory committee completed a study of the future of high-magnetic-field research, and recommended that the US National Laboratory on this topic, which had been located on the MIT campus from 1964–1990, should move to Tallahassee, Florida. Since my own family was located in the Boston area, I was not free to move to Florida, and I decided the time had come to change fields after 30 years of fruitful research at high magnetic fields.



Although painful at first, this decision turned out to be a very good one both for science and for my career. Changing career directions every 15 years seems to be a good plan, and has kept me active and excited about science. While working with high magnetic fields, I had a number of side projects. In the 1970s, I was working on graphite intercalation compounds, which was a topic that appealed to Professor von Hippel because it involved discovery of new fundamental scientific principles, the finding of new and interesting materials with novel properties of both experimental and theoretical interest, and the training of many graduate students on exciting, frontier topics. In the 1980s, I continued studying graphite intercalation compounds, but expanded my research activities to the study of carbon clusters with Professor Venkatesan (first at Bell Laboratories and later at the University of Maryland) and very small diameter carbon wires with Professor Endo in Shinshu University, Japan. These studies, in turn, led to studies of Raman and infrared spectroscopy of these compounds with my postdoc Peter Eklund starting in 1974, and later took off through the pioneering work on fullerenes of Smalley, Kroto, and Curl in the late 1980s, making use of my teaching a group theory course at MIT for many years, which included icosahedral symmetry.

With this background and the question asked of Professor Smalley and myself at a seminar on the connection between fullerenes and carbon fibers, the idea of a nanotube one atom thick surfaced. The calculations of Riichiro Saito and Mitsutaka Fujita, who were both young faculty visitors to my laboratory in 1992, indicated that a single-walled nanotube could be either semiconducting or metallic, depending on the orientation of the hexagons relative to the nanotube axis. These findings, which we published in 1992, stimulated broad interest in Professor von Hippel from a distance. However, his interest in the research I was involved with on carbon nanotubes became increasingly less detailed after his 90th birthday. The recent graphene revolution started in 2004, which was inspired by the work of Wallace in 1947 and known to Professor von Hippel, but came too late to get on Arthur von Hippel's radar screen.

On leadership in energy and science policy

My entry into leadership positions in energy and science policy started with my election to the National Academy of Engineering (NAE) in 1974, which soon resulted in my election to membership on the Council for the National Academy of Engineering. There I met leaders in US industry and academia and became involved in discussions of national needs and goals. Arthur von Hippel had always been interested in science policy and encouraged me to become involved and to contribute to such discussions actively. In the 1970s, there was significant interest in energy security and K-12 education for future leaders

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in industry, government, and academia in the United States. All of these topics were of great interest to Professor von Hippel, and we often discussed them.

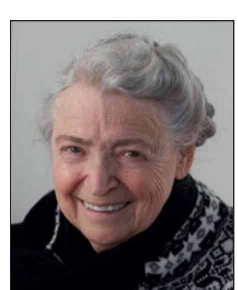
At that time, the US economy was strong, and both Europe and Asia were in a rebuilding mode. Japanese industry, in particular, was moving forward in the areas of electronics and materials research. I found my work on National Academy committees to be interesting, and I benefited a great deal from discussions with other NAE leaders on the Council and NAE elected officers. My involvement increased significantly when I was elected to the National Academy of Sciences (NAS) in 1985, and soon thereafter to the NAS Council. Involvement in NAE and NAS affairs provided broad experience in national science policy discussions. Because of the very small number of women NAE and NAS members, I was invited and encouraged to participate in many activities of current interest, with energy security being one of these issues.

My involvement in energy-related policy issues increased dramatically in 1999 when I became the Assistant Secretary of Energy and Head of the DOE Office of Science in the Clinton administration, working directly under the DOE Deputy Secretary Ernie Moniz and DOE Secretary Bill Richardson. My meetings with Secretary Richardson occurred at about 8 am on Monday mornings. Every week, I flew into Washington DC on the Monday 6 am flight from Boston and took the Washington Metro directly from the airport to DOE Headquarters for the weekly staff meeting. I was always the first person called on by Secretary Richardson to relate relevant happenings in science and engineering, in general, and the happenings under my watch at the DOE. I was happy to know that although Secretary Richardson was not a scientist himself, he had a deep appreciation of science and its importance in advancing energy production technology and energy security worldwide.

Conclusion

I am very much honored to be cited in the MRS Von Hippel Award for mentoring the next generation of scientists and engineers in materials research. Arthur von Hippel was a great mentor to me and many other people over his long career. In the early days when I came to MIT, he introduced me to many new research directions where new and better materials could have an impact, and introduced me to many people who could be helpful in research and teaching. He was a great mentor because he took an interest in people and tried to offer help to get them started. Over the years, I have learned of the importance of offering help and encouragement to young researchers and young faculty members.

Arthur von Hippel was the faculty member in the MIT Electrical Engineering Department who was closest in research fields to me when I joined the department. Furthermore, I was the first tenured female faculty member in the MIT Engineering School in 1968 when I was appointed as a professor in the Electrical Engineering Department. This was after spending seven years at the MIT Lincoln Laboratory and one year as a visiting professor at MIT. I held the chair established by the Rockefeller Family as the Abby Rockefeller Mauzé Professor, honoring the older sister to the five younger brothers in that illustrious philanthropic family. She was a strong advocate for promoting education for women in science and technology. In the spirit of the endowed chair that I held from 1967 to 1985, I became heavily involved in the mentoring of women students at the undergraduate and graduate levels throughout MIT via mentoring sessions and through classroom teaching in a course called, "What is Engineering," which was aimed at broadening the perspective of young students, particularly women and underrepresented minorities, about available career opportunities. Arthur von Hippel's appreciation of revolutionary and innovative ideas had a long-term impact on me and for many other generations to come.



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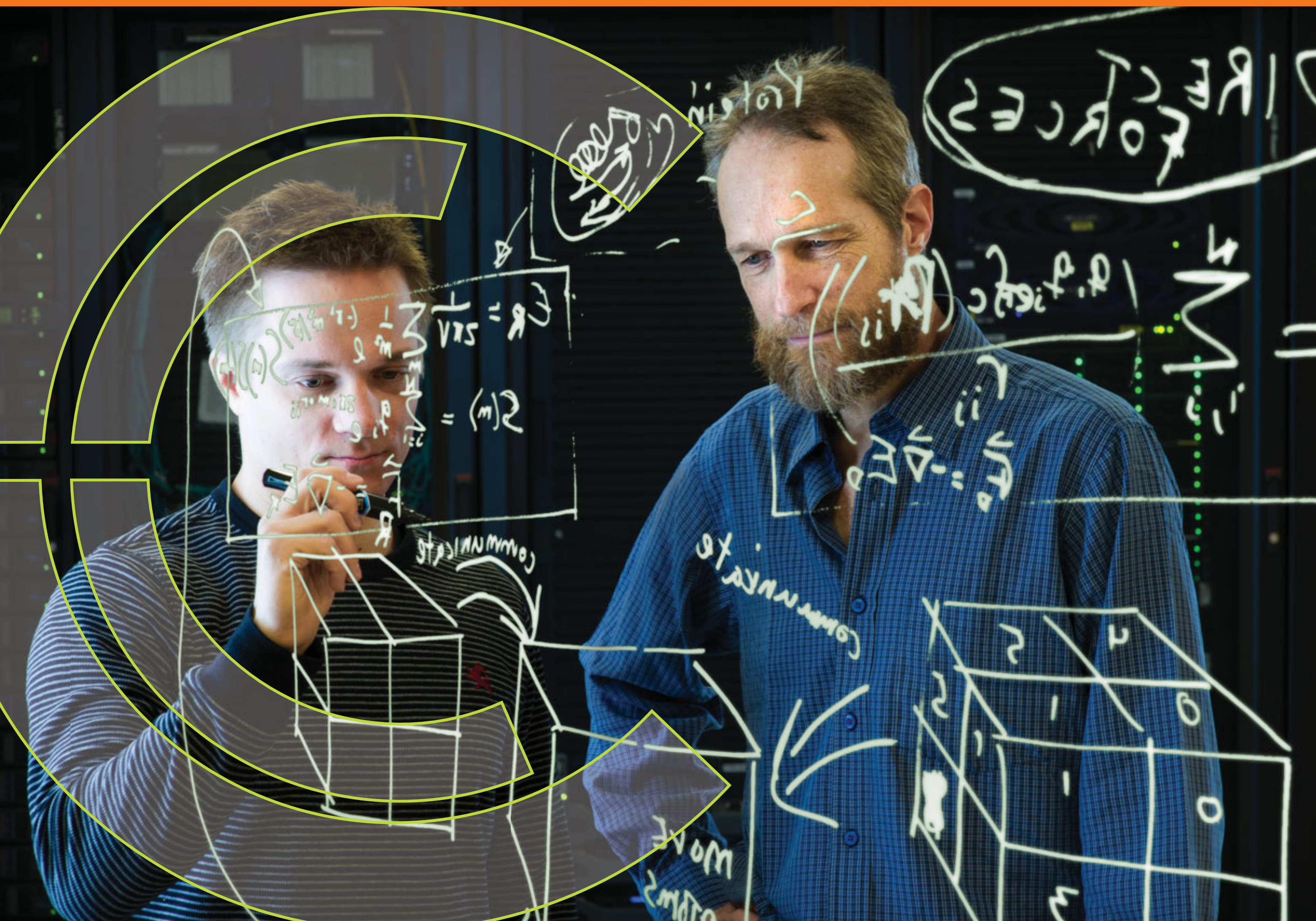

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