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A brief biography of Fritz Haber (1868-1934)*

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On January 29, 1935, a "purely internal and strictly private" memorial service was to be held in Harnack House, the faculty club and conference center of the Kaiser Wilhelm Society, in Berlin-Dahlem. Max Planck, the Society's president, picked up Otto Hahn, the designated orator, at his office at the Kaiser Wilhelm Institute for Chemistry. The directive prohibiting all members of the Kaiser Wilhelm Society to enter Harnack House that morning was posted on the notice board. As Hahn recollected:[1]

> Planck was, however, excited and pleased that the ceremony will take place in spite of all the odds, unless perhaps on our short walk [to Harnack House] a group [of thugs] sent by the [Nazi] Party will try to prevent us from entering by force. But nothing happened … The lovely large reception hall of Harnack House … was full. … Most of those present were women, the wives of Berlin professors [or] of members of the Kaiser Wilhelm Society … They came as representatives of their husbands who had been prevented by a brutal prohibition from bidding their final farewell to an important person and scientist.

The "important person and scientist" Hahn referred to was Fritz Haber. Effectively banished from Germany for "opposing the National Socialist State," Haber had died a year earlier to the day in exile.

* This is a "living document," periodically amended and expanded as newly surfaced materials and connections are brought to the author's attention. Current version posted on February 20, 2016.

> Privy councilor Planck gave the introductory address, pointing out that had Haber not made his magnificent [ammonia synthesis] discovery, Germany would have collapsed, economically and militarily, in the first three months of World War I. … The two main speeches, by myself and [Karl Friedrich] Bonhoeffer, dealt with Haber's personal side, the significance of his famous institute [the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry], as well as his scientific work. As … Bonhoeffer was not able to be present – had been forbidden to come – I read Bonhoeffer's manuscript in his name.

However telling Hahn's and Bonhoeffer's orations may have been, it remained a recalcitrant problem for Haber's colleagues, historians, and lay public alike to come to grips with Haber's complex and contradictory legacy. In an obituary,[2] published in *Naturwissenschaften* in 1934, Max von Laue predicted that Haber would be primarily remembered as the inventor of the synthesis of ammonia from its elements, a process that revolutionized chemical industry and, through its use in the production of fertilizers, provided nourishment for billions of people. Apart from yielding "bread from air" (as von Laue called it), the ammonia synthesis also afforded the production of "gunpowder from air," its primary employment at the time, which drove the implementation, on an industrial scale, of what's known as the Haber-Bosch process (the Leuna Werke of the Badische Anilin- und Sodafabrik, BASF, became fully operational as late as 1916, Ref.[3]). However, what has interfered with von Laue's prediction most destructively was Haber's promotion of the first weapons of mass destruction.[4],[5] Driven by his patriotic zeal and acting under the credo "In peace for mankind, in war for the fatherland!" Haber devoted himself and his Kaiser Wilhelm Institute to the development of "poison instead of air" – to World War I chemical warfare.

The work of the historian in sorting out the triumphs, failures and paradoxes of Haber's life has been greatly facilitated by the endeavor of one of Haber's former coworkers, Johannes Jaenicke, who headed the unsuccessful "gold from seawater" project. Jaenicke assembled a total of

2290 items related to Haber's life and bequeathed them to the Archive of the Max Planck Society (whose forerunner he ran for a while). Jaenicke's collection is a historian's goldmine. So far it has been tapped systematically only by the chemist/historian Dietrich Stoltzenberg[3] and the historian Margit Szöllösi-Janze[6]. Their complementary, award-winning accounts provide a high-resolution image of Haber's life, work and times.

Fritz Haber was born in Breslau, Prussia (today Polish Wroclaw) on December 9, 1868, into a family whose forbears can be traced back to the beginning of the 1800s. His father was a wealthy merchant dealing in dyes and pharmaceuticals, with far-reaching family and business connections. His mother died in childbirth. The female element in Fritz's childhood was mainly represented by his three stepsisters, from his father's second marriage. Fritz's strongest early influence was his uncle Hermann, a liberal who ran a local newspaper to which Fritz had later contributed. Uncle Hermann also provided space, in his apartment, for Fritz's early chemical experiments. Fritz's interest in chemistry may have been ignited by his father, who possessed some chemical expertise. At that time, Fritz was attending a humanistic high-school (Gymnasium), closely affiliated with the largest protestant church in Breslau, St. Elisabeth's. Half of its pupils were Jewish, as was Fritz. Instead of an apprenticeship that would prepare him for taking over the family business, Fritz, with some help from uncle Hermann, was able to prevail upon his father and go to college. Aged 18, he entered Berlin's Friedrich-Wilhelms-Universität (now the Humboldt University) to study chemistry and physics, drawn to both fields by the towering figures of August von Hofmann and Hermann von Helmholtz. The next year, he spent at Robert Bunsen's Institute in Heidelberg, only to return to Berlin to study organic chemistry under Carl Liebermann at the Technische Hochschule Charlottenburg (now the Technical University Berlin). Haber also developed a bent for philosophy, especially Kantian, under Wilhelm Dilthey. He graduated *cum laude* in 1891 from the Friedrich-Wilhelms-Universität with a PhD thesis on piperonal (an indigo derivative) under Hofmann. Upon his return to Breslau, he was uncertain about what to do next. On his father's urging, he took several "apprentice jobs" in chemical industry.

Fritz Haber, shortly after his graduation in 1891

This was a watershed for Haber, as he discovered some pressing deficiencies in his education, particularly in chemical technology. Thus he went to the ETH Zurich, in 1892, to work under Georg Lunge, a family friend, and to Jena, where he became research assistant to Ludwig Knorr. From Jena, Haber applied for a research assistantship with the physical chemist Wilhelm Ostwald, whose field was then regarded as the basis of both chemistry and chemical technology. Despite several attempts, he never got the job, just a single disappointing interview. Ostwald never warmed up towards Haber. During his time in Jena, Haber, at age twenty five, converted to Christianity, likely fired up by Theodor Mommsen's essay (written in reaction to Heinrich von Treitschke's anti-Semitic article) to foster the newly fledged German unity: Germans were to abandon "those loyalties and affiliations that divided them." In the Spring of 1894, he moved to the

Technische Hochschule Karlsruhe, where he was to stay for the next seventeen years. He started as assistant to the professor of chemical technology, Hans Bunte, habilitated as Privatdozent in 1896, became *Extraordinarius* in 1898, and was finally named full professor, of physical chemistry, in 1906. Haber never attended a single lecture on physical chemistry apart from his own, as he would later admit with glee[7].

In Karlsruhe, during the “first heyday period” of his career, Haber developed a remarkably diverse research program. As Stoltzenberg emphasizes and exemplifies,[3] this ranged from chemical technology, to electrochemistry, to gas-phase chemistry.

Haber’s crowning achievement was the synthesis of ammonia from its elements. The need to find new ways of replenishing agricultural soil with nitrogen in a form that can be metabolized by plants was articulated, in 1898, by William Crookes (who also coined the term “fixation,” as in fixing a date between nitrogen and hydrogen), and was widely perceived as a challenge. A number of people before Haber could have laid a claim to coming up with the idea for a direct “fixation” of nitrogen, such as William Ramsey, Le Chatelier – or Ostwald, who actually did. Ostwald wrote about it in his 1920 autobiography:[8]

> As the expert immediately recognizes, the basic ideas for the synthesis of ammonia … had been clearly and unambiguously stated [in March 1900; the ideas comprised elevated temperature and pressure, a copper or iron catalyst, and recirculation of the nitrogen and hydrogen gases]. Thus I am justified in calling myself the intellectual father of [the ammonia] industry. I have certainly not become its real father, for all the difficult … work needed to create a technologically and economically viable industry from the right ideas was carried out by those who took on the abandoned infant.

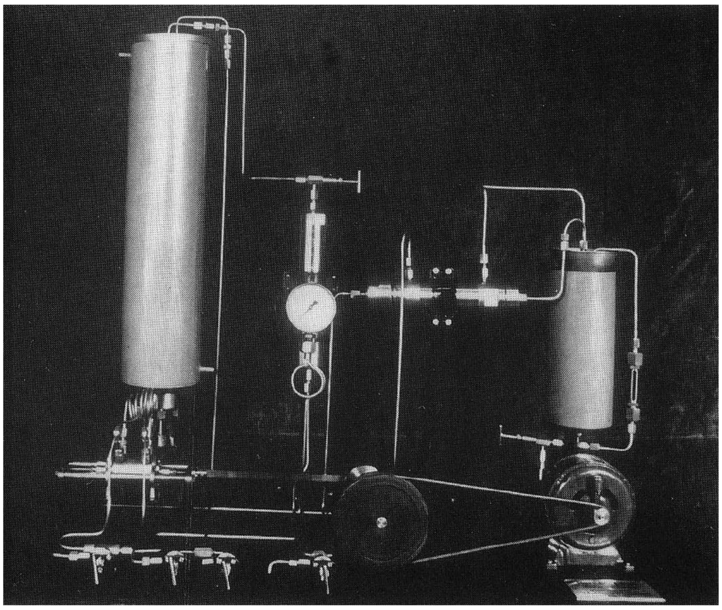
Haber had first studied the ammonia equilibrium in 1903, in response to a query from the Österreichische Chemische Werke. The equilibrium constant that Haber found at normal pressure and a temperature of about 1000^{o}C was way too low (corresponding to a 0.0044% yield of ammonia) for a direct synthesis from the elements to be of any commercial use. Haber later commented:[9]

> If one wished to obtain practical results with a catalyst at normal pressure, then the temperature must not be allowed to rise much above 300°C. … The discovery of catalysts which would provide a rapid adjustment of the point of equilibrium in the vicinity of 300°C and at normal pressure seemed to me quite unlikely.

And indeed, no such catalysts were ever found. Although the effects of elevated temperature and elevated pressure on the yield of the reaction had been well established by that time (in 1905), Haber put the ammonia research on the back burner, due to the lack of its anticipated technical feasibility.

Fritz Haber in his laboratory in Karlsruhe, ca 1909

But then two events, in 1908, compelled Haber to turn the heat on the ammonia problem again:[9] First, he caught a glimpse of an industrial procedure that was making use of a gaseous reaction under heat and elevated pressure; second, Haber was sharply attacked by Walther Nernst, who claimed, in talks and in writing, that Haber's equilibrium constant was "far from the truth." Nernst reached this conclusion based on his measurements of the heat capacities of the reagents and products, which, aided by Nernst's heat theorem, he then related to the equilibrium constant. Haber's reaction to Nernst's onslaught was shrewd: he remeasured the heat capacities himself – and found them in agreement with his value of the equilibrium constant. Furthermore, along with Robert Le Rossignol, who came from Ramsey's London lab, he explored the so far neglected high-pressure regime. Le Rossignol and Haber found that at a pressure of about 200 atmospheres and a temperature of 600°C, a yield of about 18% could be obtained, with the aid of an osmium catalyst. Haber lived through his *Eureka* moment, when synthetic ammonia had begun to drip, with the words "There's ammonia!"



Haber-Le Rossignol ammonia synthesis apparatus

In the industrial-scale Haber-Bosch process, developed by Carl Bosch and his coworkers at BASF, an iron catalyst was used instead of osmium. This added an entirely unexpected twist. Haber commented on it, in 1910:[10]

[It] is remarkable how … new special features always come to light. Here iron, with which Ostwald had first worked and which we later tested a hundred times in its pure state, is now found to function when impure.

Members of Haber's Department at the Technische Hochschule Karlsruhe (1908). Seated in the first row second from the left is Robert Le Rossignol

Bosch and his principal coworker at BASF, Alwin Mitasch, made use of Swedish iron ore, which introduced aluminum and potassium as beneficial impurities that acted as promotors of iron's catalytic activity.[11] Later, Nernst's unexpected favorable testimony became instrumental for granting the ammonia patent to BASF and to Haber.[3] In turn, the agreement between the predictions of Nernst's theorem and Haber's data played a role in recognizing the theorem's value and helped secure a Nobel Prize for Nernst, in 1920.[12]

Meanwhile, in Berlin, a group of prominent chemists, including Nernst, Ostwald, and Emil Fischer, pondered on creating an elite institution dedicated to research in chemistry. Aided by their contacts with the Prussian official Friedrich Schmidt-Ott and the Kaiser's personal friend, the royal librarian and distinguished theologian Adolf von Harnack, they developed the idea for what was to become the Kaiser Wilhelm Society (now the Max Planck Society) for the promotion of all sciences. The society came into being in 1911, and its first two institutes were inaugurated – by Wilhelm II – in 1912 in Berlin-Dahlem. One of them was the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry, funded from an endowment donated by the banker and entrepreneur Leopold Koppel. On the recommendation of Svante Arrhenius and under pressure from Koppel, Fritz Haber was invited to become its first director. It was an offer that Haber could not resist: Haber was guaranteed a generous operating budget, the status of a state official, professorship at the Berlin university, and membership in the Prussian Academy. The Institute was designed to Haber's image by the chief imperial architect, Ernst von Ihne, and included a director's mansion that served as Haber's residence. As Stoltzenberg put it:[3]

> [Haber's] influence depended as much on his scientific success as it did on the perfect fit between his own career and the spirit of the times.

Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry, with the director's mansion on the right, cca 1912

In late 1913, Berlin's academic luster got even brighter as Albert Einstein arrived on the scene, to assume a Professorship, likewise funded by Koppel, at the Prussian Academy of Science and to direct the Kaiser Wilhelm Institute for Physics. Haber and Einstein quickly developed a rather close relationship. Einstein's personal circumstances – his increasingly dysfunctional marriage with Mileva Maric – may have fostered the closeness with Haber who, at times, even acted as an intermediary between Einstein and his wife. This and much more has been told by Fritz Stern[13] and Thomas Levenson.[14] There was also a scientific interaction between the two. According to a Berlin legend,[15] Haber called upon Einstein "to do for chemistry what he [Einstein] did for physics." After all, Einstein's first paper and his thesis dealt with molecules …

Fritz Haber (left) and Albert Einstein in the stairwell of Haber's Institute, cca 1914

The era of peace and prosperity that Prussia had enjoyed for 43 years came to an end with the outbreak of the Great War. Its first salvos were echoed by verbal exchanges between the academics of the warring parties. This "war of the spirits"[16] took a lethal form once the scientific communities became ensnarled in promoting and developing new weapons systems, in breach of the ethos of the *Republique des Lettres* – and, eventually, of international law. Haber's initiative to develop chemical weapons and his involvement in their deployment remain among the best examples of the breach of both. Brought to glistening prominence by Germany's need to produce "gunpowder from air," Haber, backed by the profiteering chemical industry, was able to persuade his country's military leadership to stage a battlefield test of a chemical weapon. Emil Fischer, who foresaw the proliferation of chemical weapons as a necessary consequence of their first use "wished for [Haber's] failure from the bottom of [his] patriotic heart."[3]

Haber on the front during WWI

On April 22, 1915, a 6 km stretch of the front at Ypres, Belgium, was exposed to 167 tons of chlorine released from 5,700 gas cylinders, and carried towards the British and French trenches by a long-awaited wind. The chlorine cloud, which passed through the front within a few minutes, left behind at least 5,000 casualties. Among the 1,000 dead were also Germans, hit by the inherently inaccurate weapon. The attack was repeated two days later under more favorable conditions, causing another 10,000 casualties and 4,000 dead.[17] The New York Times reported on April 26, 1915:

> Some [soldiers] got away in time, but many, alas, not understanding the new danger were not so fortunate and were overcome by the fumes and died poisoned. Among those who escaped, nearly all cough and spit blood, the chlorine attacking the mucous membrane. The dead were turned black at once … [The Germans] made no prisoners. Whenever they saw a soldier whom the fumes had not quite killed they snatched away his rifle … and advised him to lie down 'to die better'.

The lethality of the chlorine attack at Ypres lured the German military into adopting chemical warfare. Haber was promoted, by an imperial decree, to the rank of captain.

Clara Haber, nee Immerwahr,
whom Haber married in 1901

The chlorine cloud attack at Ypres was soon followed by the suicide of Haber's first wife, Clara, nee Immerwahr (1870-1915). Born into a well-to-do assimilated Jewish family in Breslau, Clara decided, against all odds, to study chemistry. In 1900, she became the first woman to earn a doctorate in chemistry from the University of Breslau. The "doctissima virgo" was celebrated by the dean with caution, however, as he didn't wish to see the dawn of a new era with women enlisted outside of home and family. Her thesis, on the solubility of heavy metal salts, was supervised by Richard Abegg, a chemist well known for contributing to the "octet rule," and a friend and former *Kommilitone* of Fritz Haber's. It was Abegg who helped to rekindle the affair between Fritz and Clara that led to their marriage, in 1901. Their son, Hermann, was born a year later. With no employment available for female scientists/chemists, Clara, so long as her health and that of her son had permitted, freelanced as an instructor in the continued education of women, mostly housewives, while struggling not to become a housewife herself. This proved increasingly difficult at the side of Fritz Haber, who had a dominant personality – and was rising rapidly on his steep career path. Clara's duties as a designated head of an increasingly posh household and a hostess to Haber's prominent guests hardly brought the much-sought fulfillment to her life. Combined with Haber's chronic absence from family life, Clara grew increasingly frustrated and her marriage dysfunctional. The outbreak of WWI further exacerbated the situation, as Fritz Haber applied himself in extraordinary ways to aid the German war effort. Clara, too, expressed patriotic feelings and sought to be "helpful" and "useful" to her country. At one point, she cared for "57 poor children," whose fathers presumably served on the front. However, the night of May 1-2, 1915 that Fritz Haber sported his self-designed chemical uniform and celebrated the "success" of the first chlorine cloud attack at Ypres, Clara shot herself, with Haber's army pistol, in the garden of their mansion. Clara was found dying by their son Hermann, then 13 year old. Haber, unable to secure a permission to stay, left the next day for the Eastern front, to join his "*Pionierregiment*," a unit charged with the deployment of chemical weapons.

A survey of the historical record provides little evidence to support claims that Clara was an outspoken pacifist whose disagreement with Fritz

Haber's involvement in the German war effort in general and in chemical warfare in particular led to her suicide. Rather, it seems that the "catastrophic failure" (to borrow an engineering terms as a metaphor) resulted from a most unfortunate confluence of circumstances that included, apart from what was said above, Haber's philandering, the death of Richard Abegg (in a ballooning accident) and another close friend of Clara's, the physical chemist Otto Sackur (in a laboratory accident) and the death and destruction of the war itself. "The myth of Clara Immerwahr" that took root in the 1990s presented Clara as an outspoken pacifist and a beacon of feminine, life-preserving science. However, available scholarly sources lend little support to this image.[18]

Fritz Haber with his second wife Charlotte, nee Nathan, cca 1917

Haber advertised the first use of a chemical weapon as an important milestone in the "art of war" – and saw its psychological effect as key:[19]

> All modern weapons, although seemingly aimed at causing the death of the adversary, in reality owe their success to the vigor with which they temporarily shatter the adversary's psychological strength.

Apart from developing additional chemical agents at his Kaiser Wilhelm Institute (such as phosgene and the contact poison LoSt, named for Haber's coworkers Lommel and Steinkopf), Haber introduced the procedure of "Bunteschiessen" (variegated shelling), which consisted of first deploying "Maskenbrecher" – irritants based on organic arsenides that penetrated all available filters and forced those under attack to remove their gas masks – and subsquently of shelling with poisons such as phosgene or LoSt (better known as mustard gas or yperite).

Otto Dix: German gas attack (1924)

The universal abhorrence of chemical weapons as manifestly inhumane is surprisingly recent and so is their classification as weapons of mass destruction. While the latter is a concept of the nuclear age, the former is not … At the time of their use in the First World War, the perverse-sounding notion that chemical weapons were in fact humane had been a part of the vocabulary of munitions and war experts of the Central Powers and the Entente alike, including, e.g., that of the U.S. Assistant Secretary of War and Director of Munitions, Benedict Crowell:[20]

> The methods of manufacturing toxic gases, the use of such gases, and the tactics connected with their use were new developments of this war; yet during the year 1918 from 20 to 30 per cent of all American battle casualties were due to gas, showing that toxic gas is one of the most powerful implements of war. The records show, however, that when armies were supplied with masks and other defensive appliances, only about 3 or 4 per cent of the gas casualties were fatal. This indicates that gas can be made not only one of the most effective implements of war, but one of the most humane.

Fritz Haber viewed chemical weapons as a means to break the stalemate of trench warfare by forcing the adversary to surrender, shorten the war, and thereby preclude the slaughter of millions by artillery and machine gun fire. The few who forewarned Haber and the German military leadership that the German use of chemical weapons will lead to a quick retaliation by the Entente powers and a widespread use of chemical weapons were ignored. And indeed, the Entente introduced its own potent chemical arsenal within a few months of the first German chlorine cloud attack at Ypres. Artillery shells filled with chemical agents grew from a negligible proportion in 1915 to about 50% of the German, 35% of the French, 25% of the British, and 20% of the American ammunition expenditure by the Armistice.[21] Providing little advantage to either of the equally equipped belligerents, chemical weapons greatly increased the already unspeakable suffering of the troops on both sides of both the Western and Eastern fronts. The British historian Edward Spiers recently characterized the WWI chemical weapons as "weapons of harassment."[21] According to Augustin Prentiss's count,[22] a total of about 90,000 soldiers were killed and 1.3 million injured by chemical weapons in WWI. What put finally an end to the war was the economic collapse of Germany.[23]

The image of a circus elephant hauling an empty hay-cart through snow-covered Berlin evokes the level of Germany's exhaustion.

Albert Einstein's pacifist view contrasted sharply with that of his friend Haber. As he would put it later:[24]

> Warfare cannot be humanized. It can only be abolished.

Strangely enough, there is no record of Einstein's criticism of Haber's WWI efforts, although Einstein occupied an office at Haber's institute at the time and must have been aware of what was going on. Gruesome as they were, chemical weapons have been banned only since 1997. Much of the military death toll in WWI (estimated to be at least 10 million troops) was, however, due to high explosives produced by the chemical industries of the warring nations. Hence the characterization of WWI as the "chemists' war." We may add that the development and acquisition of the Haber–Bosch technology by Germany just in time for the Great War was key to sustaining her war effort: Without it, the embargoed supplies of Chilean saltpeter would have run out within months and WWI would have indeed been as brief as anticipated by the German military planners, except that it would have ended not in Germany's speedy victory but rather her abrupt defeat.

According to Szöllösi-Janze,[6] after the armistice, the victorious powers published a list of about 900 alleged war criminals, with Haber's name among them. In response, Haber shed his "chemical" uniform, grew a beard, and fled to Switzerland, where, in the hope of securing immunity from prosecution, he acquired the citizenship of St. Moritz. Unexpectedly, the Allies dropped the charges soon thereafter (presumably because of the complicity of their academic establishments in the illegal war effort), and so Haber could return to Berlin and to his Institute.

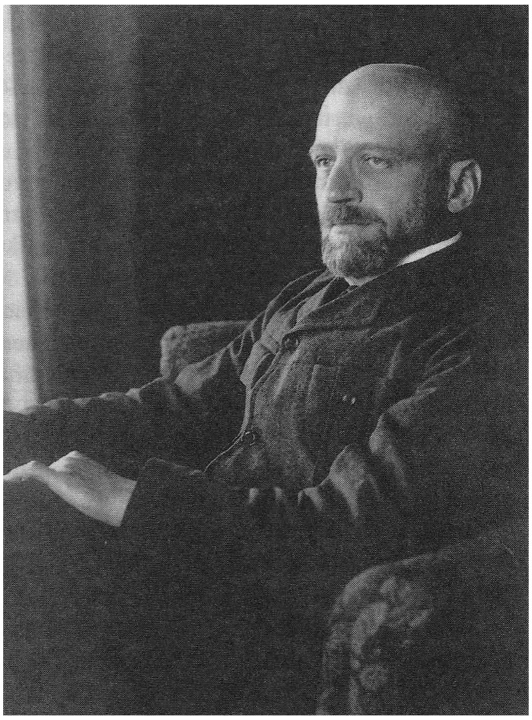
Berlin, cca 1917

In 1920, the Swedish Royal Academy dropped a bombshell: it announced the 1914-1919 Nobel Prizes, five of which were awarded to elated Germans: to Max von Laue, Richard Willstätter, Max Planck, Johannes Stark – and Fritz Haber, who received the 1918 Chemistry Prize, "for the synthesis of ammonia from its elements." The indignation in the French and British communities was boundless …

As Stoltzenberg put it:[3]

> … the laudatory address [by the president of the Swedish Royal Academy] is remarkable for its omissions: although he described in detail the significance of the ammonia synthesis for agriculture, he made no mention of its significance for the explosives industry …

One may add that Haber happily followed suit in his Nobel lecture – and left out the issue of "gunpowder from air" as well. There was no mention, by anybody, of Haber's involvement in chemical warfare.



Fritz Haber, cca 1919/1920

But Haber had been involved in chemical warfare even as he spoke at the Nobel ceremony:[3,6] In 1919 Germany launched a secret program to continue the development and production of chemical weapons, under Haber's tutelage. In order to avoid inspections instituted by the Versaille treaty, the program had been moved to third countries, one of them being the Soviet Union. Stoltzenberg's father, Hugo, was in charge as Haber's proxy. Haber's involvement came to an end only in 1933, when he fell out of grace. The chemical weapons production lines in Germany were converted, in part, to accommodate the manufacture of fumigants, legal under Versaille. The necessary research & development was provided by Haber and his Institute. Among the agents then developed was probably also "Zyklon B," later used in the Nazi extermination camps to poison millions of people, mainly Jews, among them several members of Haber's family.

Between 1920-1926, Haber toiled on the patriotic "gold from seawater" project. The hyperinflation that beset Germany in 1923 must have contributed to Haber's drive. But the concentration of gold in seawater (averaging roughly 10 ppt) turned out to be about a thousand times smaller than what would be needed for making its extraction profitable, so the project had to be scrapped. In 1927, Haber broke up with his second wife, Charlotte, whom he had married in 1917. Charlotte described aspects of her life with Haber in an autobiography.[25] They had two children, Eva and Ludwig (Lutz). Lutz Haber wrote a definitive and authentic volume on chemical warfare in WWI, *The Poisonous Cloud*.[26]

An economic historian, Lutz Haber was well prepared to probe the connections between industry and the military. His personal interest in the topic was fueled not just by his family lineage but also by his acquaintance and friendship with Harold Hartley, whose confidant—and in a sense heir of his extensive collection of materials connected with chemical warfare in WWI – Lutz Haber had become. Sir Harold Hartley was Fritz Haber's counterpart at the British War Office during WWI who, after the war, was in charge of inspecting German research and production facilities related to chemical warfare, and banned by the Versailles Treaty. He had also met the "great Haber", as he put it, during his visit to Haber's Kaiser Wilhelm Institute. Apparently their conversation slipped quickly into a joking mode when Haber pointed out to Hartley what one of the differences between them was: While Hartley had been promoted to the rank of general, Haber had made only a captain. A similarly amiable relationship would evolve between Fritz Haber and Sir William Pope, who was Haber's British counterpart as head of a team that developed mustard gas.

A noteworthy but largely neglected account of chemical warfare in WWI comes from Fritz Haber himself. In a series of lectures presented to the German parliament in 1920–1923, Haber puts squarely the blame for any legal issues with chemical warfare on the German Chief of General Staff, Erich von Falkenhayn. Haber does not shy away, however, from playing a legalistic shell game when he argues that German gas attacks were carried out either without the use of shells (like the chlorine attack at Ypres) or with shells loaded, in addition to poison gas, with explosives (whereas the Hague conventions prohibited the use of shells or grenades filled solely with poisonous substances). Haber also claims that chemical weapons were first used in WWI by the French – in August 1914 – when they fired rifle grenades filled with the highly toxic ethyl bromoacetate. Although ineffective for technical reasons, the intended purpose was, according to Fritz Haber, the same as that of the German chlorine cloud: to force the enemy out of his trench positions by exposing him to an asphyxiating agent.

The period 1926-1933 of Haber's life was largely dedicated to pioneering basic research – and, as Stoltzenberg put it,[3] "can be described as the second heyday of Haber's life." Haber hired a great number of young first-class researchers and gave free rein to their pursuits. Here's how Paul Harteck[27], the co-discoverer, with Bonhoeffer, of para-hydrogen, characterized Haber's leadership during "the second heyday" period:[28]

> Haber, by his personality, set the tone at the institute. He was wise enough to know that one had to give the group leaders and also the keen young members of the institute a far-reaching scientific freedom [in order] to create an atmosphere of free scientific thinking and enterprise.

At the same time, Haber was able to secure adequate funding, mainly through his contacts with industry; BASF was among the principal sponsors. Funding was also provided by the Notgemeinschaft der Deutschen Wissenschaft (later Deutsche Forschunsgemeinschaft), which Haber co-founded, together with Schmidt-Ott, in 1920.

The diversity and quality of the work done at Haber's Institute is astounding. Although physical chemistry remained the principle subject, the themes pursued ranged from fundamental physics to physiology. The embryonic quantum mechanics, on the minds of physicists and physical chemists from the 1910s on, "ushered in the new structural era (and spawned chemical physics)," as Dudley Herschbach described it in his 1986 Nobel lecture.[29] Haber's Institute was instrumental in pushing the departure from thermochemistry, by then complete, towards the study of structure.

Perched on the armrests, Mr Physics and Mr Chemistry – i.e., Einstein and Haber. James Franck, flanked by his wife and Lise Meitner, jokes with his assistant, Hertha Sponer, while Otto Hahn makes himself ready to jump in the conversation. Standing in the back are (from right to left) Gustav Hertz, Peter Pringsheim, Otto von Baeyer, Wilhelm Westphal and Walter Grotrian. Such a photo (taken in 1920) embodies what Erwin Chargaff must have meant when he characterized Berlin during the Weimar era as the "very empyrean [highest heaven] of science."

Here's a sampling of the science done at Haber's institute during the "second heyday:" In 1916, Haber hired Herbert Freundlich, well-known for his work on gas absorption; Freundlich did later pace-setting work in colloid chemistry. Two years later, James Franck joined the institute, to expand his research on electron scattering; his collaborators included Walter Grotrian, Paul Knipping and Hertha Sponer, who all reached prominence later. Rudolf Ladenburg laid the foundations of the quantum theory of dispersion, and related it to atomic structure. Michael Polanyi pioneered gas-kinetic studies and, with his student Eugene Wigner and postdoctoral collaborator Henry Eyring, developed the conceptual framework of reaction kinetics compatible with quantum theory. Their work also anticipated reaction dynamics that succeeded the structural era in the late 1950s. Wigner (who was an "apprentice" of the mathematician Karl Weissenberg before becoming Polanyi's student), deployed group theory and symmetry arguments in general across quantum mechanics. Hartmut Kallmann studied ionization of molecules by slow electrons, outlined the basic principles of a heavy-ion linear accelerator, and, together with Fritz London, provided a quantum-mechanical description of energy transfer between atomic systems. Bonhoeffer, Harteck, and Ladislaus Farkas (the last of whom would later found the first school of physical chemistry in Israel) tackled the kinetics of free radicals and undertook studies of flames and of autoxidation. Farkas and Bonhoeffer established a connection between the diffuse bands in the electronic spectra of ammonia with predissocciation and interpreted the bands' widths in terms of the energy-time uncertainty relation. Hans Kopfermann and Ladenburg demonstrated negative dispersion in a neon gas discharge tube as evidence of stimulated light emission. The last pet-theme of Haber's was the decomposition of hydrogen peroxide catalyzed by iron salts. This much for the sampling of the topics pursued and the key results obtained.

The Institute was also famous for its bi-weekly colloquia, moderated by Haber, often with Einstein, Hahn, von Laue, Otto Warburg, and Leonor Michaelis (to name just a few) in the front row. The colloquia were highly interdisciplinary, covering subjects "from the helium atom to the flea."

Stoltzenberg characterizes Haber's attitude towards his work – and what he considered his duties – as follows:[3]

> The outmost exertion, often to the limits of his physical strength, was a constant habit throughout his life. He could never totally relax, and he found idleness unbearable. His mind had to be constantly in use.

Haber made several social commentaries that were as apt in his time as they are today. In particular, he believed that Germany had to vigorously foster science if the German-style welfare state were to remain in place.

Fritz Haber, likely in the early 1920s

The happy period ended in 1933. With the Nazis at the helm, Germany "was done with the Jew Haber" – in the words of Bernhardt Rust, the infamous *Kultusminister*. One is reminded of Einstein's jibes aimed at his good friend Haber, such as "that pathetic creature, the baptized Jewish *Geheimrat* [privy councilor]."[14] As an institute director, Haber found himself under the obligation to implement Hitler's "Law for the Restoration of the Professional Civil Service" of April 7, 1933, and fire all twelve (according to Stoltzenberg's count) of his coworkers of Jewish ancestry. Among these were Farkas, Freundlich, Kallmann, and Polanyi. Haber had soon realized that what remained for him to do was to help find jobs abroad for his dismissed coworkers – and to quit. He handed in his resignation letter on April 30, 1933 in protest against the Nazi law, in which he firmly stated that racial considerations were inconsistent with his approach to academic appointments. Haber's resignation fired up Max Planck who made an attempt at saving Haber's institute from dissolving, first by pleading with Rust, and subsequently by asking Hitler, in person, to intercede with the

Minister. As Planck later vividly recollected,[30] Hitler didn't budge, and embellished his refusal with a satanic tantrum worthy of a furious Führer.

As Stoltzenberg recounts,[3] the nets that Haber had spread on his own behalf brought him job offers from Japan, Palestine, France, and Britain. Haber decided for the last – and accepted the invitation of Sir William Pope to join him at Cambridge University. During his two-month stay there, he may have lived through his last happy moments in science: a reunion with some of his Dahlem coworkers. As Kallmann recollected "a scientific discussion [unfolded] more wonderful than you can imagine."[31]

Farewell gathering of Haber's institute (1933)

Haber also had a standing invitation from Chaim Weizmann to come to Palestine and take a position at the nascent Daniel Sieff Institute (later the Weizmann Institute of Science), in Rehovot. Weizmann, preoccupied with establishing Jewish academic institutions in Palestine, visited Haber in Dahlem in 1932 – and was impressed by Haber's Institute to the point that he modeled the Sieff Institute on Haber's. Moving to Palestine became a serious temptation for Haber in the last months of his life,[32] although his correspondence from that period suggests that he wasn't ready yet to give up on his German identity and homeland and move far away from either.[3] Rita Crakauer, Haber's secretary and "the soul of the Institute," later became Weizmann's secretary.

The harsh English winter that year took a toll on Haber's fragile health; he let himself be persuaded to set out on a south-bound journey, but not as far as Palestine, since a long trip could have further aggravated his condition. On his departure from Cambridge, Haber left behind a letter in which he spoke of the "chivalry from King Arthur's time still [living] among [English] scientists."[3]

The gravestone of Fritz and Clara Haber in Hörnli, Basel, Switzerland

In this time of humility and contrition, before leaving Cambridge, Haber drafted his testament. In it, he expressed his wish to be buried alongside his first wife Clara – in Dahlem if possible, or elsewhere "if impossible or disagreeable," and to have the following words inscribed on his grave "He served his country in war and peace as long as was granted him." Haber's son Hermann, the will's executor, later admitted that he "never found out how [Haber really] meant it."[33]

Renaming the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry after its founding director (9 December 1952). Karl Friedrich Bonhoeffer delivered at this occasion the speech he was forbidden by the Nazis to give in 1935.

Haber died of a heart attack on January 29, 1934 in Basel, Switzerland, on a journey "south," without a clear destination, in the presence of his family friend and former *Habilitant* in Freundlich's department, Dr. Rudolf Stern, who accompanied Haber at the time as his personal physician.[34] Haber was buried there. In accordance with his will, Clara's ashes were reburied beside his. There's no credo inscribed on the couple's gravestone.

Einstein's words read like an epitaph to Haber:[35]

> At the end, he was forced to experience all the bitterness of being abandoned by the people of his circle, a circle that mattered very much to him, even though he

recognized its dubious acts of violence. … It was the tragedy of the German Jew: the tragedy of unrequited love.

We may amend what Einstein had said: despite the ambiguity grounded in Fritz Haber's work, his love is no longer unrequited in Germany: on Max von Laue's suggestion, Haber's institute in Berlin was named, in 1952, after its founding director and incorporated, in 1953, into the Max Planck Society (founded in 1948).

Haber is also remembered in Israel: The Hebrew University of Jerusalem jointly with the Minerva Foundation established, in 1981, the Fritz Haber Center for Molecular Dynamics "for promoting Israeli-German scientific collaboration in all theoretical aspects of the field of Molecular Dynamics, with applications in chemical reaction dynamics, biophysics and biochemistry, materials science, spectroscopy, photochemistry and molecular electronics."[36] And the library of the Weizmann Institute of Science in Rehovot holds Haber's private book collection, donated to the institute by Hermann Haber.

In 1936, the Haber Library was inaugurated at the forerunner of the Weizmann Institute, consisting of "a unique collection of books" from Haber's personal library

Appendix: A partial list of Haber's accomplishments in science and society

(1) Haber laid the scientific foundations for the Haber-Bosch process for producing ammonia from its elements on an industrial scale. The work amounted to an exemplary service to humankind, as it resulted in providing the means for alleviating the world food production problem – perceived as a challenge at the time of Haber's discovery. It was key among the factors that enabled the world's population growth from 1.6 billion in 1910 to 7.4 billion today. An additional twist: China is the largest producer today; its opening to the West in the 1970s was likely driven by the need to allay an impending food crisis by importing the Haber-Bosch technology from the West.[37]

(2) Equally exemplary was Haber's directorship of the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry, which he developed into a center of pace-setting research at the intersection of chemistry and physics. At his institute, Haber created "an ideal environment for scientific research," as captured and, indeed, glorified by Michael Polanyi in his work in the philosophy/sociology of science, whose founder he is considered to be: "Polanyi was not only an accomplished physical chemist but also a leading figure in the philosophy of science whose works are still widely read. He was a leader in the shift in focus within history and philosophy of science toward issues of scientific practice rather than scientific method. ... As historian Mary Jo Nye has pointed out, the ideal organization of science that Polanyi [took into account] closely resembles his own descriptions of his experiences as a researcher at Haber's Institute."[28]

(3) Haber spent six good years of his life, from 1920 until 1926, toiling on the (secret) "gold from seawater" project, whose goal was to help Germany

to recover from economic ruin inflicted by WWI and the payment of war reparations to the victorious Entente powers. Although unsuccessful in reaching its original goal (the concentration of gold in seawater is too low), the project led to significant progress in the development of analytic methods.

(4) Unlike most of his colleagues, Haber embraced the Weimar Republic and openly supported its democratic institutions.

(5) Haber co-founded the forerunner of the Deutsche Forschungsgemeinschaft (DFG). By Haber's design, the Gemeinschaft was administered not by the state but by the academics: most of its executives were elected by the academic community based on their academic merit.

(6) In 1926, Haber co-founded the Japan Institute, to foster cultural and economic cooperation between Germany and Japan, which became a major importer of German goods, thereby offsetting the loss/weakness of European markets at the time.

(7) Haber's Jewish origins along with his democratic attitudes were a thorn in the eye of the Nazis, who treated him as a *persona non grata*. Pressured by the Nazis to dismiss the Jewish employees of his institute, Haber refused to budge and demonstratively resigned in protest.

(8) Some of the best known acts of civil courage on record by the German academic community during the Third Reich are related to Haber: Max von Laue's 1934 obituary for Haber published by *Naturwissenschaften*; Max Planck's appeal to the Nazi minister of education Bernhard Rust, and his subsequent personal plea with Hitler; the memorial service for Fritz Haber in Harnack-Haus in 1935.

(9) In his time, Haber was not just well-respected, but revered in many quarters, including significant segments of the German academic community. Among his most vocal admirers were: Max von Laue, Richard Willstätter, James Franck, Karl Friedrich Bonhoeffer, to name just a few. A precious "character testimonial" about Haber was provided by Rudolf Stern, who spent two years at Haber's institute as a researcher and acted as Haber's personal physician after Haber's forced emigration from Germany.

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