BIOGRAPHICAL MEMOIRS

Mildred Cohn

July 12, 1913–October 12, 2009
Elected to the NAS, 1971

A Biographical Memoir by Judith P. Klinman and Susan R. Wessler

Mildred Cohn was inspiring as a scientist and a woman who had to overcome many obstacles to become a major figure in twentieth-century biochemistry and biophysics. She made wide-ranging contributions to understanding biological methyl transfer reactions and the enzymology of phosphate-containing metabolites. She is best known for her development of NMR methodologies, in combination with EPR, to study enzyme-substrate complexes and their progression to mechanistically relevant chemical intermediates. She pioneered the introduction of paramagnetic ions to map out metal- and substrate-binding sites in enzymes and worked toward the application of NMR for the monitoring of cellular metabolism in situ.

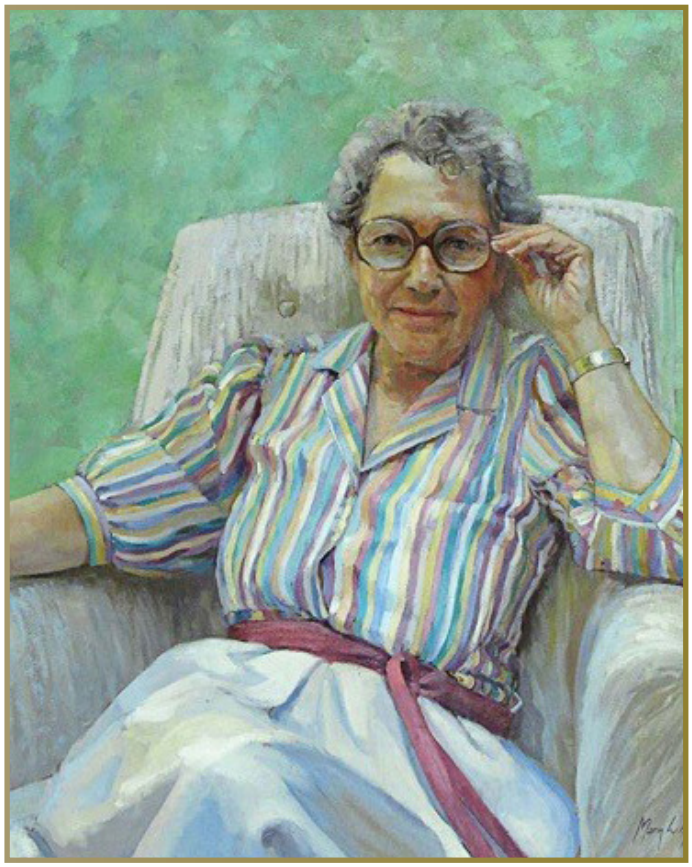

Figure 1 Oil painting of Mildred Cohn. *Courtesy of the University of Pennsylvania Art Collection, Philadelphia, Pennsylvania.*

Early Life

Mildred was born in 1913, the daughter of Bertha Klein Cohn and Isadore Cohn, who had been childhood sweethearts in Russia. They immigrated to the Bronx, New York, amid the political and social upheavals of 1905–1907 that culminated in the Russian Revolution of 1917. Upon arrival in the United States, her father found work in the needle trade. He later invented a machine to cut pants and created his own business, but the company went bankrupt during the Great Depression.

Though the family was poor, they were successful in securing an apartment at the Heim Gesellschaft, a cooperative housing project for secular Jewish needle trade-workers. This community had been formed as an alternative to the tenements of the lower East Side, offering high-quality apartments and access to many facilities for learning and for social interactions. This environment was a perfect match for her father's passion for Yiddish culture.[1] Thus, as a child, Mildred (Figure 2) found herself immersed in a highly progressive and innovative environment with access to a wide range of cultural activities. Her keen intellect was fostered by her father's strong belief in the values of scholarship and intellectual pursuits.

This home environment contrasted dramatically with her educational experiences, beginning in Evander Childs High School in the Bronx. After finishing fifth in a class of over

Figure 2 Mildred as young child, ca. 1918. *Photo courtesy of Nina Primakoff Rossomando.*

500 students at the age of fourteen, she was summoned to the dean's office, where she was told that she could not graduate because she was too young to get working papers (most girls never went to college). Further, she was informed that no college would admit her at fourteen. In Mildred's words:

> "Here was this woman who never paid attention to me. Today if they had a 14 year old who was near the top of the class, they would give her counseling, they would tell her that she could get scholarships and that kind of thing. Nobody told me that.… As far as going to college is concerned, I'll take care of that. It was just assumed by my family that I would go to Hunter College. It was free and in the city, so I went to Hunter College."[2]

This interaction and her response—"I'll take care of that"—became the credo for her academic life, as the officials who paid attention to her were usually those trying to block her from moving up the academic ladder. In response, she created her own path that ultimately led to her remarkable success both as a scientist and as a mother.

Hunter College

Mildred entered Hunter College in 1928. Years before, the father of a childhood friend who owned several beauty salons and made beauty products had told her family that chemistry was a wonderful career for women. At that time, however, Hunter was a women's college with no research labs and where the vast majority of students were education majors. She managed to take a few chemistry courses and graduated in 1931, when the country was in the depths of the Depression and it was very difficult to get a job.

What she really wanted was to go to graduate school, but she couldn't go to most without a scholarship. Again, her "I'll take care of that" maxim kicked in. Columbia University had an outstanding chemistry department, was only $300 a year, and she could live at home to save on room and board. She had prepared for this opportunity and earned the money by working summers as a counselor at a day camp and as a salesgirl at Macy's, where she even had turned down a job as an assistant buyer.

She was awarded a master's degree in 1932 after completing the required thirty credits of courses. Although none of those courses involved research, two (thermodynamics and molecular spectroscopy) were taught by Harold Urey. This connection would ultimately prove crucial to her future as a research chemist. But yet another roadblock prevented her from taking the next logical career step. To continue to do research and obtain a Ph.D., she needed financial assistance**,** which for graduate students at Columbia was provided by teaching assistantships. This path was not available to women students because the teaching assistantships were only available in Columbia College**,** which was until 1983 an all-male school.

National Advisory Committee for Aeronautics

Instead, she searched for and found one of the few potential research opportunities available to her. From 1932 to 1934, Mildred worked at the National Advisory Committee for Aeronautics (NACA) at Langley Field in Virginia. NACA was an independent agency, not part of any federal department, and the predecessor of the National Aeronautics and Space Administration (NASA), which was not created until 1958. The job she initially wanted was one of the few open to women and involved doing computations in aerodynamics. These were the famous women calculators, later including a team of female African American mathematicians, who served a vital role in NASA during the early years of the U.S. space program and whose role was revealed only many years later in the 2016 book and film entitled *Hidden Figures.*

Mildred noted that the calculator staff spent eight hours a day with their adding machines. After watching these women at work, Mildred decided that such a position was worse than being a secretary and was not for her.

As she recalled, she "let it be known far and wide that I was a chemist and asked if there was a place in the research establishment that needed a chemist." She was given a position studying combustion in engines and worked there for more than two years and published two scientific reports.[3,4] Being the only woman among seventy male researchers, her presence was noticed when the head of the agency toured the facility. He immediately banished her from the lab and commented that women in the lab would lead to too many divorces. Again, her "I'll take care of that" mantra led her to arrange for a male stand-in to do the experiments that she designed.

Graduate and Postdoctoral Studies

In 1934, she went back to Columbia to pursue her interest in chemical engineering. Yet again, she was blocked when the department head told her that despite her two publications, he didn't have women in the department and didn't want any. The trajectory of Mildred's scientific career began in earnest that same year, though, with her final acceptance into the Ph.D. program of the Department of Chemistry at Columbia under the tutelage of Harold Urey. Urey was a scientist with broad interests and, according to Mildred, "he had the fastest mind" of all the remarkable scientists she interacted with throughout her long career. In 1931, Urey had discovered the more prevalent heavy isotope of hydrogen (deuterium), and many investigators began to pursue physical models that could distinguish and predict the behavior of deuterium and isotopes in general. These studies were to become especially important to the Manhattan Project during World War II, given the use of enriched deuterated water to moderate nuclear reactions.

Mildred was very keen to compare the properties of protium, deuterium, and tritium. Tritium was not yet available, however, and she instead turned to the heavy isotopes of carbon and oxygen. Her first project was to set up a method for separating ^{12}C from ^{13}C based on a chemical reaction-based isotopic fractionation factor. Although this project did not go well and was terminated after about one year, the experience provided Mildred with a combination of both theoretical and experimental tools. The project that "stuck" involved an analysis of the rates of exchange of ^{18}O water into various organic molecules using water that Urey had already enriched to the level of 2.0 percent. Until a mass spectrometer became available for the analyses, Mildred followed the exchange progression by simply measuring the increase in mass of the products! Her first major publication with Urey appeared in 1938 in the *Journal of the American Chemical Society* and described the positions and time courses of ^{18}O isotopic exchanges and, in the process, expanded the understanding of solvent exchange reaction mechanisms.[5]

The tool of ^{18}O exchange would later prove absolutely instrumental to uncovering the mechanism of oxidative phosphorylation (see below). More broadly, the growing availability of enriched isotopes (both stable and radioactive) would provide new materials for mapping the course of a myriad of metabolic pathways. Mildred's Ph.D. training expanded her expertise from chemical physics to physical organic chemistry, excellent disciplinary training for her future studies of the inner workings of enzymes.

Moving on after her Ph.D. once again proved challenging for Mildred. Urey had pointed out that being both a woman and Jewish was going to make it very difficult or impossible for her to obtain a research position. In this context, the offer of a postdoctoral appointment in the laboratory of Vincent du Vigneaud was a godsend. She joined his laboratory at George Washington University in 1937 and the following year accompanied him in his move to Cornell University. She would remain there as a research associate for many years after her postdoctoral studies. She was the resident physical chemist—on call to both repair and build new equipment, including a mass spectrometer, with a major theme of the laboratory being the application of isotopes to study biochemical pathways.[6] Mildred also served as the resident synthetic chemist, synthesizing deuterated methyl alcohol that was used to produce deuterated methionine for the investigation of biological methyl transfer reactions. The ensuing studies were the beginnings of the recognition of the universality of transmethylation from methionine in cellular pathways.[7–11]

During this period and way ahead of her time, Mildred was also developing a keen interest in applying magnetic resonance, which included electron paramagnetic resonance (EPR) and nuclear magnetic resonance (NMR), to the chemical understanding of biological reactions and systems. Du Vigneaud eventually agreed to a preliminary study of the impact of paramagnetic ions (such as cobalt and nickel) on proteins, and Mildred chose insulin (which normally binds zinc ion) as a proof of concept. With time, more meaningful studies of biological magnetism would emerge following the development and availability of more advanced instrumentation.

Independent Research at Washington University, St. Louis

Mildred had met and married Henry Primakoff while they were both students at Columbia (cf. Figure 3). Throughout their lives, they would work to accommodate each other's careers by finding separate positions at the same institution. In 1946, life took an especially fortuitous turn when Henry

Figure 3 Mildred and her husband, Henry Primakoff, ca. 1983. *Photo courtesy of Nina Primakoff Rossomando.*

Figure 4 Mildred as young scientist at Washington University, St. Louis, ca. 1949. *Photo courtesy of Nina Primakoff Rossomando.*

was offered a faculty position in the Department of Physics at Washington University in St. Louis. Mildred was offered the position of research associate in the laboratory of Gertie and Carl Cori (Figure 4). The following year, the Coris were jointly awarded the Nobel Prize for their discovery of the mechanism by which glycogen (a derivative of glucose) is broken down in muscle tissue into lactic acid and then resynthesized in the body and stored as a source of energy. Mildred again stated her interest in comparing protium, deuterium, and tritium to Carl Cori (radioactive isotopes and instruments for their measurements had become available), but Cori preferred a project where isotopes could be used to follow the reaction course of phosphate transfer in glycolysis and glycogenolysis.

Everyone, even those with only casual knowledge of the history of twentieth-century biological chemistry and physiology, recognizes the importance of Washington University in the 1940s and 1950s as a hot bed of extraordinarily talented scientists that included eventual Nobel laureates Earl W. Sutherland Jr., Edwin G. Krebs, Arthur Kornberg, and then visiting scientist, Christian de Duve. Mildred became immersed in enzymology in the company of some of the most rigorous, inventive, and thoughtful biochemists of that era.

Mildred's initiation into the search for chemical intermediates in enzyme reactions began in a collaboration with Gertie Cori in which they used radioactive inorganic phosphate (^{32}P) and ^{14}C-labeled glucose to study the enzymes phosphorylase and phosphoglucomutase. These investigations confirmed an earlier proposed mechanism that phosphoglucomutase would use glucose-1,6-bisphosphate as an essential donor to interconvert glucose-1-phosphate and glucose-6-phosphate.[12,13,14]

Over the next forty years (first at Washington University and later at the University of Pennsylvania), Mildred would continue to make use of isotopic tracers to detect enigmatic chemical intermediates and mechanisms in enzymes that had eluded more direct measurements. Mildred quickly noted that phosphate compounds labeled with ^{18}O offered the possibility of identifying intermediates that were either too unstable or too low in concentration to be isolated. An important early experiment followed the time course of loss of ^{18}O from labelled inorganic phosphate and its connection to oxidative phosphorylation.[15–18]

This experimental strategy laid the critical groundwork for the elaboration of the mechanism of ATP synthase, in which ATP is formed from ADP and Pi via a readily reversible chemical reaction on the protein, with the energy needed for net ATP production being coupled to the exergonic flow of protons and the conversion of bound to free product. Paul D. Boyer, who would go on to win the Nobel Prize in Chemistry in 1997 for his discovery of the mechanism of

ATP synthase, acknowledged the importance of the methodology introduced by Mildred's ^{18}O-exchange studies in the unraveling of the mechanism of oxidative phosphorylation. Mildred further introduced the use of ^{18}O-labeled water to differentiate C-O from P-O bond cleavages for enzymatic reactions of carbon substrates bearing phosphate groups.[19,20]

During the 1950's, Mildred was becoming increasingly proficient at applying magnetic resonance methods to understand the enzymology of phosphate-containing metabolites. In a classical set of studies, she used NMR to monitor spectra for the hydrogen and phosphorus atoms of the nucleotides ATP and ADP.[21] She also finally had the chance to measure the impact of paramagnetic (as well diamagnetic) metals on NMR spectra of ATP and ADP, publishing the first direct evidence of complexation of these nucleotides with metal ions.[22,23,24]

Independent Research at University of Pennsylvania

In 1960, Henry was offered the Donnor Professorship of Physics at the University of Pennsylvania, and the family prepared to relocate to Philadelphia. Once again, Mildred encountered difficulty in finding a suitable position. She had just recently received her first faculty position as associate professor at Washington University in 1958. This appointment was largely in response to the policy of the American Heart Association (AHA), which was funding Mildred's research, as their support depended on the recipient holding a regular faculty appointment. In 1964, Mildred became the first female career investigator for the AHA, a position she held for fourteen years until her retirement.

Upon moving to the University of Pennsylvania, Mildred was similarly appointed as an associate professor in 1961. Within one year of her arrival, she was promoted to full professor of biochemistry and biophysics. The real mover and shaker in this regard was Britton Chance, then head of the renowned Eldridge Reeves Johnson Foundation for Research in Medical Physics. As Mildred herself noted, Britt was free of the usual biases of academic research and welcomed her to the faculty with open arms. Finally, Mildred had the autonomy to "follow her nose" and the authority and resources to apply magnetic resonance methods to the study of enzyme structure and mechanism.

Her first major paper from her work at Penn was published, with Jack Leigh, in *Nature* in 1962 and used the paramagnetic metal ion Mn^{2+} (as a surrogate for Mg^{2+}) to follow proton relaxation rates of water within enzyme ternary complexes.[25] This accomplishment occurred before the widespread application of X-ray crystallography to obtain protein structure and provided early evidence for the position and number of water molecules within an enzyme active site. Their combined use of NMR with paramagnetic ions was important, given the very low sensitivity of NMR in 1962. The full application of NMR would emerge later, through the development of Fourier transform spectroscopy (using pulsed rather than continuous wave NMR), the availability of higher and more homogeneous magnetic fields with superconducting magnets, and the introduction of mutidimensional NMR methods.

In subsequent years, a long list of novel advances emerged from Mildred's pursuits: (1) determination of distances at the active site of enzyme-substrate complexes from the impact of paramagnetic Mn(II) on the relaxation rates of nearby nuclei; (2) evaluation of reaction rates of the central complexes in kinase reactions from the line width of the ^{31}P resonances, thereby using a static measurement to define a dynamic parameter; (3) estimating the distance between substrate and amino acid residues of an enzyme on the basis of the nuclear Overhauser effect (NOE); and (4) using EPR to obtain structural information on the immobilization and asymmetry of protein-bound metal ions.[26]

In the course of her studies, Mildred would make the serendipitous observation that incorporation of ^{18}O into ATP gives rise to a different ^{31}P chemical shift depending on whether the ^{18}O is in a bridging or non-bridging position. This discovery saw the coalescence of Mildred's development of magnetic resonance studies of enzymes with her earlier use of ^{18}O exchange methods and introduced a novel and powerful tool for probing the mechanisms of phosphate-based enzymology through the detection of otherwise invisible chemical intermediates.[27] Quoting from Mildred, "I think the research that gave me the greatest personal satisfaction both aesthetically and intellectually was the demonstration of the isotopic shift due to the ^{18}O bonded to phosphorus in the ^{31}P NMR spectrum."[28] Another important and unexpected finding came from her ability to measure equilibrium constants for the interconversion of enzyme-bound substrate complexes and the finding of their deviation (by many orders of magnitude) from values of K_{eq} for the same interconversion of unbound species. This property, initially shown to be of central importance in elucidating the ATP synthase mechanism, would go on to be regarded as a general feature of enzyme-catalyzed reactions.

Over her decades of research activity, Mildred worked with a very large number of talented people that included, while at the University of Pennsylvania, Jacques Reuben, Albert S. Mildvan, George H. Reed, June S. Taylor and Eileen K. Jaffe.[29–33] It is particularly striking how much of Mildred's body of work was accomplished without the involvement of graduate students and postdocs. In fact, the major portion of her publications reflect collaborations with other senior investigators and, in many instances, resulted from experiments performed with her own hands.

Moving into Retirement

Mildred formally retired in 1982 at the age of sixty-nine, in the process changing her affiliation within the medical school from the Department of Biochemistry and Biophysics to become the Benjamin Rush Professor of Physiological Chemistry, Emerita. Although she had accepted an appointment at the Institute for Cancer Research at Fox Chase Cancer Center, Philadelphia, she was not happy there and greatly preferred the environment of the University of Pennsylvania. She left Fox Chase in 1985 and continued her research, largely through collaborations. Some of these activities were refinements of earlier studies of the interaction of metal ions with enzyme-bound ATP and ADP, for example, using sulfur-containing nucleotide analogs to shift the internal enzymatic equilibration of bound nucleotides with substrates and to restrict the number of possible nucleotide-binding modes.[34] Mildred also became increasingly involved in using magnetic resonance to understand enzyme regulation in both normal and cancer cells, performing studies of the inhibitory roles of creatine and its analog cyclocreatine in tumor progression.[35] The use of magnetic resonance was extended to ^{19}F-labelled compounds, for example in a study of the anti-tumor drug 5-fluorouracil substituted into tRNA.[36,37]

New collaborations ensued during this time, including work with her good friend Hadassa Degani at the Weizmann Institute for Science in Rehovot, Israel. Mildred's association with the Weizmann Institute extended over many decades of service as a member of their governing board, and in 1988, the institution awarded her an honorary Ph.D. (one of many such honorary degrees conferred upon her over the course of her later career).

In addition to Mildred's post-retirement pursuit of fundamental research, she would take on two important projects. The first was writing essays on the history of biochemistry during the twentieth century and the second was a biography of Harold Urey, a project that was underway at the time of her death.

Legacy and Impact

At the time that Mildred was born and began her education, the role of women in science and society was profoundly limited and different than it is today. To quote Mildred:

> "My career has been affected at every stage by the fact that I am a woman, beginning with my undergraduate education, which was very inferior in chemistry, and physics was not even offered [as a major] at Hunter College, unlike the excellent science education that my male counterparts received at City College. In my day, I experienced discrimination in academia, government, and industry."

Figure 5 Mildred receiving the National Medal of Science from then President Ronald Reagan in 1982. *Photo courtesy of Nina Primakoff Rossomando.*

Mildred broke through barriers at every turn, a true testament to her brilliance and determination. She successfully combined her scientific pursuits with a deeply satisfying marriage, enjoying a lifetime partnership with Henry, who became a prominent physicist. Mildred was incredibly level-headed and patient—it would take her twenty-one years to obtain her first faculty position. As Mildred said herself, there were benefits to her working outside of a traditional appointment, and her decades-long role as research scientist allowed her to focus fully on research and to successfully raise and enjoy her family of three children, Nina Primakoff Rossomando, Paul Primakoff, and Laura Primakoff. Mildred chose her colleagues and collaborators well, working alongside some of the most exciting and accomplished biochemists of the twentieth century.

She had a strong connection to the American Society of Biological Chemists (later renamed the American Society for Biochemistry and Molecular Biology), becoming the first woman to serve on the editorial board of the society's *Journal of Biological Chemistry* and the first woman president of the society. She was elected to the National Academy of Sciences in 1971 at a time when the number of women members was vanishingly small. She has said that was her proudest moment, but certainly not her only recognition. Among her many honors were eight honorary Ph.D.s and receipt of the Cresson Medal from the Franklin Institute (1975) and the National Medal of Science (1982) (Figure 5). Shortly before her death in 2009, she was honored with election to the U.S. Women's Hall of Fame.

Figure 6 Mildred with her young family while she was at Washington University, ca. 1950. *Photo courtesy of Nina Primakoff Rossomando.*

Amidst her struggles, Mildred took great pleasure in life, and one of us (J.P.K.) had the benefit of her friendship and many enjoyable times together. On putting together this tribute to Mildred, I was particularly struck by our overlapping research interests that relied on the use of isotopes to explore the properties of enzymes—those amazing workhorses of the cell. The passing of the baton from one generation to another is a central part of Mildred's history, beginning with her close association and mentorship by Carl and, in particular, Gertie Cori at Washington University and her subsequent mentoring of other women, including myself. It was very gratifying to work with the Department of Biochemistry and Biophysics at the University of Pennsylvania Medical School and the ASBMB to create an annual Mildred Cohn Award. The inaugural award (2013) was given to Jennifer A. Doudna, who had been recruited to the University of California, Berkeley while I was the first female chair of our Department of Chemistry, one of the most respected in the nation. Jennifer would later go on to receive the Nobel Prize in Chemistry in 2020 for her development of the CRISPR-Cas9 gene editing technology. The trajectory of Mildred's impact on an ever-widening stage for the advancement and acknowledgement of women's contributions to science is an important chapter of American history. We suggest several fascinating interviews conducted with Mildred while she was alive[38,39] for interested readers who wish to learn even more about her personal and scientific life.

A Message to Succeeding Generations of Women Scientists

Mildred's career was unusual from so many perspectives, especially the long period of time that she spent as a research associate in the laboratories of du Vigneau and Cori. The delay in her appointment to a regular faculty position was not unusual for women of her generation. What is remarkable is how Mildred used this time optimally, to raise her family of three children (Figure 6) while pursuing and ultimately applying new methodologies for interrogating important scientific questions. Her autonomy as a powerful scientist emerged in force, independent of the trappings of a faculty appointment. This arrangement may have limited Mildred's access to students and postdocs, but it also opened many opportunities for her to interact with the leading and emerging scientists of her era. A major upside was her ability to create the time and space to raise her family in a focused and generative manner.

Later in her life, she recognized how fortunate her circumstances had been for her and her family and how much the younger generations of scientists have had to struggle to balance two of the most important things in their lives—family and career. The much greater availability of parental leave for childbirth, childcare, and accommodation for women who are caring for elder parents has presented relief and a hope that future changes in local and national policy will become standard practices enabling women to balance career and family. We write this statement at a time when the political climate in the United States has become more reactionary, with newly introduced restrictions on access to abortions and women's control of the trajectory of their own lives. If Mildred were here to comment, she would say: carry on, advocate for yourselves and focus on the privilege of being able to pursue science in a much more open and less restrictive way than was available for women of my own generation.

To summarize some of the obstacles and challenges that Mildred had to overcome in her life: that her parents were immigrants from Russia and their struggles to overcome poverty, that she was a Jewish woman at a time when either of these features was considered a death knell for a career in science, the emergence of the Great Depression the year after she entered Hunter College, that she pursued physical chemistry (a field dominated by men), and the challenge of raising three children while maintaining the trajectory of her creative and innovative endeavors.

The lasting high esteem that the faculty of the University of Pennsylvania held for her is reflected in the beautiful oil painting (Figure 1) that sits in the lobby of the University of Pennsylvania Medical School. Mildred had stated that she deliberately wore a brightly colored dress while posing for her painting, in marked contrast to the monochrome of dark suits worn by her male colleagues.

Acknowledgments

We would like to thank the American Philosophical Society for opening their library during the COVID-19 shutdown to allow us access to Mildred's files. These proved invaluable in researching this memoir. Thank you also to Mildred's daughter, Nina Primakoff Rossomando, for proofreading the document and for providing the photos in Figures 2-6. Figure 1 is courtesy of the University of Pennsylvania Art Collection, Philadelphia, Pennsylvania.

Chronological List of Awards to Mildred Cohn

1952-1958	Established Investigatorship of the American Heart Association
1963	Garvan Medalist, American Chemical Society
1964-1978	Career Investigatorship of the American Heart Association
1968	Member American Academy of Arts and Sciences
1971	Member National Academy of Sciences
1972	Member American Philosophical Society
1973	Hall of Fame, Hunter College
1975	Cresson Medal of the Franklin Institute
1975	Outstanding Professional Achievement Award, Hunter College
1975	Sc.D. (honoris causa): Women's Medical College
1977	Foreign Member—Institut de Biologie Physico-Chimique, Paris, France
1978	Sc.D. (honoris causa): Radcliffe College
1979	Award, International Organization of Women Biochemists
1980	Award, U.S. Senior scientist, Humboldt Foundation, Fed. Rep. of Germany
1981	Sc.D. (honoris causa): Washington University, St. Louis
1982	National Medal of Science
1984	Award, American Academy of Achievement
1984	Sc.D. (honoris causa): Brandeis University
1984	Sc.D. (honoris causa): Hunter College
1984	Sc.D. (honoris causa): University of Pennsylvania
1985	Sc.D. (honoris causa): University of North Carolina
1986	Chandler Medal, Columbia University
1987	Distinguished Service Award, College of Physicians, Philadelphia
1988	Honorary National Member Iota Sigma Pi
1988	Remsen Award, Maryland Section, American Chemical Society
1988	Ph.D. (honoris causa) Weizmann Institute of Science, Israel
1990	Sc.D. (honoris causa): University of Miami
1992	Women in Science Award, New York Academy of Science
1993	Governor's Award for Excellence in Science, Pennsylvania
1994	Founders Medal, Magnetic Resonance in Biology
1997	Stein-Moore Award, Protein Society
2000	Oesper Award, University of Cincinnati and American Chemical Society, Cincinnati Section

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