BRETISLAV FRIEDRICH AND HISTORY OF SCIENCE

Symposium for Bretislav Friedrich

Fritz Haber Institute, Max Planck Gesellschaft, Harnack-Haus, 12 April 2019

Mary Jo Nye, Oregon State University, Corvallis, Oregon USA

It is a great pleasure to be here today, and I sincerely thank Gerard Meijer for inviting me to contribute to this occasion by discussing some aspects of Bretislav's contributions to the history of science. As many of you know, Bretislav's scientific publications are complemented by researches and writing in the history of science, especially focusing on the history of physical chemistry, theoretical chemistry, and atomic and molecular physics. His historical work is partly a reconstruction of experiments and theories—how science works in an everyday way—but his contributions are considerably more, as well: studies of individual scientists, their institutional and cultural environments, and the intersections of scientific life with politics, war, and ethics. Altogether, approximately 15% of Bretislav's publications since 1979 have been articles, books reviews, and book volumes focused on the history of science, beginning with an article co-authored with Dudley Herschbach in 1996. I want to begin my remarks by asking: How did this historical commitment come about and gradually evolve?

In an autobiographical essay, Bretislav recalls that he and Gymnasium friends in Prague routinely engaged in boisterous conversations about literature, art, and philosophy when they began Neruda High School in the politically difficult period following August 1968. In deciding on a field of study at Charles University in 1972, Bretislav writes that he decided to partly repress his humanistic instincts for the politically less sensitive study of physical chemistry.[1] While at Harvard from 1987 until 2003, conversations with Dudley, in particular their mutual puzzlement over the way the textbook history usually is told about the Stern-Gerlach molecular beam experiment, led Bretislav to visit the Harvard Physics Library's depository room, lined with old journals and books. In a certain sense, Bretislav never escaped that room, and he gradually began an intermittent historical career that has become more intense in the last ten years. While at Harvard, he also integrated his historical interests into teaching, for example in a Freshman Seminar at Harvard, after Bretislav became a Lecturer in 1997. He designed his Freshman course as a hybrid of physics and history of physics, reconstructing the story of light from Empedocles to teleportation of quantum photons. [2]

As in his scientific research, much of Bretislav's historical work is highly collaborative, along with single-authored studies, essays, and book reviews. The individual historical figures most often in his focus have been Otto Stern, Fritz Haber, Otto Sackur, Michael Polanyi, and Clara Immerwahr. In addition to masterly biographical accounts, Bretislav has written about the history of physical chemistry in Germany, in particular in Berlin and Leipzig, and he has illuminated what has happened in other settings, for example in Prague, Breslau (Wroclaw), and Frankfurt. He was co-author and spokesperson for the Centennial project that resulted in an authoritative volume on the history of the Fritz Haber Institute from its founding in 1911 to 2011, co-authored with Jeremiah James, Thomas Steinhauser, and Dieter Hoffmann, and published right on time, in 2011.[3] Since then, Bretislav has co-organized symposia on Michael Polanyi and on Fritz Haber, each resulting in published papers by Bretislav and others.[4] The darker side of Haber's legacy is the starting point of a symposium and published volume on *One Hundred Years of Chemical Warfare,* co-edited by Bretislav with four other MPG researchers, which appeared in 2017.[5]

In what follows, I would like to focus on some of the leading themes in Bretislav's historical work, beginning with the studies of Otto Stern. Bretislav's and Dudley's own research with molecular beams led them to puzzle over the paradox that the famous molecular beam experiments by Otto Stern and Walther Gerlach in 1922 are commonly said to have demonstrated space quantization due to electron spin, but electron spin was not discovered until 1925.[6] Stern had studied and worked in Breslau with Otto Sackur, and in Prague and Zurich with Albert Einstein, before moving to Frankfurt in 1914 where he later worked in Max Born's research group. There, Stern proposed an experimental test of quantum theory that did not involve spectroscopy but rather a beam of neutral (silver) atoms intersected by a magnetic field. Stern predicted that the beam would split into two distinct components in the magnetic field, rather than simply broaden, if the electron orbit possesses discrete values of angular momentum as a vector perpendicular to the electron's orbit. The limitations of orientation were called directional or spatial or space quantization, as discussed by Wolfgang Pauli in 1920.[7]

Stern and the experimental physicist Walther Gerlach succeeded in detecting the beam splitting, much to the surprise of Born, who had been skeptical that spatial quantization was anything other than a symbolic expression. Peter Debye likewise viewed spatial orientation as a calculation device rather than a physical reality.

Similarly, write Bretislav and Dudley, Einstein and Paul Ehrenfest struggled to understand how atomic magnets could assume definite orientations in the field. [8] Spatial quantization turned out to be due to the electron's spin and a spin quantum number, discovered in 1925. Bretislav and Dudley found that spin was first said to account for the Stern-Gerlach results in a paper published in 1927.

Altogether, Bretislav has written four papers on Stern and the Stern-Gerlach puzzle, including three with Dudley and a more recent paper that included among its four co-authors Stern's biographer Horst Schmidt-Böcking. Important themes in these papers are the roles in everyday science of chance, coincidence, and unanticipated results, along with the persistence of established theories. As re-enacted experimentally by Dudley and Bretislav in 2003, Stern and Gerlach initially saw no trace of beam splitting on a glass detection plate, until Stern leaned over the apparatus while smoking his usual cheap cigar, and the smoke turned the silver atoms into silver sulfide, which is jet black.[9] Thus, the role of chance. Secondly, although it turned out that Stern's theoretical assumption about the numerical value of orbital angular momentum was wrong, just as the planetary model for the atom was wrong, there was a lucky cancellation of errors due to a relativistic effect not recognized until 1926.[10] Thus, the role of coincidence. Thirdly, as he later said in an interview of 1961, Stern did not expect the molecular beam to split. In fact, he set out to demonstrate that the whole concept of quantum spatialization was flawed.[11] His unexpected result turned out to be decisive in support of quantum theory. Thus, an unanticipated result.

Stern is by no means the only scientist who has initially resisted radically new theories in favor of trying to preserve the classical framework. Another example of conservatism is the physical chemist Otto Sackur, as narrated in two quite original articles by Bretislav, co-authored with Massimiliano Badino. Sackur died prematurely at the age of 34 in an explosion in Fritz Haber's wartime institute in December 1914. Before coming to Berlin, Sackur studied energy, entropy and equilibrium in gas systems at the University of Breslau, where he developed in 1911 the first quantum-statistical expression for entropy of an ideal gas (in the limit of high temperatures and low densities). In studying the thermal behavior of systems at low temperatures, with attention to Nernst's third law, Sackur ended up doubting the quantum hypothesis as a physical assumption, and instead preferred to use the quantum hypothesis as an extension of statistical mechanics that could be used to sharpen the concept of probability.[12] Bretislav and Massimiliano show how Sackur's example demonstrates the complicated landscape of quantum physics in the 1910s. While formal tools and mathematical tools might be shared, the quantum hypothesis did not have a commonly held meaning.[13]

It may be that Otto Stern imbibed some of Otto Sackur's critical misgivings about quantum applications, since Stern completed his dissertation with Sackur in Breslau in 1912. Another graduate from Breslau was Clara Immerwahr, who became the first woman to receive a doctoral degree at the University, working with the physical chemist Richard Abegg who later was Sackur's mentor. It was Immerwahr, who married Fritz Haber, who recommended Sackur to a position at Haber's Institute. The way in which such personal and professional networks emerge and influence scientific development is a frequent theme in Bretislav's historical work.

Immerwahr's scientific research in solution chemistry and electro-affinity consisted of her dissertation and three research papers. Her science was cut short by her marriage to Fritz Haber in 1901 and the birth of her son Hermann in 1902. Some historians and popularizers have portrayed her as a woman, who similarly to accounts in the early 1990s of Mileva Marić Einstein, was thwarted in a scientific career by the self-interest and ambitions of her husband.[14] Immerwahr's life is much more dramatic, however, because of its end. She killed herself with her husband's revolver at the end of the first day of May 1915 shortly after the first use of chlorine at Ypres. There is a puzzle, then, about Immerwahr. Why did she commit suicide?

Bretislav and Dieter Hoffmann have closely interrogated this puzzle, and they conclude that a too-simplistic myth has been created about Clara Immerwahr as a pacifist protesting against chemical weapons in which her husband was playing a major role.[15] In a 1993 biography of Immerwahr, Gerit von Leitner largely made this argument, which has been repeated in subsequent publications and radio and film dramas, most recently in a 2014 movie on German television.[16] In her 1998 biography of Haber, Margit Szöllösi-Janze critically evaluated the sources for Leitner's argument and found it inadequately documented by historical evidence.[17] Bretislav and Dieter have updated Szöllösi-Janze's evaluation in light of more recent biographies of Haber, as well as documents in the MPG Archives, correspondence first published in 2015 between Immerwahr and Setsuro Tamaru, and letters written in 1915 by Immerwahr's friends Edith Hahn and Lise Meitner. The result is a complex portrait of Immerwahr's professed dissatisfaction with her role as a professor's wife and her husband's obsession with his work, their lack of affection, her responsibilities in running a kindergarten for children whose fathers were at the war front, her despondency at the deaths of her mentor Richard Abegg and friend Otto Sackur, and the apparent discovery, on the night of her suicide, of her husband's affair with Charlotte Nathan. In short, in Dieter and Bretislav's words, the reasons for Immerwahr's suicide were perhaps catastrophically over-determined. [18]

And what about Haber himself? Bretislav has been writing about Fritz Haber since 2005, beginning with an essay review of the English translation of Dietrich Stoltzenberg's biography of Haber.[19] Since then, Bretislav has written about Haber's scientific investigations, his years of leadership at the Institute, and his research and implementation for gas warfare. These accounts have appeared in articles in *Bunsen-Magazin*, *Physik in unserer Zeit*, and on the history website of the Fritz Haber Institute, as well as in the co-authored Centennial history of the Fritz Haber Institute and in essays written with Dieter Hoffmann and Jeremiah James.[20]

What emerges in these portraits of Fritz Haber are valuable narratives and perceptive insights into the personality, motivations, achievements, and flaws of a towering figure in early twentieth century science. As Bretislav describes, on the one hand, Haber played a crucial role in creating an ideal institution for fundamental scientific research, what Michael Polanyi called a "city" or "republic" of science," but Haber also masterminded a newer and vaster scale of collusion between science, government, the military, business, and industry in what Haber's godson Fritz Stern called the "military-industrial-academic complex."[21]

What we learn, or relearn, about Haber is how he came to develop, with

Robert Le Rossignol, the process for the formation of ammonia from the direct reaction of nitrogen and hydrogen gases under high pressure with an osmium catalyst.[22] Subsequent industrial synthesis of ammonia for the production of fertilizers and expansion of agriculture provided Germans with food during the First World War, despite embargos, and it played a role in Haber's receiving the Chemistry Nobel Prize of 1918 for chemical innovation and for benefits to mankind.

What was not mentioned at the Nobel ceremony held in 1920 was the role played by the industrial Haber-Bosch process in providing explosives for traditional munitions during the war or Haber's role in introducing large-scale gas warfare. As Bretislav writes, the use of chlorine clouds at Ypres was Haber's idea: "backed by the profiteering chemical industry, [he] was able to persuade his country's military leadership to stage a battlefield test of a chemical weapon," and, writes Bretislav, "The lethality of the chlorine attack at Ypres lured the German military into adopting chemical warfare."[23]

By 1916 Haber had transformed the Institute into a research and manufacturing center for offensive and defensive chemical weapons, eventually with nine departments employing approximately 150 scientists and engineers and 1300 support staff, the latter mainly women. Bretislav writes that the Institute became a prototypical example of Big Science and, quoting Fritz Stern, a kind of forerunner of the Manhattan Project.[24] Particularly troubling for Haber's legacy, too, is his decision after the War to direct a program of chemical weapons research with secret facilities, working through Dietrich Stolzenberg's father Hugo as proxy. Haber did not live to see the use of one of the chemicals, Zyklon B, in extermination camps under the Nazis.[25]

In contrast to the moral questions associated with Haber's wartime conduct, which Haber himself later described as making him "one of the mightiest men in Germany," Bretislav and his co-authors in the Centennial history characterize the later years of the 1920s and the early 1930s as "the golden years" for Haber and his Institute. [26] Haber's own scientific research picked up again, as shown in a graph constructed by Bretislav.[27] Furthermore, Haber "helped pave the way for the transition from classical physical chemistry to chemical physics" in a targeted research program for electrochemistry, colloid chemistry, reaction kinetics, and aspects of quantum physics, including atomic structure.[28] The framework for the Institute, as set up under Haber, was eventually resurrected after the Second World War. In the golden era, that structure included four major departments of some 50 researchers, each department including small "research groups" and attracting foreigners, women, and scientists of Jewish ancestry, a recruitment made possible by the Institute's partly "third-party" private mode of funding, in contrast to universities.[29]

What made Haber a successful leader and director? In a formal interview of Dudley Herschbach in 2012, Bretislav remarked that one of the defining features of the Kaiser Wilhelm and Max Planck Society "is to fund people and not projects."[30] This framework took its origins in the first Kaiser Wilhelm Institutes, with Haber, according to Bretislav, "hiring a great number of young first-class researchers and giving free rein to their pursuits."[31] One of those young researchers, initially hired in 1920, was Michael Polanyi whose research group in physical chemistry became internationally known. Bretislav characterizes the year 1931 as the "annus mirabilis" of theoretical chemistry when Fritz London, Henry Eyring and Michael Polanyi, with input from Eugene Wigner, re-interpreted the conditions for the making and breaking of chemical bonds in their semi-empirical theory of the potential energy summit and the transition state.[32]

Bretislav and his Centennial history coauthors narrate and analyze the much longer history of the Institute after 1933, showing continuity in the Institute's emphasis on fundamental research problems after the Nazi years when Peter Adolf Thiessen had led the Institute in goal-oriented war-relevant research with an ethnically and ideologically purged staff. After 1951, under the directorship of Max von Laue, and then under Laue's successor Rudolf Brill, research programs extended to electron microscopy and electron diffraction. Brill and then Heinz Gerischer renewed emphasis on surface science and catalysis, harking back to the interests of Haber and Polanyi. Recent research with molecular beams in electric and magnetic fields likewise harkens back to proposals by Polanyi, Hartmut Kallmann and Fritz Reiche.

The Centennial history includes the reorganization under Gerischer of the Institute's leadership into one of collective administration.[33] It also offers detailed accounts not only of Haber, but of the work and roles at the Institute of Herbert Freundlich, Polanyi, Thiessen, Von Laue, Brill, Ernst Ruska, and Gerhard Ertl, as well as dozens of vignettes of other researchers.

What do we learn from these histories? What is the value of the history of science, other than a record of events and personalities? In their 1998 article on

Otto Stern, Bretislav and Dudley begin with a quotation from the physicist and historian of physics Gerald Holton who writes: "Much of my [own] work has had its origin in the notion that science should treasure its own history, that historical scholarship should treasure science, and that the full understanding of each is deficient without the other."[34] In interviewing Dudley in 2012, Bretislav came back to the role of history of science in teaching science. Dudley replied that it is inspirational, it is reassuring about the foibles as well as feats of scientists, and it often helps a scientist to understand better a method or technique or concept.[35]

Bretislav also broached to Dudley a question that had been posed by Helmut Schwarz: "What would you choose as a scientist: freedom without means, so to speak, without very much funding; or a lot of funding with strings attached?"[36] This question reminds us of the similar question posed by historian of science Loren Graham in his 1998 book *What Have We learned about Science and Technology from the Russian Experience?*[37] Loren found that many Russian scientists and mathematicians in the Stalinist and later era put their heads down and lost themselves, as well as they could, in research that was well funded, even if not for reasons they approved. Loren concluded with the unfashionable argument that very good fundamental science was in fact accomplished in some fields under successive Soviet regimes despite frequent purges and limited freedom, and that science, already firmly established, proved remarkably resilient.

Bretislav similarly has often interrogated the circumstances under which scientific work has thrived and the ethical dimensions of scientists' lives and influence. A recurring theme, which I mentioned earlier in my talk, is the importance of scientific exchange and scientific networks. In his "Autobiography," published in the 2013 *Festschrift* for Bretislav, and in an earlier interview with his mentor Zdenek Herman, we are told of the crucial role of exchanges during the Communist era in Czechoslovakia. Bretislav recounts the stream of visitors to the Cermak-Herman Laboratory in Prague in the 1970s and early 1980s at a time when Czech scientists' travel abroad was carefully controlled. Herman, who had spent time as a postdoc at Yale and at the University of Colorado in the mid-1960s, recalled that visitors to Prague kept Czech scientists internationally linked in the early 1970s.[38] Bretislav recalls his own travels to East Berlin in the 1970s and in 1980, followed by permission for research at the University of Utah in 1982, then in Göttingen, followed by Harvard in 1987.[39] Travel was not as free politically as it had been in the early twentieth century, but travel and collaboration provided a lifeline for science and scientists to thrive.

Related to the question of freedom in science, Bretislav also has addressed in his historical work the moral or ethical dimensions of scientific life. In writing about Haber in World War One, Bretislav and Jeremiah James reflect that Haber's "efforts during WWI illustrate how quickly the fine line between the tolerable and the unacceptable can be crossed."[40] In an obituary of Fritz Stern, the great German historian who addressed questions of freedom, responsibility, and evil in his work, Bretislav and Gerhard Ertl quote Stern's reflection on his godfather Fritz Haber: "The scientist's ethical and civic responsibilities must be heeded, honored and taught—to the benefit of science and mankind and as a tribute to a great man, to Onkel Fritz."[41]

As Bretislav notes elsewhere, Albert Einstein, a close friend of Haber's in the 1910s and early 1920s, and an outspoken pacifist and opponent of the war, appears never to have been recorded criticizing Haber's war effort. As I found in my own research on Michael Polanyi, Polanyi, over twenty years Haber's junior, offered only unstinting praise for Haber in a speech in 1928, but in the spring of 1933 drafted an unsent letter asking Haber to use his high position to stand openly in resistance to Nazi persecution of Jews.[42] In an article on Polanyi, Bretislav quotes Polanyi on the subject of personal freedom and ethical responsibility: "The freedom of a subjective person to do as he pleases is overruled by the freedom of the responsible person to do as he must."[43] Of course, the trick is to understand what is the morally responsible thing to do.

Bretislav's historical research often challenges readers on exactly this question, in all its complexity. His writings excel in explaining science clearly and in examining institutions, social networks and personalities that have undergirded major developments in physical chemistry, theoretical chemistry and atomic and molecular physics. We see the roles of chance, coincidence, and commitment. Bretislav brings to his historical writing what Polanyi called the personal and tacit knowledge of an experienced and successful scientist, but also the thoughtfulness, erudition, and integrity of a historian in search of complex answers to difficult questions.

ENDNOTES

---

[1] Bretislav Friedrich, "Autobiography of Bretislav Friedrich," *Molecular Physics: An International Journal at the Interface between Chemistry and Physics*, 111, #12-13

[2] Ibid., 1639.

[3] Jeremiah James, Thomas Steinhauser, Dieter Hoffmann, and Bretislav Friedrich, *One Hundred Years at the Intersection of Chemistry and Physics: The Fritz Haber Institute of the Max Planck Society 1911-2011* (Berlin: Walter de Gruyter, 2011).

[4] Bretislav Friedrich, "Tributes to and Reminiscences of Michael Polanyi (1891-1976), *Bunsen-Magazin*, 19, #3 (2017): 117-119. Bretislav Friedrich, Marcus Popplow, and Anthony S. Travis, "Berlin, Jerusalem, and Karlsruhe Mark Fritz Haber's 150th Birthday," *Bunsen-Magazin*, 21, #2 (2019): 47-50.

[5] *One Hundred Years of Chemical Warfare: Research, Deployment, Consequences,* ed. Bretislav Friedrich, Dieter Hoffmann, Florian Schmaltz, Jürgen Renn, and Martin Wolf (Springer Open, 2017.

[6] Friedrich, "Autobiography," 1641.

[7] Bretislav Friedrich and Dudley Herschbach, "Space Quantization: Otto Stern's Lucky Star," *Daedalus*, 127, #1 (Winter 1998): 165-191, on 168-177. Also see Bretislav Friedrich and Dudley Herschbach, ""The Stern-Gerlach Experiment," *Macmillan Encyclopedia of Physics*, 4 vols., ed. John S. Rigden (New York: Simon and Schuster Macmillan, 1996).

[8] Ibid., 177, 179. 181.

[9] Ibid., 178-179. See Figure 5, p. 58, in Bretislav Friedrich and Dudley Herschbach, "Stern and Gerlach: How a Bad Cigar Helped Reorient Atomic Physics," *Physics Today*, 56, #12 (December 2003): 53-59.

[10] Friedrich and Herschbach, "Lucky Star," 183.

[11] J. Peter Toennies (Göttingen), Horst Schmidt-Böcking (Frankfurt), Bretislav Friedrich and Julian C. A. Lower (Frankfurt). Historical Article. "Otto Stern (1888-1969): The Founding Father of Experimental Atomic Physics." Annalen der Physik, 523, #12 (2011): 1045-1070, on 1052. Schmidt-Böcking published *Otto Stern: Physiker, Querdenker, Nobelpreisträger, Herausgeber* (Goethe Universität Frankfurt, Reihe: Gründer Gönner and Belehrte (Frankfurt: Societätsverlag, 2011) and co-edited with Karen Reich

[12] Massimiliano Badino and Bretislav Friedrich, "Much Polyphony but Little Harmony: Otto Sackur's Groping for a Quantum Theory of Gases," *Physics in Perspective*, 15 (2013): 295-319, on 310-312. Also see the more mathematically written Massimiliano Badino and Bretislav Friedrich, "Putting the Quantum to Work: Otto Sackur's Pioneering Exploits in the Quantum Theory of Gases," in *Traditions and Transformations in the History of Quantum Physics*, ed. Shaul Katzir, Christoph Lehner and Jürgen Renn (Berlin: Edition Open Access 2013): 61-84. http://mprl-series.mpg.de/proceedings/5/

[13] Badino and Friedrich, "Much Polyphony," p. 314. They cite Suman Seth, *Crafting the Quantum: Arnold Sommerfeld and the Practice of Theory, 1890-1926* (Cambridge, Mass. and London: The MIT Press, 2010), pp. 2–4.

---

[14] Jürgen Renn, *Albert Einstein, Mileva Marić: The Love Letters* (Princeton: Princeton University Press, 1992). Also see John Stachel, "Albert Einstein and Mileva Marić: A Collaboration That Failed to Develop," in *Creative Couples in the Sciences*, eds. Helen M. Pycior et al. (New Brunswick, NJ: Rutgers University Press, 1996): 207-219.
[15] Bretislav Friedrich and Dieter Hoffmann, "Clara Haber, nee Immerwahr (1870-1915," *Zeitschrift für anorganische und allgemeine Chemie*, 642, #6 (2016): 437-448. Bretislav Friedrich and Dieter Hoffmann, "Clara Immerwahr: A Life in the Shadow of Fritz Haber," in *One Hundred Years of Chemical Warfare: Research, Deployment, Consequences,* ed. Bretislav Friedrich, Dieter Hoffmann, Florian Schmaltz, Jürgen Renn, and Martin Wolf (Springer Open, 2017): 45-68. Also, Bretislav Friedrich and Dieter Hoffmann, "Clara Haber, nee Immerwahr: In and Out of Her Element," in *Women in Their Element: Selected Women's Contributions to the Periodic System*, ed. Brigitte Van Tiggelen and Annette Lykknes, in press.
[16] Gerit von Leitner, *Der Fall Clara Immerwahr: Leben für eine humane Wissenschaft* (Munich: C. H. Beck, 1993). See, e.g., the BBC radio drama by Jason Hopper, "The Greater Good," broadcast 23 October 2008, and "Clara Immerwahr" a German television movie of 2014. http://laurenceraw.tripod.com/id108.html; https://www.telegraph.co.uk/news/worldnews/europe/germany/10863000/PIC-PLS-Germans-rediscover-First-World-War-heroine-in-new-TV-drama.html
[17] Margit Szöllösi-Janze, *Fritz Haber, 1838-1934: Eine Biographie* (Munich: C. H. Beck, 1998).
[18] Friedrich and Hoffmann, "Life in the Shadow," 53, 58-59, n. 14 on 59, Table 1 on p. 5.
[19] See book reviews of Dietrich Stoltzenberg's 2004 biography of Haber and Daniel Charles's 2005 biography: *Angewandte Chemie International Edition*, 44 (2005): 3957-3961; *Angewandte Chemie International Edition*, 45 (2006): 4053-4055;
[20] Bretislev Friedrich, "Fritz Haber at One Hundred Fifty: Evolving Views of and on a German Jewish Patriot," *Bunsen-Magazin*, 21 (2019), in press; "Fritz Haber und der 'Krieg der Chemiker': Leben und Werk eines umstrittenen Wissenschaftlers," *Physik in unserer Zeit*, 46, #3 (2015): 118-125; Bretislav Friedrich, "A Brief Biography of Fritz Haber (1868-1934)" (2016) at www.fhi-berlin.mpg.de/history/ ; James et al., *One Hundred Years*, 11-99; Bretislav Friedrich, Dieter Hoffmann and Jeremiah James, "One Hundred Yeas of the Fritz Haber Institute," *Angewandte Chemie International Edition*, 50 (2011): 1022-10049, esp. 1022-10025, 10029-10031; Bretislav Friedrich and Jeremiah James, "From Berlin-Dahlem to the Fronts of WWI: The Role of Fritz Haber and his Kaiser Wilhelm Institute in German Chemical Warfare," in *One-Hundred Years*, pp. 25-44.
[21] On Polanyi and his view of Haber and the Institute, Mary Jo Nye, *Michael Polanyi and His Generatoin: Origins of the Social Construction of Science* (Chicago: University of Chicago Press, 2011), pp. 81-83. Fritz Stern, *Einstein's German World* (Princeton: Princeton Unviersity Press, 1999), pp. 59 on his relationship to Haber, p. 82 for quotation. Fritz Stern's father Rudolf Stern was Haber's personal physician who was present at Haber's death in Zurich (Friedrich, "Brief Biography," p. 27.
[22] Friedrich, "Brief Biography," pp. 7-8.
[23] Ibid., 11-12.

[24] Friedrich, Hoffmann and James, "One Hundred Years," 10024.
[25] Friedrich, "Brief Biography," p. 19.
[26] For the quotation from Haber, Chaim Weizmann, *Trial and Error: The Autobiography of Chaim Weizmann* (New York: Harper and Brothers, 1949), p. 354. On golden years (era), Friedrich, Hoffmann and James, "One Hundred Years," 10024; James et al. *One Hundred Years*, p. 35.
[27] Friedrich, "Fritz Haber at One Hundred Fifty," Figure 14.
[28] Friedrich, Hoffmann and James, "One Hundred Years," 10024.
[29] Ibid., 10025.
[30] John Rigden and Bretislav Friedrich, "Interview [with Dudley Herschbach]," *Molecular Physics*, 110, nos. 15-16 (2012): 1549-1590 on 1570.
[31] Friedrich, "Brief Biography," p. 21.
[32] For "annus mirabilis," Friedrich, "Tree of Knowledge," p. 5382. On Polanyi and his collaborators, Bretislav Friedrich, "Michael Polanyi," 163.
[33] James et al., *One Hundred Years*, 117, 172, 232, 241, 248, 256; Friedrich, Hoffmann and James, "One Hundred Years," 1028.
[34] Bretislav Friedrich and Dudley Herschbach, "Space Quantization: Otto Stern's Lucky Star," *Daedalus*, 127, #1 (Winter 1998): 165-191, on p. 165 from Gerald Holton, *The Advancement of Science, and Its Burdens* (1986), p. 197.
[35] Rigden and Friedrich, "Interview," 1774-1575.
[36] Ibid., p. 1570.
[37] Loren Graham, *What Have We Learned about Science and Technology from the Russian Experience?* (Stanford: Stanford University Press, 1998).
[38] Bretislav Friedrich, Michael Henchman and Dudley Herschbach, "Zdenek Herman, Bohemian at Large," *Journal of Physical Chemistry*, 99, no. 42 (1995): 15317-15326, on 15321.
[39] Bretislav Friedrich, "Autobiography," 1634-1637.
[40] Friedrich and James, "From Berlin-Dahlem," p. 15.
[41] Gerhard Ertl and Bretislav Friedrich, "Obituary: Fritz Stern (1926-2016)," *Angewandte Chemie International Edition,* 55 (2016): 9470-9741, on 9471. On the occasion of the 100th anniversary commemoration of the founding of the Institute, Fritz Stern delivered the lecture "Fritz Haber: Flawed Greatness of Person and Country," *Andwandte Chemie International Edition*, 51, no. 1 (2012): 50-56.
[42] Nye, *Michael Polanyi and His Generation*, p. 76. Quoted in William T. Scott and Martin X. Moleski, S.J., *Michael Polanyi: Scientist and Philosopher* (Oxford: Oxford University Press, 2005), 138.
[43] Friedrich, "Michael Polanyi," quoted on p. 166 from *Personal Knowledge* (1958), p. 309.