OPINION
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An International Symposium (Wilhelm and Else Heraeus Seminar # 702) Marked the Centennial of Otto Stern's First Molecular Beam Experiment and the Thriving of Atomic Physics; A European Physical Society Historic Site Was Inaugurated

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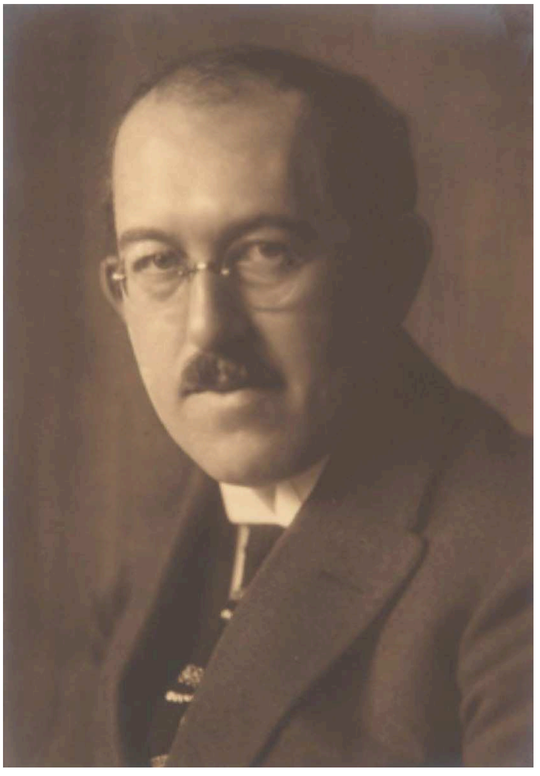
An international symposium entitled "Otto Stern's Molecular Beam Research and its Impact on Science" was held on 1–5 September 2019 on the historic premises of the former Institute for Theoretical Physics of the University of Frankfurt. During the period 1919–1922, key discoveries were made at this Institute, then headed by Max Born, that contributed decisively to the development of quantum mechanics. In 1919, Otto Stern (1888–1969) launched there the revolutionary molecular beam technique that made it possible to send atoms and molecules with well-defined momentum through vacuum and to measure with high accuracy the deflections they underwent when acted upon by transversal forces. Thereby, heretofore unforeseen quantum properties of nuclei, atoms, and molecules could be revealed that became the basis for our current understanding of quantum matter [1–4].

In the first quantitative molecular beam experiment, carried out in 1919, Otto Stern made use of the deflection imparted to a beam of silver atoms by the Coriolis force to determine the mean velocity pertaining to the atoms' Maxwell-Boltzmann velocity distribution.

The subsequent iconic experiment of Stern and Walther Gerlach, completed in 1922, relied on the deflection imparted to a beam of silver atoms by an inhomogeneous magnetic field. The Stern-Gerlach experiment demonstrated the reality of space quantization of atomic magnetic moments and thereby also, for the first time, the quantization of atomic angular momenta.

A host of prominent descendants of the Stern-Gerlach experiment make use of the key concept of space quantization of angular momentum. Foremost are nuclear magnetic



Otto Stern in Frankfurt, circa 1920 (courtesy of Alan Tempelton).

resonance, optical pumping, the laser, and atomic clock, as well as incisive discoveries such as the Lamb shift and the anomalous increment in the magnetic moment of the electron, which launched quantum electrodynamics. In the 1960s, the molecular beam technique made inroads into chemistry as well, by enabling to disentangle from gaseous chaos elementary chemical reactions as single binary collisions of well-defined reagents. Reaction dynamics that ensued has remained one of the chief preoccupations of chemical/molecular physics to date. In the 1990s, the diffraction of atoms, pioneered by Stern's group, became one of the leading methods for the non-destructive investigation of surface structures. This was then complemented by inelastic diffraction, which today is the major source of information on surface phonons and adsorbate vibrations. At about the same time, a renaissance had begun in atomic physics, nurtured by the development of techniques to cool and trap atoms. Based on a combination of molecular beams with laser cooling, these techniques enabled the realization of quantum degeneracy in atomic gases, launched condensed-matter physics with tunable interactions, and transformed metrology. In 1923, Otto Stern was appointed Professor of Physical Chemistry at the University of Hamburg. During the heyday period of his career that followed, Stern and his illustrious coworkers published a series of 30 seminal papers (*Untersuchungen zur Molekularstrahlmethode* 1–30). Paper number 27 of the series, which reported on the magnetic dipole moment of the proton, revealed that the proton is not an elementary particle but entails further constituents. For this discovery—and for the development of the molecular beam technique—Stern was awarded the 1943 Nobel Prize in Physics (unshared).

Stern's happy Hamburg period ended abruptly with the rise of the Nazis to power in Germany and Stern's forced emigration. He settled at the Carnegie Institute in Pittsburgh in 1933 and continued his research there until 1945. In 1939, Stern became a U.S. citizen and took part in war-related research. In 1945, he retired to Berkeley where his older sister and her family lived. In the aftermath of World War Two, Stern was generously helping many of his friends and colleagues with CARE packages. And he would not miss an opportunity to visit Europe—to see his friends at conferences and meetings, in particular in Copenhagen, London, and, foremost, in Zurich. He died in Berkeley in 1969.

The aim of the symposium was to show that many key areas of modern science, in particular of physics and chemistry, originated in the seminal molecular beam work of Otto Stern and his school. The symposium's nine sessions highlighted the current state of the art in magnetic and electric resonance spectroscopy, including magnetic resonance imaging (MRI) and its medical applications, high-precision measurements, femto- and atto-science, cold atoms and molecules, reaction dynamics, matter-wave scattering, magneto-optical traps and optical lattices, and exotic beams (microdroplet chemistry, liquid beams, helium droplet beams). Two additional sessions covered historical aspects as well as the foundations of quantum mechanics, including the problem of quantum measurement.

In 1988, the German Physical Society established the Stern-Gerlach Prize (since 1993 the Stern-Gerlach Medal) as its highest award in the field of experimental physics.

The Physics Department at Frankfurt has been recently recognized by the European Physical Society (EPS) as an "EPS Historic Site." A plaque marking the site was unveiled during the Otto Stern symposium. It honors the work of Born, Stern, Gerlach as well as Elisabeth Bormann and Alfred Lande done at Frankfurt during 1919–1922.

Both the symposium and the EPS Historic Site ceremony had a *Musikalische Umrahmung*. The music performed ranged from J. S. Bach to J. Stanley to klezmer.

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AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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