The Scientific Life of Maria Göppert-Mayer

Maria Göppert-Mayer in middle age.
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Researcher and educator Maria Göppert-Mayer, winner of the 1963 Nobel Prize in physics for her work on the nuclear shell model, loved science and learning. That love sustained her through the difficulties she encountered in pursuing her profession, including relocation from Europe to America prior to the war years and never being granted a full-time salaried academic position until she was 53 years old. A study of Maria Göppert-Mayer's life reveals insights into the influence of her parents on her education and achievements, as well as into the role of her mentors, physicists James Franck and Edward Teller, on her professional development.[1] Göppert-Mayer's doctoral thesis, published in 1931, predicted multiphoton excitation processes and served as a precursor to the development of multiphoton excitation microscopy.

As we all know, the influence of parents on children is paramount, and this fundamental truth is nowhere better illustrated than by the life of Maria Göppert-Mayer. She was proud of her heritage which was linked, on her father's side, to seven generations of professors. Her father instilled a strong feeling of high self-esteem in the young Maria, and encouraged experimentation, discovery, and wonder at the natural world–all critical to the formation of a scientist.

When she was four the family moved to Göttingen where her father, who she considered her model in life, became a professor of pediatrics. The father held and openly expressed high expectations for his daughter, encouraging her to strive to be "more than a housewife." As a result, she decided at a young age to become a scientist. Her father instilled in her a strong feeling of self-confidence and a free spirit. As she grew older there was never a doubt in her mind, or that of her parents, that she would study at the university at which her father taught.

As Maria Göppert was growing up, and later during her studies at the University of Göttingen, she lived in a haven of mathematics and physics. In those scientifically fertile and exciting years before World War II, Göttingen was the world center of mathematics and physics, especially quantum mechanics. Close family friends included luminaries such as James Franck, Max Born and David Hilbert. The department of mathematics at the University of Göttingen hosted Richard Courant, Hermann Weyl, and Edmund Landau. Maria's fellow students included Max Delbrück and Victor Weisskopf.

During her Göttingen years, Maria Göppert interacted with a number of eminent contributors to the theoretical development of quantum mechanics: Arthur Compton, Paul Dirac, Enrico Fermi, Werner Heisenberg, John von Neumann, J. Robert Oppenheimer, Wolfgang Pauli, Linus Pauling, Leo Szilard, and Edward Teller. At Göttingen, she studied theoretical physics under Max Born. In a scientific life studded with important intellectual influences, James Franck stands out because of his ongoing role as her lifetime mentor.

Göppert-Mayer with daughter Marianne, circa 1935.
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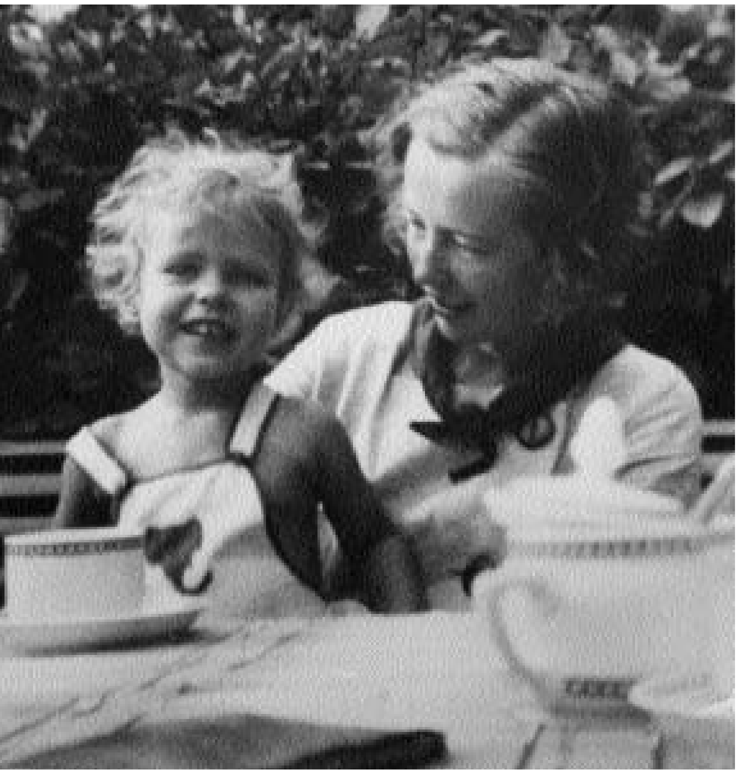

Victor Frederick Weisskopf (left), Maria Göppert-Mayer and Max Born.
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In January 1930, Maria Göppert married Joseph Mayer, an American chemical physicist. Two months later she completed her thesis and passed her final exam. Her examination committee consisted of three Nobel Prize winners. The couple relocated to America in the spring of 1930.

Professional life

In Baltimore, Joseph Mayer obtained an appointment in the Department of Chemistry at Johns Hopkins University. Ostensibly because of the rules on nepotism, his wife was not considered for a faculty appointment; however, she was given a small stipend as an assistant, as well as access to the university facilities. She presented lecture courses in the graduate school. For three years while she was at Johns Hopkins, because she was technically not a professor, she was able to return to Germany and work on quantum mechanics with her former professor Max Born.

In 1938, after Johns Hopkins fired Joseph Mayer to cut expenses, the Mayers left Baltimore and moved to New York. Joseph Mayer was appointed an associate professor of chemistry at Columbia University; his wife did not receive an appointment but was given an office. While at Columbia, she interacted with the great scientists Harold Urey, Willard Libby, Enrico Fermi, I.I. Rabi and Jerrold Zacharias.

In 1941, Sarah Lawrence College offered Göppert-Mayer a half-time teaching position. She accepted the position, electing to teach a unified science course. She concurrently accepted a half-time position at Columbia University, alongside Harold Urey, where the two worked on isotope separation. In the spring of 1945, she conducted research with Edward Teller at Los Alamos Laboratory.

After the war, the Mayers relocated to the University of Chicago where Joseph Mayer became a professor of chemistry and his wife accepted yet another voluntary position, this time as an associate professor of physics. When Edward Teller joined the University of Chicago, Maria Göppert-Mayer continued her work with him on the theory of nuclear structure. When Argonne National Laboratory was formed she worked there as a senior physicist with a half-time appointment. Incredibly, she continued to maintain her voluntary appointment at the University of Chicago: as an unpaid volunteer she lectured, served on university committees, directed students' theses, and was involved in other university work.

It was during her research at the Argonne National Laboratory that she developed the nuclear shell model for which she would earn the Nobel Prize in 1963. Her development of the nuclear shell model, based on her theory of spin-orbit coupling, is a fascinating story that merits examination in its own right. She discovered that there are nuclei with "magic numbers" of protons or neutrons that exhibit unusual stability. These "magic numbers" are 2, 8, 20, 28, 50, 82 and 126. Her theory predicted the nuclear stability of these elements.

Joseph Mayer, an American chemical physicist, married Maria Göppert in 1930.

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In 1960, the Mayers moved to the University of California at San Diego, where Maria Göppert-Mayer accepted a full-time appointment as professor of physics, her first full-time university professorship with pay: she was 53 years old.

In addition to being awarded the Nobel Prize for physics in 1963, Maria Göppert-Mayer was elected a member of the National Academy of Sciences and a corresponding member of the Akademie der Wissenschaften in Heidelberg. She received honorary degrees from Russell Sage College, Mount Holyoke College, and Smith College.

Experimental verification of Göppert-Mayer's theory predicting two-photon absorption processes

What is the relevance of Maria Göppert-Mayer's doctoral thesis to the field of nonlinear optics? In 1930, she submitted her doctoral dissertation in Göttingen on the theory of two-photon quantum transitions in atoms.[2] She wrote her doctoral thesis on the decay of excited states by the simultaneous emission of two quanta. Her thesis work is often cited in modern publications on multiphoton excitation microscopy.

The field of nonlinear optics is the study of the interaction of intense laser light with matter.[3] Nonlinear optics may have begun with the experimental work of Franken and his group in 1961 on second harmonic generation of light.[4] They showed that if a ruby laser pulse at frequency ω propagates through a quartz crystal, then light at the second harmonic frequency 2ω is generated; light from the ruby laser at 694 nm which was incident on a quartz crystal generated light at 347 nm.

Microscopic implementation of nonlinear spectroscopy

The principle of nonlinear scanning microscopy is simply explained. If a high powered beam of light impinged on a specimen, the specimen would behave in a nonlinear manner and higher optical harmonics would be produced.[3] This nonlinear harmonic generation would be a function of the molecular structure of the specimen.

After Franken *et al.* first observed second harmonic generation, several groups demonstrated the practical applications of a second harmonic microscope. Kaiser and Garret in 1961 demonstrated the two-photon excitation of CaF_2:Eu^{2+}.[5] In 1974, Hellwarth and Christensen developed a second harmonic microscope and observed microstructures in polycrystalline ZnSe materials.[6] Two-photon absorption processes were experimentally verified 32 years after they were predicted by Maria Göppert-Mayer.

The Oxford University group of Sheppard, Kompfner, Gannaway and Wilson, building on the earlier work of Hellwarth and Christensen, realized that nonlinear optical imaging could be combined with their development of the scanning optical microscope.[7] They pointed out that the nonlinear processes are confined to the focal plane of the objective and that the image intensity would depend quadratically on the illumination power. They also discussed improved resolution when combined with confocal detection, and the advantages of pulsed lasers as well as the potential for severe thermal damage due to the extremely high intensities used.

Early implementations of nonlinear optical microscopy used a laser scanning microscope to image second harmonic generation in crystals. The development of the mode-locked laser, which generated femtosecond laser pulses at a repetition rate of 100 MHz, provided the technical light source for the next step in the development of the multiphoton excitation microscope.

The seminal work of Denk, Strickler and Webb, published in *Science* in 1990, launched a new revolution in nonlinear optical microscopy.[8] By integrating a laser scanning microscope (scanning mirrors, photomultiplier tube detection system) and a mode-locked laser which generates pulses of near-infrared light, they succeeded in demonstrating a new type of microscope based on two-photon excitation of molecules. The pulses of red or near-infrared light (700 nm) were less than 100 fsec in duration and the laser repetition rate was about 80 MHz.

The benefits of two-photon excitation microscopy include: improved background discrimination, reduced photobleaching of the fluorophores and minimal photodamage to living specimens. The inventors proposed the application of two-photon excitation microscopy for optical sectioning three-dimensional microscopy and for uncaging of molecules inside cells and tissues. A recent application to the field of biomedical optics is the in vivo functional imaging of human skin with a multiphoton excitation microscope.

References

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