Chapter 1

An Homage to Otto Stern

Dudley Herschbach

Abstract This chapter outlines an International Symposium held at Frankfurt on 1–5 September 2019. It marked the centennial of quantitative experiments with molecular beams, pioneered by Otto Stern. The European Physical Society declared Stern’s original laboratory a Historic Site, the fifth in Germany. As a graduate student in 1955, I learned about Otto Stern (1888–1969) and the impact of his molecular beams on quantum physics. I was intrigued and undertook crossed-beam experiments at Berkeley. In 1960 Otto came to a seminar that I gave. Later I met him, and heard some of his stories. The rest of the chapter describes his Nobel Prize and other Fests. In 1958 his long-term colleague, Immanuel Estermann, organized a celebration and Festschrift for Otto’s 70th birthday. In 1988, as a guest editor, I organized a Festschrift for the centennial of Otto’s birth. That year, the German Physical Society established the Stern-Gerlach Prize as its highest award for experimental physics. Bretislav Friedrich and I wrote three papers about Stern. Since 2000, Horst Schmidt-Böcking at Frankfurt and colleagues have produced historical articles, along with a book about Otto, edited and bound all of his research papers into books, and diligently pursued letters to and from Otto, collecting them into large volumes.

1 The Frankfurt Conference

The joyful voluntary for trumpet [1] and organ made for a wonderful start for the Otto Stern Conference on 2 September 2019 in Alte Aula at the University of Frankfurt [2]. Professors Horst Schmidt-Böcking (Frankfurt) and Bretislav Friedrich (Berlin) were the Organizers; they developed a festive conference with a hefty booklet. As elders, J. Peter Toennies (Göttingen) and I (Harvard) were glad to be Honorary Chairs. About 140 participants were engaged in talks and discussions over three

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Fig. 1 Photo of Otto Stern during his Frankfurt time, circa 1920; courtesy of Alan Templeton, grandnephew of Otto Stern

days. The first session of the Conference focused on history, marking the centennial of experiments with molecular beams launched by Otto Stern (Fig. 1). A dozen other sessions highlighted current areas of modern physics and chemistry. On the second day, Stern's original laboratory was declared a European Physical Society Historic Site, the fifth in Germany. The ceremony included a keynote lecture, along with superb music [3], and unveiling of a plaque (Fig. 2) honoring the key discoveries made during 1919–1922 at Frankfurt. Most iconic was the experiment by Stern and Walther Gerlach that proved the reality of space quantization, thereby contributing decisively to the development of quantum mechanics.

The Conference booklet [4] had two historical articles. One is titled “*Stern and Gerlach: How a Bad Cigar Helped Reorient Atomic Physics*,” by B. Friedrich and D. Herschbach (Physics Today, 2003 [5]). The second article, extensive and titled “*Otto Stern (1888–1969): The founding father of experimental atomic physics*,” by J. P. Toennies, H. Schmidt-Böcking, B. Friedrich, and J. C. A. Lower (Ann. Phys., 2011 [6]). The booklet articles had some festive aspects, suited for Otto. Along with his cigar, he liked amusements, movies, music, dancing, dining and travel by ship. At the Conference dinner, held in the Dorint Oberursel, Professor Ludger Wöste (Berlin) exhibited (Fig. 3) some of his *Physical Amusements*, fascinating and charming toys [7]. More fun came with a post-conference event, on September 5. A bus from Frankfurt took us to Geisenheim, for a boat ride on the Rhein to Braubach and back, accompanied with a wind ensemble, lively hornblowers!

Fig. 2 Plaque that marks the European Physical Society Historic Site honoring the Physics Department at Frankfurt, dedicated on 3 September 2019, the fifth such in Germany

Fig. 3 Photo of Ludger Wöste, exhibiting one of his *Physical Amusements*

The Conference booklet also mentions that Otto Stern had a heyday period at the University of Hamburg (1923–1933), but Stern was forced by the Nazi regime to emigrate. He settled in the United States, first in Pittsburg at the Carnegie Institute (1933–1945) and then in Berkeley (1946–1969). He became a U.S. citizen in 1939 which enabled him to serve as a consultant in some military research projects. After the Second World War, 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.

2 Learning About Otto Stern and Molecular Beams

In the spring of 1955, as a student at Stanford University, I took a course on statistical thermodynamics taught by a physics professor, Walter Meyerhof (1922–2006). In a brief digression, less than 5 min, he described Stern's first beam experiment done in 1919 at Frankfurt to test the Maxwell-Boltzmann velocity distribution. Meyerhof had to emigrate (Fig. 4) in the Nazi era, and barely escaped the Gestapo [8]. Otherwise, it is likely he would not have been in a Stanford classroom, captivating a susceptible student. For me, learning about molecular beams was love at first sight. I remember a

Fig. 4 Photo of Walter Meyerhof, on face of his book *In the Shadow of Love—Stories from My Life* (Fithian Press, 2002)

flush of excitement at the thought that this was *the way* to study elementary chemical reactions. Only five years later my own first beam apparatus was functioning at Berkeley and I had met Otto Stern himself.

Meanwhile, my mentor at Stanford, Harold Johnston (1920–2012), had imbued me with his passion for chemical kinetics. It seemed to me a fundamental thing to try to understand how reactions occur at the molecular level. I wanted to find out what molecules are really doing, making and breaking bonds, instead of the gross macroscopic way that chemists were limited to before, trying to unravel many elementary steps at the same time. Hearing about Otto Stern, I thought by using molecular beams, you can really find out whether or not a reaction occurs as an elementary step. I immediately contacted Hal Johnston, with the naïve notion that chemical reactions could be studied by crossing two such molecular beams in a vacuum to isolate single collisions and directly detect the products. Hal laughed and said, “Well, sure, of course, but there’s not enough intensity.” It looked difficult. Molecular beam methods had found many applications in physics, but as of the early 1950s, very little had been done in chemistry.

In the fall of 1955 I learned more about Otto, when I moved to Harvard as a graduate student, aiming to obtain a Ph.D. in chemical physics. By golly, Norman Ramsey had just completed his book, titled *Molecular Beams* (Fig. 5). Ramsey gave a sparkling course, handing out the galley proofs. His excellent book reviewed the

Fig. 5 Photo of Norman Ramsey's book, *Molecular Beams* (Oxford Press, 1956)

essence of Stern's work and covered a wealth of further experimental and theoretical methods that produced many important discoveries. Early in Ramsey's course, he discussed Stern's velocity analysis study and actually announced, in his booming voice: "This would be a wonderful way to do chemistry!"

Ramsey also described the career of his mentor, Isidor Rabi, who made epochal molecular beam contributions to physics. Rabi had worked in Stern's lab at Hamburg in 1927–1929 as a postdoctoral fellow before joining the physics faculty at Columbia. There he gladly displayed in his office a photo of Stern (Fig. 6) that he took in the early 1960s. In 1938, Rabi invented a versatile new beam instrument, delivering radiofrequency spectroscopy with extremely high resolving power. In October of 1955, Rabi was invited to give a special lecture at Harvard Physics. His title was "Science and the Humanities." I was intrigued and still am. A friend, John Rigden, wrote a superb book: *Rabi, Scientist and Citizen* (Fig. 7).

In the chemistry department, an ebullient young instructor, William Klemperer, invited me to help build a high-temperature microwave spectrometer. This led us to study ionization of alkali atoms as a function of the surface temperature. Ramsey kindly lent us one of his beam machines over the Christmas vacation in 1956. This was a key episode for both Bill and me. He too fell in love with molecular beams, and immediately undertook to build an electric resonance beam apparatus. Bill and his

Fig. 6 Photo of Otto Stern in his early 70s that I.I. Rabi kept on display in his office at Columbia University

students developed that into a cornucopia for molecular spectroscopy, unprecedented in resolution and chemical scope [9].

3 Meeting Otto Stern and Hearing Stories from Him

In the summer of 1959, I joined the chemistry faculty at the University of California at Berkeley as an assistant professor. With two graduate students, George Kwei and Jim Norris, we built a rudimentary crossed-beam apparatus that enabled us to measure the angular distributions for reactants and products. Our first reaction was $K + CH_3I \rightarrow KI + CH_3$. In the fall of 1960, the physics department invited me to give a seminar about our work. In presenting the seminar, I naturally began with homage to Otto Stern, writing his name on the blackboard and sketching his velocity analysis and magnetic deflection experiments. During my seminar, I was surprised that two of the professors in the first row were engaged in animated conversation and swiveling around to look back at the audience. After the seminar, one of them asked me, “Did you know Otto Stern was in the audience?” Actually, I had noticed a fellow seated by

Fig. 7 Photo of book of *Rabi, Scientist and Citizen*, by author John S. Rigden (Basic Books, New York, 1987)

himself, many rows up and back at left. In size and dark attire, he resembled Charlie Chaplin.

A meeting was arranged so that researchers using molecular beams at Berkeley could meet him. That was a week or so after the seminar. Professors Howard Shugart and William Nierenberg gathered a group of more than a dozen graduate students and postdoctoral fellows, systematically measuring spins and magnetic moments of radioactive nuclei using the Rabi molecular beam magnetic resonance method. George Kwei and Jim Norris came along with me. At the meeting, supplied with coffee, tea, and cookies, Stern at first seemed very shy. Soon, however, in response to questions, he began telling stories with gleeful verve. Six of them I have retold often.

1. In his velocity analysis experiment, the results were in approximate agreement with the Maxwell-Boltzmann distribution, as anticipated, but deviated from it in a systematic way. After sending off a paper, Stern received a letter pointing out that he should have included an additional factor of v , the velocity, that enters because the detected atoms must pass through a slit. That amendment improved the agreement with theory. After explaining this, Stern laughed heartily as he added: "That letter came from Albert Einstein!"
2. He spoke happily about his gratitude to Max Born, who was renowned as a fine speaker and raised money to build Stern's apparatus at Frankfurt by giving public lectures.

3. With wry humor, Stern recalled that when he began teaching a physics course, he found it necessary to work late into the night preparing his lectures. He got into the habit of drinking strong black coffee to stay awake. Since then, he had found he could not fall asleep unless he first had a cup of such coffee.
4. The birth of the celebrated Stern-Gerlach experiment was told by Stern this way [10]: “The question whether a gas might be magnetically birefringent (in the words we used in those days) was raised at a seminar. The next morning I woke early, too early to go to the lab. As it was too cold to get out of bed, I lay there thinking about the seminar question and had the idea for the experiment.”
5. Stern said when he got to the lab, “I recruited Gerlach as a collaborator. He was a skillful experimentalist, and I was not. In fact, each part of the apparatus that I constructed had to be remade by Gerlach.” Cheerfully, Stern also said: “We were never able to get the apparatus to work before midnight.”
6. Stern’s “cigar story” was my favorite. As I remember, he told it with relish: “When finally all seemed to function properly, we had a strange experience. After venting to release the vacuum, Gerlach removed the detector flange. But he could see no trace of the silver atom beam and handed the flange to me. With Gerlach looking over my shoulder as I peered closely at the plate, we were surprised to see gradually emerge two distinct traces of the beam. Several times we repeated the experiment, with the same mysterious results. Finally we realized what it was. I smoked cheap cigars. These had a lot of sulfur in them, so my breath on the plate turned the silver into silver sulfide, which is jet black so easily visible. It was like developing a photographic film.”

This meeting with Stern lasted about two hours, whereas his cigar episode happened about four decades earlier. Another four decades came ahead: a new Center for Experimental Physics at the University of Frankfurt was dedicated in February 2002 to be named in honor of Stern and Gerlach. At the dedication, I expected to tell Stern’s cigar story, having told it many times over forty years. However, historical sleuthing by Bretislav Friedrich showed that two major aspects of my version of the cigar story were wrong. The cigar episode must have occurred at an earlier stage, because Stern was away in Rostock. When Gerlach had finally resolved a pair of distinct traces and by then he was using a photographic development process. The occasion of the Frankfurt dedication prompted Bretislav and me to carry out an experimental test. We found that bad breath did not suffice, although when cigar smoke is exhaled directly onto the deposition plate, the silver traces did rapidly become visible.

I had hoped to meet Stern again at a seminar. But I didn’t have the sense to ask Shugart to invite Stern again. In 1963 my group and lab moved to Harvard; alas, I failed to invite him there.

4 Fests with Otto Stern Present

With the Stern-Gerlach experiment, Stern had acquired fame and liked to visit other countries. In 1930 he lectured for some weeks at the University of California at Berkeley and was awarded an honorary degree of L.L.D. On the way there, during December 1929, he met Ernest Lawrence on coincident visits to Harvard. Unaccustomed to Prohibition, Stern asked Lawrence to take him to a speak-easy. While contemplating the circular rings left by their wine glasses, Lawrence diagrammed an idea he had been mulling over for months, a means to accelerate ions in a magnetic field. Stern urged him to stop talking about it, get back to his lab at Berkeley, and work on the idea. Lawrence took the advice and soon developed his cyclotron [11]. As early as 1931, Stern reported in Europe with great enthusiasm on the future of the cyclotron. However, when Stern was forced to emigrate in 1933, he did not receive an offer from Berkeley.

Otto likely enjoyed a fine cigar on December 10, 1944. The Nobel Prizes broke the five-year respite owing the Second World War; no prizes were awarded from 1940 until 1944. The Swedish Academy made up part of the loss by naming the 1943 winners along with those for 1944. The 1943 prize for physics went to Otto Stern and the 1944 prize to Isidor Rabi [12]. They couldn't go to Sweden—the war was still on—so the ceremony was held in New York, at the Waldorf-Astoria (Figs. 8 and 9). Rabi said: “It was an enormous pleasure and an excuse for many parties ...” At the parties, a little ditty was sung with the refrain: “Twinkle, twinkle Otto Stern/How did

Fig. 8 Otto Stern's *Nobel Document*. Photo, courtesy Diana Templeton Killen

Fig. 9 The Swedish ambassador Eric Boström presents the Nobel awards in physics to Stern (left) and Rabi (middle) at the New York Waldorf Astoria Hotel on December 10, 1944. *Courtesy Diana Templeton Killen*

Rabi so much learn?” Otto did come to Stockholm for the 1946 Nobel celebration, and he delivered his *Les Prix Nobel* lecture, only 7 pages [13].

In 1958, a *Festschrift* was held for Stern’s 70th birthday, organized by Immanuel Estermann (1900–1973). A long-term colleague, Estermann obtained his doctorate in 1921 at Hamburg, and began working with Otto, first at Rostock, then at Hamburg. When forced to emigrate in 1933, he was hired by the Carnegie Institute (now Carnegie-Mellon University) at Pittsburgh alongside with Otto. During the Second World War, Immanuel worked first on Radar and then transferred to the Manhattan Project. After Otto retired to Berkeley in 1945, Estermann left Pittsburgh in 1950 to join the Office of Naval Research. He also became editor of the series of *Advances in Atomic and Molecular Physics*.

Estermann edited a book: *Recent Research in Molecular Beams* (Fig. 10), a collection of ten chapters dedicated to Otto Stern (Academic Press, 1959) [14]. Estermann wrote the first chapter about the historic work in Hamburg (1922–1933). The other chapters describe fresh research among seven institutions. Only one dealt with chemistry. Sheldon Datz and Ellison Taylor, at Oak Ridge National Laboratory, in 1955 had published a crossed molecular beam reaction, $K + HBr \rightarrow KBr + H$. It made an impact on eager physical chemists. By 1965, a Gordon Research Conference in New Hampshire was accepted. A lively group of 60 graduate students and mentors were discussing theory and experiments for reactions with molecular beams. When I mentioned Otto Stern, a shout came from Sheldon Datz: “For all of us, he is our Father.” Of course, I responded: “Otto is a bachelor.” There was a roar: “We are all

Fig. 10 Photo of book *Recent Research in Molecular Beams*, *A collection of papers dedicated to Otto Stern on the occasion of his 70th birthday*; edited by Immanuel Estermann (Academic Press, 1959). Table of Contents displayed

bastards!” Since then, dynamics of molecular reactive collisions has flourished, with conferences every two years or so for more than 50 years.

In 1961, Otto Stern had an oral interview, by Res Jost [15]. Also, in 1962, Immanuel Estermann had an extensive oral history interview by John L. Heilbron [16]. Immanuel was engaged in writing a book on the History of the Molecular Beam Method when he died in 1973. A paper in 1975 was published in *Am. J. Phys.* [17] covering the essence of the first two chapters (edited by S. N. Foner) on the important evolutionary period, 1919–1933. It contains some amusing historical sidelights on the research personalities that dominated that period.

In 1973 Emilio Segrè (1905–1982) delivered a biographical memoir of Otto Stern for the National Academy of Sciences [18]. Segrè had worked with Otto Stern and Otto Frisch (1904–1979) during 1931–1933 at Hamburg on space quantization. When Otto Stern retired to Berkeley, Emilio was on the faculty, so they often met. During his last years, Otto remained interested in discoveries in particle physics and astrophysics. A few days before his death, Otto argued vehemently about enormous energy output of quasars and was dissatisfied that astrophysicists rejected his interpretation! Emilio and many others count Otto Stern among the greatest physicists of the twentieth century.

5 Centennial of Otto Stern and Beyond

In 1987, after writing a long article, *Molecular Dynamics of Elementary Chemical Reactions* [19], I felt attention was deserved in 1988, to have a Festschrift for the centennial of Stern's birth. In his Hamburg era, 1923–1933, Stern had inaugurated a series of papers which he called Untersuchungen zur Molekularstrahlmethode (U.z.M.) published in *Zeitschrift für Physik*. The series reached 30 papers. That journal fifty years later had grown to four categories. So I urged the Editor in Chief, Ingolf V. Hertel, to produce a centennial issue. He asked me to do it as a Guest Editor for *Z. Phys. D Atoms, Molecules and Clusters* (Fig. 11). Here are parts of the Preface, An homage to Otto Stern:

His legacy abides in many domains of physics, but especially in vigorous progeny exemplifying his favorite theme: "the characteristic simplicity and directness of the molecular ray method." Concepts and techniques developed by Stern have proved remarkably durable and versatile, yet still more vital for science is his exemplary pursuit of insight and beauty.

Next comes a reprint of Otto's 1921 paper (plus an English translation); it proposed "an experiment which, if successful, will decide unequivocally between the quantum and classical views." A list of his publications follows—only 60 (Stern's total was 71, including publications in nonscientific venues). Then come reminiscences of Stern by I. I. Rabi as told to John Rigden, some in the last days before Rabi's death (11 January

Fig. 11 Festschrift in memoriam Otto Stern on the 100th anniversary of his birth: *Zeitschrift für Physik D, Atoms, Molecules and Clusters* **10**, 109–392, June 1988 (Springer International); with six samples among the 31 articles

1988). A review of Stern's development of molecular beams was given by Norman Ramsey, from his lecture presented at a convocation in Hamburg commemorating Stern (4 February, 1988). Ramsey provided a list [20] of 32 major "advances that contributed to physics from the field of molecular beams ... during the past seventy years."

The Festschrift indeed had 31 exceptional papers, largely from Stern's kindred spirits. Here are six samples (Fig. 11). Among them are a "continuous Stern-Gerlach effect" that glimpses the primordial Big Bang. Or is "spin coherence like Humpty-Dumpty?" Also, a liquid jet. Or an Otto Stern double bank shot. Or using an electrospray source that generates molecular beams of huge proteins.

Also in 1988 the German Physical Society established the Stern-Gerlach Prize. In 1993 the Prize became the Stern-Gerlach Medal. It is awarded for excellence in experimental physics, in parallel with the existing Max Planck Medal for excellence in theory.

Hamburg also had in 1988 an Otto Stern Symposium, as noted, with Norman Ramsey. A two-day Stern event was held in 2013 with many speakers. This is available on *YouTube*. A single-day Stern event was held in 2018.

In 1998 Bretislav Friedrich and I contributed to an unusual event: *Science in Culture*, held in Proceedings of the American Academy of Arts and Science, Cambridge, Massachusetts [21]. The event was dedicated to Gerald Holton, an outstanding historian of science, for his studies of Einstein. Bretislav and I delivered a sizeable paper titled: *Space Quantization: Otto Stern's Lucky Star* [21]. We hoped to make it accessible to anyone with only vague memories of high-school science, and to induce chuckles rather than growls.

During December 11–14, 2000 there was held in Berlin a Quantum Theory Centenary, celebrating the famous talk of Max Planck. Fifty scientists were invited to present reviews of their fields to a large international audience. The proceedings were collected as a Festschrift in the "Annalen der Physik". I was asked to talk about Otto Stern and molecular beams, before 1935. That led to five decisive episodes: discovery of space quantization; de Broglie matter waves; anomalous magnetic moments of the proton and neutron; recoil of an atom of emission of a photon; and the limitation of scattering cross-sections for molecular collisions imposed by the uncertainty principle [22]. The Centenary Symposium was splendid, having quantum entanglement and teleportation, discovery of quarks, quantum cosmology and more!

In 2002, when the Stern-Gerlach Center for Experimental Physics at Frankfurt was named, a memorial plaque (Fig. 12) was mounted near the entrance of the building where the Stern-Gerlach experiment took place. Horst Schmidt-Böcking had a major role in the installation of the SGE plaque and much more. At the 2019 Conference, the plaque was moved near the room where the SGE was done. The inscription, in translation reads: "*In February 1922 ... was made the fundamental discovery of space quantization of the magnetic moments of atoms. The Stern-Gerlach Experiment is the basis of important scientific and technological developments in the 20th century, such as nuclear magnetic resonance, atomic clocks, or lasers ...*"

Frankfurt was busy well before the 2019 Conference. In 2005, Wolfgang Trageser collected papers [23] to form a *Stern-Stunden* book (Fig. 13). In 2011, Horst produced

Fig. 12 A memorial plaque honoring Otto Stern and Walther Gerlach was mounted in February 2002 next to the entrance of the building where the S-G experiment took place 80 years earlier

with Karin Reich [24] an Otto Stern book (Fig. 14). He wrote historical articles [25] with others (2011, 2016) and edited all of Otto's research papers [26] into books (Fig. 15). Moreover, Horst with Alan Templeton and Wolfgang Trageser were extraordinarily diligent in pursuing letters to and from Otto, organizing and collecting them into large volumes [27] (Fig. 16).

When I visited Berkeley again, to give a Commencement address in 2012, Alan took me to the Chemistry Library to see Otto's magnificent desk that he had donated to the library (Fig. 17).

The 2019 Conference aimed to show that many key areas of modern physics and chemistry originated in the seminal molecular beam work of Otto Stern and his colleagues. The sessions highlighted the state of the art: foundations of quantum mechanics, as well the problems of quantum measurement; magnetic and electronic resonance spectroscopy, including magnetic resonance imaging and its medical applications; high-precision measurements; cold atoms and molecules; reaction dynamics; matter-wave scattering; magneto-optical traps and optical lattices; and exotic beams, among microdroplet chemistry, liquid beams, and helium droplet beams.

Beyond the history session, memories of Otto and his colleagues endure. Alan Templeton gave a festive talk: *My uncle Otto Stern*. Other presenters were Peter Toennies: *Otto Stern and Wave-Particle Duality*; Dan Kleppner: *Our Patrimony from*

Fig. 13 Photo of book by W. Trageser, ed., *Stern-Stunden Höhepunkte Frankfurter Physik*, comprised of collected articles. A sampling was made from [5] and [21], pp. 149–170

Otto Stern and My Memories of Otto Frisch; Karl von Meyenn: *Stern's Friendship with Wolfgang Pauli*; and Horst: *Stern's Relation to Gerlach*.

Concluding my introduction to the Conference, I offered a song by Cole Porter, “*Experiment*,” more than 80 years old [28].

6 Epilogue

This is the closing paragraph of Otto Stern’s Nobel Lecture [13]:

The most distinctive characteristic property of the molecular ray method is its simplicity and directness. It enables us to make measurements on isolated neutral atoms or molecules with macroscopic tools. For this reason, it is especially valuable for testing and demonstrating directly fundamental assumptions of the theory.

Fig. 14 Photo of book by H. Schmidt-Böcking and K. Reich, *Otto Stern: Physiker, Querdenker, Nobelpreisträger* (Frankfurt/Main: Societäts-Verlag, 2011)

Fig. 15 H.

Schmidt-Böcking, K. Reich,
A. Templeton, W. Trageser,
V. Vill, eds., *Otto Sterns
Veröffentlichungen—Band 1,
Sterns Veröffentlichungen
1912 bis 1916* (Springer
Spektrum, 2016)

Fig. 16 H.

Schmidt-Böcking, A.
Templeton, W. Trageser,
eds., *Otto Sterns gesammelte
Briefe—Band 1,
Hochschullaufbahn und die
Zeit des Nationalsozialismus*
(Springer Spektrum, 2018)

Fig. 17 Dudley with Alan Templeton, visiting Otto Stern's desk, now in the Chemistry Library at the University of California, Berkeley

Acknowledgements For helpful information, I am grateful to Horst, to Bretislav, to Peter, to Alan, to Diana Templeton-Killen, to my wife Georgene, and to Cole Porter.

Appendix: A Historical Puzzle

Recently, I learned from Eugene Wigner (1902–1995) that in the 1920s Michael Polanyi (1891–1976) had an original idea to use molecular beams [29]. At Haber's Institute in Berlin-Dahlem, he was famed for chemical kinetics, using a diffusion flame method involving sodium vapor, halogens, and organic halides. He must have known about the celebrated molecular beams used by Otto Stern at Frankfurt and Hamburg, not so far from Dahlem. Searches in the archives of correspondence of both turned up only one letter from Stern to Polanyi. It is dated 10 October 1928, but with questions unrelated to beams or reactions.

I first met Michael Polanyi in 1962 when he came to Berkeley to deliver a series of lectures on the philosophy of science. He also visited my lab and observed a molecular beam experiment. On other occasions, especially at a Faraday Discussion in London in 1973, Michael heard about many beam results, but didn't mention that he had once intended to try beams. In 1962, I missed an opportunity to arrange for Michael Polanyi to meet and exchange stories with Otto Stern.

Appendix: Lyrics of Cole Porter's "Experiment"

Before you leave these portals
To meet less fortunate mortals
There's just one final message
I would give to you
You all have learned reliance
On the sacred teachings of science
So I hope, through life you never will decline
In spite of philistine
Defiance
To do what all good scientists do

Experiment
Make it your motto day and night
Experiment
And it will lead you to the light
The apple on the top of the tree
Is never too high to achieve
So take an example from Eve
Experiment
Be curious
Though interfering friends may frown
Get furious
At each attempt to hold you down
If this advice you'll only employ
The future can offer you infinite joy
And merriment
Experiment
And you'll see

References

1. Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA 02138-5754, U.S.A. <https://chemistry.harvard.edu/people/dudley-herschbach-dherschbach@gmail.com>
2. Musikalische Umrahmung at the Opening of the Otto Stern Fest; the musicians were: Wolfgang Huhn, trumpet; Karsten Schwind, organ
3. Musikalische Umrahmung at the European Physical Society Historic Site Ceremony; the musician was: Roman Kuperschmidt, clarinet

4. Conference Booklet, *Otto Stern's Molecular Beam Research and Its Impact on Science*, ed. by B. Friedrich, D. Herschbach, H. Schmidt-Böcking, P. Toennies. *An International Symposium*, Frontiers Phys., vol 7, (2019), p. 208. Website: <https://indico.fhi-berlin.mpg.de/event/35/>
5. B. Friedrich, D. Herschbach, Stern and Gerlach: How a Bad Cigar Helped Reorient Atomic Physics. *Phys. Today* **56**, 53–59 (2003)
6. J.P. Toennies, H. Schmidt-Böcking, B. Friedrich, J.C.A. Lower, Otto Stern (1888–1969): The Founding Father of Experimental Atomic Theory. *Ann. Phys. (Berlin)* **523**, 1045–1070 (2011)
7. Ludger Wöste (Berlin), *Physical Amusements*, Part in [4]
8. W.E. Meyerhof, *In the Shadow of Love—Stories from My Life* (Fithian Press, Santa Barbara, 2002), pp. 38–67
9. D. Herschbach, Obituary: William Klemperer (1927–2017). *Nat. Astron.* **2**, 24–25 (2018)
10. These are not Stern's exact words, but I have presented his stories in first person as an attempt to capture his way of telling them
11. N.P. Davis, *Lawrence & Oppenheimer* (Simon and Schuster, New York, 1968), pp. 27–28
12. J.S. Rigden, *Rabi, Scientist and Citizen* (Basic Books, New York, 1987), pp. 169–170
13. O. Stern, *The Method of Molecular Rays*, Les Prix Nobel en. (M.P.A.L Hallstrom, Stockholm, 1946), pp. 123–130. Available at <https://www.nobelprize.org/prizes/physics/1943/stern/lecture/>
14. I. Estermann (ed.), *Recent Research in Molecular Beams* (Academic Press, New York, 1959)
15. Interview of Otto Stern by Res Jost, 2 December 1961, tape recording, ETH-Bibliothek Zürich (CH-001807-7 Hs 1008:8). https://search.library.ethz.ch/primo-explore/fulldisplay?docid=cmistar5eeecbf09e08143568a2a3046acf875c5&context=L&vid=DADS&lang=en_US&search_scope=default_scope&adaptor=Local%20Search%20Engine&tab=default_tab&query=any,contains,Hs%201008:8&mode=Basic
16. Interview of Immanuel Estermann by John L. Heilbron, 13 December 1962, transcript, 24 pages, available from American Institute of Physics (OH 4593), College Park, Maryland, 20740, USA at <https://www.aip.org/history-programs/niels-bohr-library/oral-histories/4593>
17. I. Estermann, *History of molecular beam research: personal reminiscences of the important evolutionary period 1919–1933*. *Am. J. Phys.* **43**, 611–680 (1975) (Edited by S.N. Foner)
18. E. Segrè, Otto Stern. *Biogr. Mem. Nat. Acad. Sci.* **43**, 215–236 (1973)
19. D.R. Herschbach, *Molecular Dynamics of Elementary Chemical Reactions*, in Les Prix Nobel 1986 (Almqvist & Wiksell Int'l, Stockholm, 1987), pp. 117–166. Also, *Angew. Chem. Int. Ed.* **26**, 1221–1243 (1987)
20. N.F. Ramsey, Molecular beams: our legacy from Otto Stern. *Z. Phys. D* **10**, 121–125 (1988)
21. B. Friedrich, D. Herschbach, Space quantization: Otto Stern's lucky star. *Daedalus Sci. Culture* **127**, 165–191 (1998)
22. D. Herschbach, Molecular beams entwined with quantum theory: a bouquet for Max Planck. *Ann. Phys. (Leipzig)* **10**(1–2), 163–176 (2001)
23. W. Trageser, ed., *Stern-Stunden* book, comprised of collected articles. Part formed from (5) and (21)
24. H. Schmidt-Böcking, K. Reich, *Otto Stern: Physiker, Querdenker, Nobelpreisträger* (Societäts-Verlag, Frankfurt/Main, 2011)
25. H. Schmidt-Böcking, L. Schmidt, H.J. Ludde, W. Trageser A. Templeton T. Sauer. The Stern-Gerlach experiment revisited. *Eur. Phys. J. H.* **41**, 327–364 (2016). Also see [6]
26. H. Schmidt-Böcking, K. Reich, A. Templeton, W. Trageser, V. Vill (eds.), *Otto Sterns Veröffentlichungen—Band 1-5*, vol. 1–5 (Springer Spektrum, Berlin, Heidelberg, 2016)
27. H. Schmidt-Böcking, A. Templeton, W. Trageser (eds.), *Otto Sterns gesammelte Briefe—Band 1-2*. (Springer Spektrum, Berlin, 2018). In [25] is a list of Archival locations where Stern's letters have been found
28. Cole Porter (1891–1964) song lyrics of “Experiment” (1931) are available at <http://www.songlyrics.com/cole-porter/experiment-lyrics/>
29. D.R. Herschbach, Michael Polanyi: Patriarch of chemical dynamics and Tacit Knowing. *Angew. Chem. Int. Ed.* **56**, 3434–3444 (2017)

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