



Legacy

Herman F. Mark: Pioneer in structural chemistry, molecular biology, and polymer science

Virgil Percec^{1,*}

Herman Francis Mark produced brilliant contributions to the fields of organic chemistry, structural chemistry, molecular biology, and polymer science in academia and in industry in four different countries from two continents. This Legacy article outlines the author's view on how Mark, who was universally known as the father of polymer science, also pioneered the science, education, publishing, and lecturing styles for the fields of structural chemistry and molecular biology with his disciplined and elegant leadership.

Herman Francis Mark was universally known as the father of polymer science. He had a brilliant impact on the development of three fields: structural chemistry, molecular biology, and polymer science. His landmark contributions in both academia and industry spun over four different countries: Austria, Germany, Canada, and the US. Mark was born in Vienna in 1895. "In my boyhood, life in Vienna was like a wheel with equal parts of discipline, creativity, and sports," he stated when referring to his home city. As G.A. Stahl writes, "The discipline [Mark] mentions was taught by example by intelligent, benevolent adults. A young middle-class Viennese was taught to seek knowledge and maintain an open mind in judging facts. He was taught cooperation and how to listen, yet intellectual freedom was also fostered. Freedom to question and analyze and rethink. A freedom which, Mark cautions, should not be confused with undisciplined, boundless movement."^{1,2} Equipped with these features, the Viennese were leading the world in advancing new music, art, and architecture. Mark's early days have been discussed repeatedly.¹⁻⁴ Mark graduated from high school in 1913, and before going to university, he decided to fulfill his one-year mandatory military service, which was extended to the end of the World War I. During the war, Mark became highly decorated; learned Italian, French, and English; and taught himself physics, chemistry, and mathematics. In 1921, he obtained a PhD in organic chemistry under the supervision of Wilhelm Schlenk for the synthesis of pentaphenylethyl free radicals.^{5,6} "The concept of free radicals was not yet known in 1920—well, perhaps in politics, but not in chemistry," Mark later stated. In 1921, Schlenk replaced Nobel laureate Emil Fischer at the University of Berlin, now known as Humboldt University, and took Mark with him. One year later, Mark was recruited by Fritz Haber (1918 Nobel Prize winner and discoverer of ammonia synthesis), who had asked Schlenk to recommend him a modern organic chemist, to join the new Institute of Fiber Research from the Kaiser Wilhelm Institute (now Max Plank Institute), where Haber was director. Michael Polanyi also joined the Institute of Fiber Research, and a broad program on X-ray crystallography began. In 1924, Mark

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Above image: Herman F. Mark. © National Academies Press.

¹Roy & Diana Vagelos Laboratories, Department of Chemistry, University of Pennsylvania, Philadelphia, PA 19104-6323, USA

*Correspondence: percec@sas.upenn.edu

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Wilhelm Schlenk
(1879 - 1943)



Herman Mark
(1895 - 1992)



Lawrence Bragg
Hermann Staudinger
(1890 - 1971)



Hermann Staudinger
(1881 - 1965)



Linus Pauling
(1901 - 1994)



J.D. Bernal
(1901 - 1971)



Max Perutz
(1914 - 2002)



Isidor Fankuchen
(1905 - 1964)

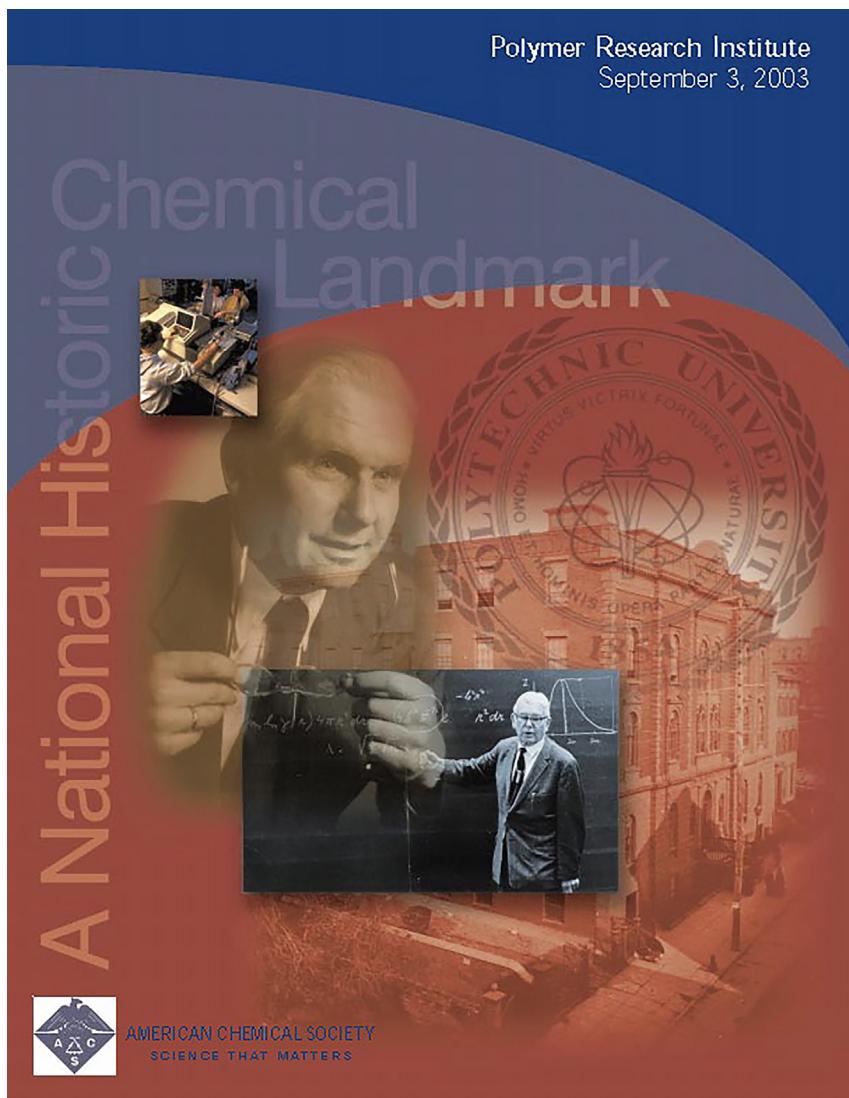
A mentor (A), student (G), and few early collaborators (C–F and H) of Mark (B). © AIP Emilio Segrè Visual Archives (B, C, E, F, and H) and the public domain (A, D, and G).

demonstrated that cellulose fibers showed crystallites oriented in the direction of the fiber, analogous to the crystal orientation in metals. This indicated that covalently bonded structures could extend beyond the crystallographic unit cell, in agreement with the macromolecular concept advanced by Staudinger (1953 Nobel Prize winner). In 1926, during the Society of German Natural Scientists and Physicians conference in Dusseldorf, Mark presented the lecture "Determination of the structure of organic, especially high molecular mass substances by X-ray studies"⁷ and met Staudinger. Although both agreed on the macromolecular structure of large molecules, Staudinger considered them to be stiff rods, whereas Mark believed in rotation around their covalent bonds. Aside from this, Mark never disagreed with Staudinger's macromolecular concept,^{8–11} but Staudinger was not friendly toward Mark because of this disagreement. In 5 years, Mark co-authored 50 seminal papers on the determination of chemical structures by X-ray diffraction of metallic and nonmetallic elements, minerals, organic and inorganic compounds, carbohydrates, condensed gases, proteins, and natural and synthetic polymers and became one of the world's experts in crystallography. A detailed discussion of his crystallographic work from these days was published by Linus Pauling,¹¹ who named Mark a pioneer of structural chemistry.

During this period, Mark collaborated with some of the greatest scientific minds of his time: Albert Einstein, Linus Pauling, and Michael Polanyi, to name just a few. In 1926, Kurt Meyer, the director of I.G. Farbenindustrie (now BASF), challenged Mark by offering him a director of research position with complete research freedom at his company in Ludwigshafen, Germany. In this position, Mark was able to apply his knowledge of fiber structure to

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the production of new polymers while continuing his fundamental research. Mark accepted this challenge and immediately added electron diffraction to his studies on structure determination. In 1928, Meyer and Mark solved the diffraction pattern of cellulose, the first polymer crystal to survive the test of time, and the structure of Hevea rubber.¹² In 1930, Linus Pauling visited Mark in Ludwigshafen and learned about his electron diffraction methodology and instrument. He asked whether he could build one at CalTech with Mark's permission and help. Mark agreed, and within 25 years, Linus Pauling with 56 graduate students and postdocs solved 225 structures by using the electron diffraction method he learned from Mark. In 1932, Meyer and Mark investigated the crystal structure of fibrous silk protein and identified that it extends along the fiber axis and is hydrogen bonded between chains.¹³ This knowledge of bond length and bond angles helped to elucidate this structural concept. Mark's 6 years in Ludwigshafen resulted in 80 publications, 3 books, and 17 patents, in addition to technological contributions to the commercialization of some polymers. Given that Nazis were taking over Germany, in 1932 Mark returned to the University of Vienna as a professor of chemistry. Immediately, he initiated the first world curriculum in polymer chemistry. In 1936, he advised and convinced his student Max Perutz to join J.D. Bernal from the Cavendish Laboratory of Cambridge University (UK) and obtain a PhD on the structure of proteins by X-ray diffraction. In 1938, the Nazis occupied Austria, and Mark clandestinely started to buy platinum wires and bent them into coat hangers in order to travel illegally and accept a position as research director of the International Paper Company in Hawkesbury, Ontario (Canada). This company produced cellulose acetate and viscose. While traveling by boat from England to Montreal, Mark finished the first English edition of his *Physical Chemistry of High Polymers*. While in Canada, he started to collaborate with DuPont. DuPont convinced Mark to join them in the fall of 1940 as a consultant and as a faculty member at Brooklyn Poly. At that time, Brooklyn Poly had some imminent professors, including the crystallographer Isidor Fankuchen (who worked with Sir Lawrence Bragg, the youngest Nobel laureate in physics at age 26), J.D. Bernal, Max Perutz (1962 Nobel laureate), and Aaron Klug (1982 Nobel laureate), in protein crystallography. Perutz wrote his first paper in Bernal's lab together with Fankuchen.¹³ Fourteen members of the Institute of Molecular Biology in Cambridge received the Nobel Prize during Perutz's leadership. In 1962, two Nobel Prizes were divided, for the first and last time, between a mentor (Perutz), two of his former graduate students (Crick and Kendrew), and a former postdoc (Watson). For his early contributions to the structure of proteins and carbohydrates and for convincing his student Max Perutz to work on the structure of proteins with Bernal, I consider Mark one of the pioneers of structural biology. Because of his friendly character, Isidor gave Mark the nickname "Der Geheimrat," which means "secret counselor." At Brooklyn Poly, Mark immediately started to teach polymer chemistry and initiated the first PhD program in polymer science in the US. He launched the famous weekly Saturday Morning Symposia at Brooklyn Poly, which were widely attended by academics and industrial chemists. He attracted research scholars and talented young faculty from all over the world to Brooklyn Poly. This program led to a rapid development of polymer science education and industry both in the US and in the rest of the world. He started the *Polymer Bulletin* in 1945 and the *Journal of Polymer Science* in 1946. The Polymer Chemistry Division of the American Chemical Society, the first Gordon Research Conference on Polymers, and the Polymer Chemistry Division of the International Union of Pure and Applied Chemistry were all initiated by Mark. In 1946, he founded the Polymer Research Institute at Brooklyn Poly. The only investment made by the president of Brooklyn Poly for the new institute was the price of a new letterhead with "Polymer Research Institute" on it.

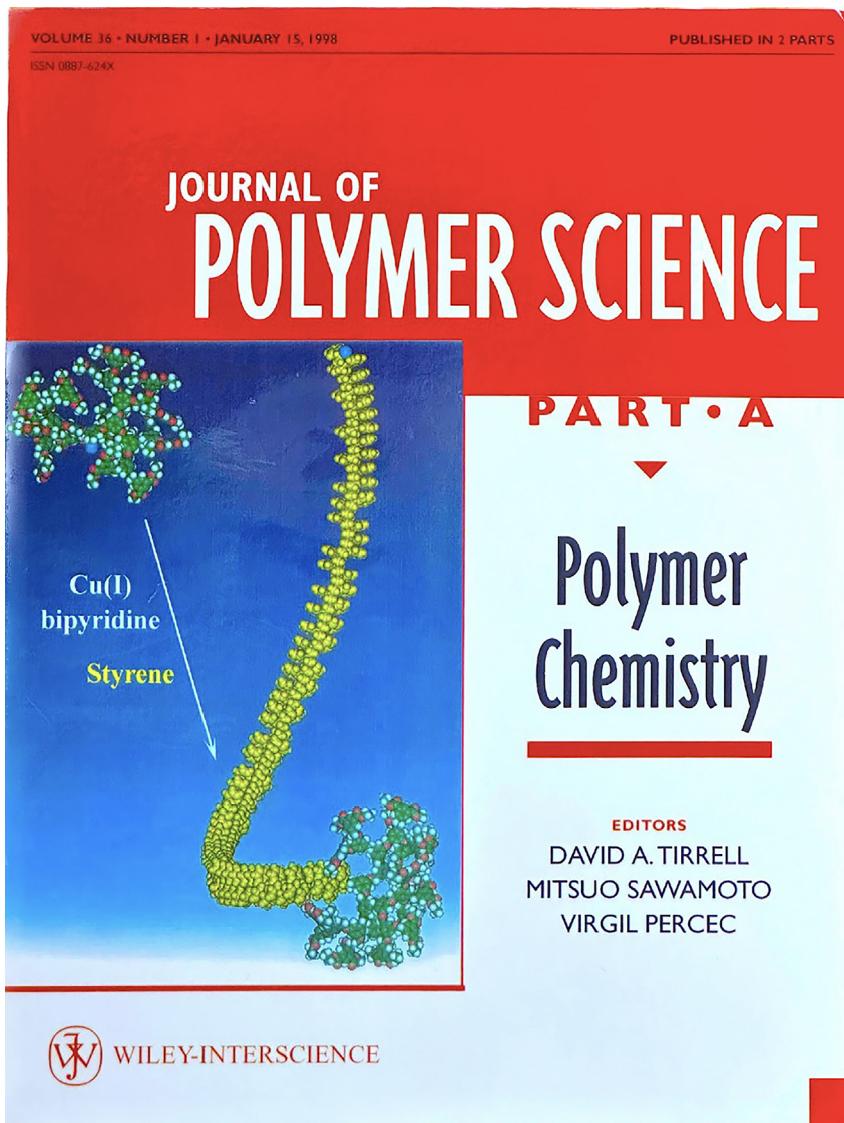


Cover of the 2003 "Polymer Research Institute" booklet. © 2003 American Chemical Society.

On September 3, 2003, a National Historic Chemical Landmark was dedicated to Herman Mark and the Polymer Research Institute, now part of New York University. Mark remained a Viennese to the core, a man of tremendous personal charm, the kind of central European who kissed ladies' hands and greeted people with "good morning" and "how are you, Herr Professor?" to make people feel important. When asked about his longevity, Mark responded simply: "You just have to pick your parents properly." When asked how he acted so young when he worked and traveled so much, he answered: "I just do not have the time to get older."

I met him first when I was an undergraduate student. He was touring the organic chemistry labs where I was doing experiments together with many other students when he received a doctor honoris causa from the Polytechnic Institute of Jassy, Romania. During the introduction of his lecture,

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The January 1998 front cover of the *Journal of Polymer Science*. ©1998 Wiley.

my future PhD mentor, C.I. Simionescu, explained how great a scientist Mark was and how honored we were that he was in Romania for the first time. Mark started his lecture by tapping my mentor on his shoulder and saying, "Young Herr Professor: first time I have been in this country was when I was a teenager in Vienna. In order to be accepted by the community, I had to make a trip by boat on the Danube to the Black Sea. The second time, it was during WWI and therefore, this is my third visit."

I met Mark for the second time in March 1981, when the University of Freiburg was celebrating the 100th anniversary of Hermann Staudinger. He wanted to attend and give a lecture in Staudinger's honor, but Magda Staudinger, Staudinger's wife, did not agree. Professor Helmut Ringsdorf, the last graduate student of Staudinger⁶⁻⁸ and former postdoc with Mark at Brooklyn Poly, convinced Magda to let Mark attend but without giving a lecture.



The H.F. Mark Medal received by the author of this paper.

The third time I met Mark was in the fall of 1981 at the 30th anniversary of a US institute. I mentioned to him that we had first met when he received the doctor honoris causa from my university but that I had immigrated to the US in the meantime and he might not remember me. He replied with his classic charm: "Of course I remember you, Virgil. Welcome to this country. Now you are one of ours." Nobody welcomed me to the US like Mark did. In a letter following this meeting, Mark even predicted the first university at which I would end up being a professor and justified why. During the late 1980s, Mark called my office and asked me to join him as an editor of the *Journal of Polymer Science*. I almost cried when I turned him down by stating: "I think I am too young at this time for this editor position." Later on, I accepted, and for 18 years I was one of the editors of his journal. Mark continued to lecture, publish, and travel while in his 90s.¹⁴ In 1989, he received the Michaelson-Morley Award from Case Western Reserve University. He spent several hours in my office and gave an after-dinner lecture during a symposium dedicated to him. His lecture and jokes were the best of the entire symposium even though he was 94. Mark received numerous awards and medals, including the Wolf Prize, but not a Nobel Prize. It could be that the most important honor to him was the Herman F. Mark Medal, established by the Austrian Research Institute for Chemistry and Technology and awarded to scientists beginning with his 80th birthday in 1975 in order to preserve Mark's Austrian legacy.

I was honored to receive the Mark Medal on November 19, 2008, during a ceremony at Eschenbach Palace in Vienna that reminded me of Mark's boyhood style and days in this city. Given that I was born in Bukovina, they introduced me as Mark did in the fall of 1981 by saying: "Virgil is one of ours." Mark passed away in 1992. Brooklyn Poly established the Herman F. Mark Endowed Chair and offered me this position. I turned it down because I did not believe that anybody could reconstruct a place that was so much under the legacy of the pioneer of the three fields mentioned above.

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DECLARATION OF INTERESTS

The author declares no competing interests.

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