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Remembering Fritz Haber in the Year 2015

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Abstract
German chemist Fritz Haber (1868-1934) was one of the greatest chemists of the 20th century. He earned a PhD in organic chemistry in 1891 but then switched to other areas and carried out important research on a broad variety of chemical problems. He had exceptional scientific talent, versatility and a superb capacity to combine theoretical science with technical application. He was awarded the 1918 Nobel Prize in Chemistry for his invention of the synthesis of ammonia from its elements, which saved the world from mass starvation by providing nitrogen fertilizers. During World War I Haber, a staunch advocate of chemical weapons, became the leader of the German chemical warfare program, for which he has been controversial to this day. As a young man he converted from Judaism to Christianity. His family life was unhappy and at times aggrieved by tragedies. Haber's exalted existence in science and public life came to an abrupt end with the Nazis' rise to power and he died in exile in 1934 a broken man. 2015 marks the centenary of the birth of modern chemical warfare, reminding us of its protagonist Haber. Moreover, today, with the world's population at over 7 billion and the threat of mass hunger, we are also reminded of Haber's key contribution to food production. It is therefore fitting in 2015 to reflect on Haber's life and work.

Keywords
Ammonia synthesis, chemical warfare, World War I, ethics and morality in science

Mots-clés
Synthèse de l'ammoniac, guerre chimique, Première guerre mondiale, éthique et moralité dans les sciences

1. Introduction

By the end of the 19th century the world's population had reached ca. 1.6 billion, and mass starvation was looming on the horizon. Indeed, the eminent British scientist Sir William Crooks warned in 1898 that within a few decades millions would starve to death, because of the lack of food due to insufficient amounts of nitrogen fertilizers, which are essential for food production [1]. But all that soon changed, with the arrival on the scene of a German chemist named Fritz Haber (Figure 1) [2-6]. He became one of the greatest chemists of the 20th century and an eminent figure of modern Germany. His invention of the synthesis of ammonia from its elements hydrogen and nitrogen has allowed the production of nitrogen fertilizers in large quantities and has thereby saved billions from death by starvation [7]. During World War I (WWI) Haber became the *de facto* leader of the German chemical-weapons (CWPs) program [8], and his role as the "father of modern chemical warfare" has been controversial. Overall, Haber's life was an exalted one at the top echelons of science and in public prominence, but, as we shall see, in the end his story turned tragic.

Figure 1 : Haber in the laboratory in Karlsruhe (Archives of the Max Planck Society, Berlin).

The year 2015 marks the centenary of the birth of modern chemical warfare (CW) in which Haber played a leading role. Moreover, today, with the ever-increasing world population – now exceeding seven billion – and the resulting threat of mass starvation, we are also reminded of Haber's ammonia synthesis and the nitrogen fertilizers it provides for food production. It appears particularly fitting therefore in this year 2015 to remember Fritz Haber.

2. Beginnings and early career

Haber was born into a liberal Jewish family on December 9th, 1868, in Breslau, a city in the Silesia region of what was then Prussia, one of the many sovereign German states of the time (today Breslau is called Wrocław and is in Poland). In January 1871, just two years after Haber's birth, the German states were unified and modern Germany was created, in the form of the German Empire.

Haber's father, Siegfried, was a prosperous merchant in dyes and pharmaceuticals. Three weeks after Haber's birth, his mother, Paula (1844-1868, née Haber, she was Siegfried's cousin), died of complications of giving birth. Haber the child was thus raised without his mother's love and guidance. But Haber's father remarried and the stepmother cherished the young boy. It has also been suggested, however, that Haber's father may have held the son somehow responsible for the death of his beloved first wife, with potentially serious psychological effects on the son [5, 9].

Haber benefited from a generally good educational system. He attended St. Elisabeth High School in Breslau, an institution oriented toward the humanities, but mathematics and science, especially physics, were also part of the curriculum. Haber became interested in chemistry early in the high-school years. He attended the University of Berlin and the University of Heidelberg, and then fulfilled his required one-year military service, after which he returned to his studies, at the Technical Institute of Charlottenburg (Berlin). He became interested in organic chemistry, and in 1891 earned his doctorate at the University of Berlin with a dissertation entitled “Über einige Derivate des Piperonals” (On some piperonal derivatives) under the guidance of Carl Liebermann, the eminent dye chemist. Haber then spent short stints at several industrial companies and at universities in Zurich and Jena. During his stays at various universities, Haber was exposed to several eminent chemists, e.g., Robert Bunsen, Georg Lunge, and Ludwig Knorr.

While in Jena (1892-1894), Haber converted to Christianity and was baptized a Lutheran. Such conversions were not uncommon among young Jewish

Figure 2 : Clara Haber, née Immerwahr (Archives of the Max Planck Society, Berlin).

professionals and were often motivated by the desire to facilitate career advancement. In 1894 Haber moved to Karlsruhe in southwestern Germany where he had been offered a position as *Assistent* at the *Technische Hochschule Karlsruhe* (Karlsruhe Institute of Technology). He became interested in physical chemistry, chemical technology, and other areas of chemistry, and carried out investigations on a variety of problems, e.g., thermal decomposition of hydrocarbons, dye technology, gas technology, electrochemistry, thermodynamics of the reactions of solids, metal corrosion, the thermodynamics of gas reactions (publishing a successful monograph on this subject in 1905), etc. The variety of subjects he tackled was indeed impressive. He worked with great diligence, and many of his findings, e.g., in electrochemistry, were of great importance and received considerable recognition. He was eventually rewarded for his hard work and achievements: in 1906 he was appointed full professor ("ordinarius") and director of the Institute of Physical Chemistry and Electrochemistry at Karlsruhe.

In 1901 Haber married Clara Immerwahr (1870-1915) (Figure 2), a chemist and perhaps the first woman to earn a doctorate in chemistry in Germany. She too was born in Breslau into a Jewish family, and she too converted to Christianity.

3. Synthesis of ammonia – "bread from air"

The history, technology, and implications of Haber's synthesis of ammonia from its elements ("the fixation of nitrogen") is described in detail in the excellent volume by Smil [7].

By the beginning of the 20th century it was well understood that to solve the problem of nitrogen-fertilizer shortage the synthesis of ammonia from its elements was required. Haber first attempted the synthesis in 1904-05 but failed. In 1908 he tried it again, with financial support from Badische Aniline und Soda Fabrik (BASF), a large German chemical company, and this time he succeeded. The reaction of nitrogen and hydrogen to form ammonia represented considerable challenges that Haber, with the help of his able assistant Robert Le Rossignol, overcame by performing careful measurements and designing laboratory equipment (Figure 3) ingeniously suitable for providing a high product yield (despite the low ammonia content in the equilibrium product gas mixture) and able to withstand the extreme conditions required: a temperature of ca. 550º and a pressure of at least 200 atm. A catalyst was also necessary, and after many experiments osmium was found to be highly effective in that role. Haber's success in the fixation of nitrogen was a unique achievement that revealed his great abilities in combining theoretical chemistry with practical technical considerations. It is noteworthy in this respect that the eminent German chemist Wilhelm Ostwald (1853-1932, Nobel Laureate 1909) had tried to synthesize ammonia from its elements some years earlier but failed.

Haber publically announced his discovery on March 18, 1910. His achievement immediately catapulted him to the forefront of German science. In 1911 he moved to Berlin where he was appointed head of the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry, a prestigious institute created for him. He was also appointed professor at the University Berlin and was elected member of the Prussian Academy of Sciences. Eventually he was awarded the 1918 Nobel Prize in Chemistry for his synthesis of ammonia.

BASF had the rights to the industrial development of Haber's discovery and entrusted the task to one of their talented scientists, Carl Bosch (1874-1940). Upscaling Haber's laboratory method to an industrial process was an immensely challenging task, including finding an economically viable catalyst (osmium was not) and designing equipment that would endure the extreme conditions of temperature and pressure previously unheard-of in industrial chemistry. Nevertheless, Bosch and his team succeeded in a relatively short time and the first ammonia plant using the Haber-Bosch process, as Haber's invention came to be known in its industrial form, began operating in 1913. In 1931 Bosch was awarded the Nobel Prize in Chemistry for his work on high-pressure industrial chemistry.

The Haber-Bosch process brought immense benefits to Germany initially and eventually to the world since it made nitrogen fertilizers available in large quantities. The ammonia produced could be con-

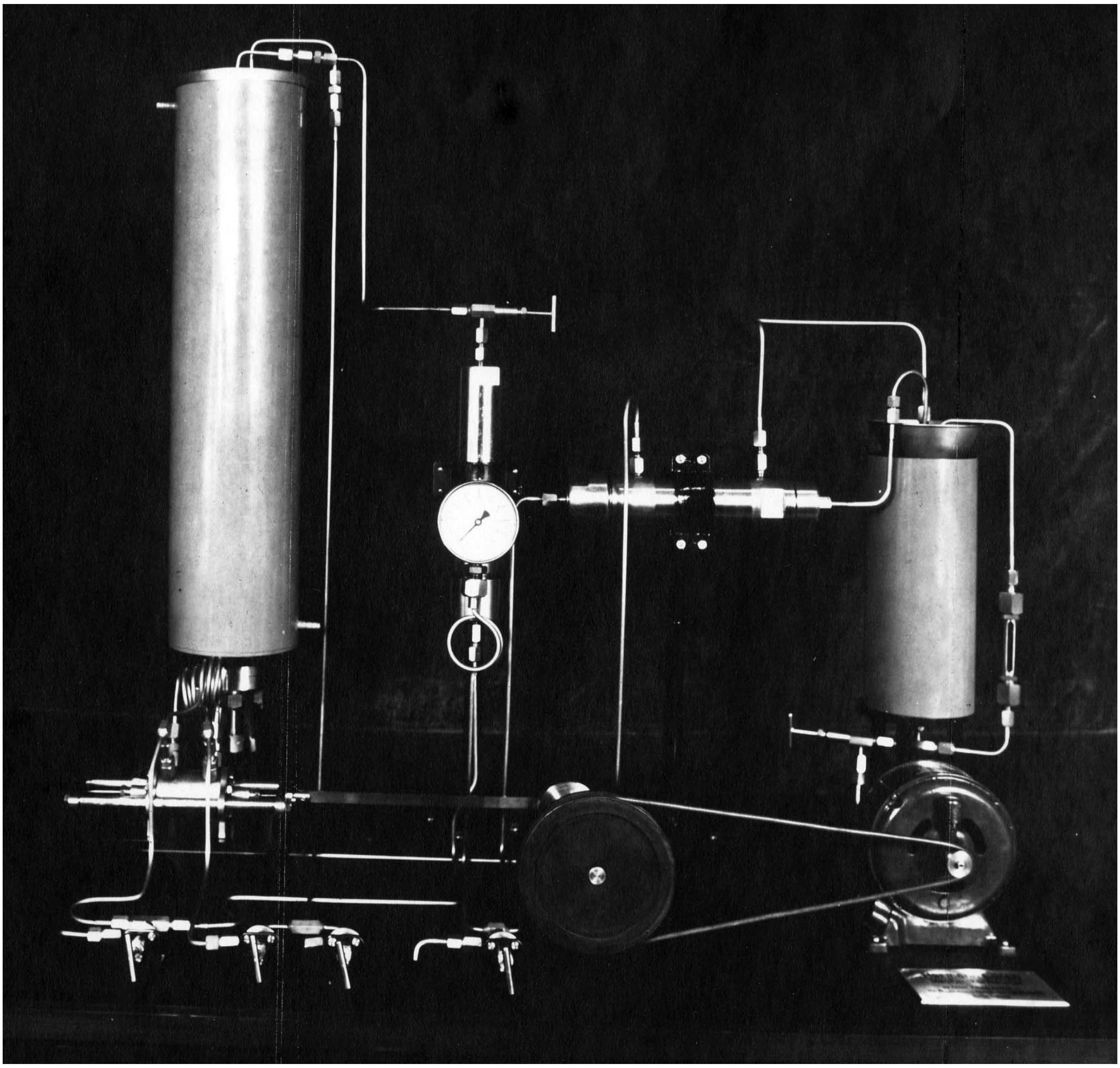

Figure 3 : Apparatus designed by Haber and Le Rossignol for the synthesis of ammonia Archives of the Max Planck Society, Berlin).

verted to a variety of fertilizers, e.g., urea, ammonium sulfate, ammonium nitrate, calcium nitrate, etc. Today the annual production of ammonia via the Haber-Bosch process exceeds 150 million tons.

There are, however, some negative aspects of the Haber-Bosch process. It is highly energy-intensive; its environmental impact, primarily the introduction of large amounts of nitrates into the soil, water, and air, is also of concern. Haber's invention has also had a particularly severe consequence, one that has caused death on an immense scale. This concerns the production of explosives and will be discussed in the next section. Overall, however, despite the negative aspects of the Haber-Bosch process, this is an indispensable technology today without which massive starvation and its catastrophic consequences would afflict humanity [7].

4. Haber in WWI

WWI began in the early days of August, 1914. Haber, along with many other German scientists, intellectuals, writers, artists, etc., and broad segments of German society, zealously endorsed the war policies of the German government and blamed the war entirely on the Allies. Haber's close friend Albert Einstein, on the other hand, strongly opposed fanatical nationalism, militarism, and the war specifically. Among scientists in 1914 Germany, however, those who agreed with Einstein were a very small minority.

To prosecute WWI, Germany needed nitrates for the production of ammunitions, since traditional explosives are all nitrates or nitro compounds, e.g., ammonium nitrate, “nitroglycerine” (glyceryl trinitrate), trinitrotoluene, etc. Germany (and other countries) obtained nitrates from South America (e.g., “Chilean saltpeter”, i.e., sodium nitrate), but with the outbreak of WWI, the British naval blockade shut down Germany’s importation of nitrates. It is estimated that at the outbreak of the war Germany’s reserves of ammunition and nitrates were sufficient for prosecuting the war for a few months, a year at the longest. But Haber’s ammonia synthesis solved that problem: in 1914-15 the industrial oxidation of ammonia to nitric acid was worked out by BASF, thereby providing the needed nitrates and nitro compounds, and Germany was thus able to prosecute the war for over four years.

Haber must not be held responsible in any sense for the eventual use of his ammonia synthesis for the production of explosives and the mass slaughter they have caused – his invention dated from well-before WWI and, in any case, he had no control over the further use of ammonia in the production of nitric acid. Moreover, it is not irrelevant here that explosives also have beneficial uses for society, e.g., in the construction of roads, mines, tunnels, bridges, etc.

Haber became involved in several important functions related to the war, e.g., as director of the chemistry program of the Ministry of War and as a highly effective intermediary between government, the military, industry, and the scientific community in matters of science and technology for war. However, his most visible – and highly controversial – role was as *de facto* leader of Germany’s CW program. He is in fact often called the “father of modern chemical warfare”. Haber was motivated in his activities during WWI by intense feelings of patriotism and nationalism.

The use of noxious or poisonous substances in war is millennia-old [10] but modern CW began in WWI [8, 11]. Soon after the beginning of the conflict, the war became immobilized, the infamous trench warfare began and neither side could advance. To get the war “moving” again, several German chemists, including Haber, proposed the use of CWPs, which would drive the enemy troops out of the trenches and thus make them more vulnerable to attack, thereby permitting the opening of breaches in the front. Several substances were suggested as CWPs, but eventually Haber’s proposal to use chlorine gas prevailed. Modern CW was born on April 22nd, 1915, when the German army released ca. 170 tons of chlorine gas from ca. 5 700 cylinders near Ypres, Belgium, on the western front. The gas was carried by the wind to the enemy lines, where it settled into the trenches since it is heavier than air. Chlorine is highly toxic, its effects being mainly respiratory, causing pulmonary edema, and poisoning by chlorine was often fatal in WWI. Estimates of the casualties caused by the chlorine attack vary widely and reliable numbers are difficult to obtain, but ca. 800-1400 fatalities and ca. 4 000 wounded appear realistic. The victims of this first attack were mostly French colonial troops but some Canadian units were also gassed. While the attack of April 22, 1915, could be considered a “success” in that it opened a 6-8-km breach in the front, the German army did not have sufficient numbers of troops stationed in the region to exploit the opening created by the chlorine.

Predictably, the Allies responded with their own chemical warfare, the British acting first, with a release of chlorine on Sept. 25th, 1915, near Loos in northeastern France. Other belligerents joined the CW, and eventually ca. 50 substances in total were used by the two sides as CWPs in the war. The “big 3” were chlorine, phosgene, and mustard agent, all three highly toxic.

While numerically the deaths and injuries caused by the CWPs in WWI were a small percentage of the overall casualties, they did produce a large physical and psychological impact. Estimates of the total number of casualties caused by CWPs in WWI vary widely, but it appears that ca. 91 000 fatalities and ca. 1.2 million injured troops may be realistic. Many of the soldiers injured by the poisons continued to suffer, often for a lifetime, from the effects of the chemicals, e.g., from respiratory

Figure 4 : Haber (pointing) somewhere at the front during World War I (Archives of the Max Planck Society, Berlin).

ailments, blindness, cardiac problems, cancer, etc. Health-care personnel were deeply disturbed by the effects of the poisons [12, 13]. The psychological injuries of CW in WWI were extensive and deep; the incidence of what was then called "shell-shock" or "neurasthenia" (termed post-traumatic stress disorder today) was significantly higher among gassed troops than among other soldiers [14].

During the war Haber converted his institute from a hub of fundamental chemical research to a center in support of the German war effort, focusing primarily on the research and development of CWPs and gas masks, and successfully recruited many capable scientists into his program. In addition, he was often present at the front as technical/scientific advisor for the deployment (Figure 4).

Haber strongly believed that Germany's use of CW would be decisive, that it would permit effective attack of the enemy, shorten the war, reduce the killing, and would eventually result in Germany's victory. Haber's son from his second marriage, Ludwig Haber, summarized Haber's (and some other scientists') views vis-à-vis the use of CWPs in WWI as follows: "A new weapon is not necessarily less humane than existing ones; therefore neither traditional practices nor the Hague Conventions are relevant, and accordingly questions of legality or morality do not arise." Such views are troubling. First, regarding the legality of CW, the Hague agreements of 1899 and 1907 unequivocally banned the use of poison weapons. The 1907 treaty was particularly clear-cut; in the Annex of its Convention [section] IV, article 23 stated the following: "Besides the prohibitions provided by special Conventions, it is especially prohibited– (a.) To employ poison or poisoned arms. " One does not need to be a legal expert to interpret this clause. By 1914 all but one (Italy) of the European belligerents of WWI were parties to the Hague agreements. As indicated above, however, Haber denied the relevance of The Hague agreements.

As for the question of whether the CWPs were "less humane than existing ones", it is clear that CWPs were particularly terrorizing, as discussed above.

Haber however does not appear to have expressed sympathy toward the victims who were killed or were condemned to life-long suffering from the physical or psychological wounds caused by the CWPs. He did not seem particularly concerned about the severe effects of the poisons and considered the CWPs no different from traditional ammunition.

However, when considering Haber's participation in CW, it is important to recognize that he was not alone: many chemists and other scientists, on both sides of the conflict, participated in some aspects of CW in WWI. Among distinguished German scientists who participated were the chemist Otto Hahn (1879-1968, Nobel laureate 1944), physicist James Franck (1882-1964, Nobel 1925), chemist and physicist Walther Nernst (1864-1941, Nobel 1920), and chemist Heinrich O. Wieland (1877-1957, Nobel 1927), to name only a few. On the Allied side, the list of eminent chemists participating included the Britons William J. Pope (1870-1939) and Harold Hartley (1878-1972); France's Victor Grignard (1871-1935, Nobel 1912) and Charles Moureu (1863-1929); the Americans Gilbert N. Lewis (1875-1946) and James B. Conant (1893-1978); and Italy's Emanuele Paternò (1847-1935).

It is essential to point out however that some scientists refused, on moral grounds, to participate in work on CWPs during WWI. Among them were such eminent figures as Sir Ernest Rutherford, New-Zealand-born British physicist (1871-1937, Nobel Prize in Chemistry, 1908); German chemist Hermann Staudinger (1881-1965, Nobel 1953); and German physicist Max Born (1882-1970, Nobel 1954). Staudinger, a professor in Zurich at the time, explained publicly his scientific and moral opposition to CW [15]. Haber responded by attacking him severely and accusing him of unpatriotic conduct. As Ludwig Haber wrote of their exchange, Staudinger's "dignified pacifism contrasts sharply with Haber's intemperate self-justification" [13].

Since the birth of modern CW in WWI, various poisonous weapons have been frequently used by armies, in war or against civilians, most recently in Syria in 2013, despite several international agreements banning CWPs. Terrorist groups have also resorted to the use of CWPs, one example being the release of the nerve agent sarin in the Tokyo subway in 1995 which killed a dozen people. Once unleashed, chemical weapons could not "be put back into the bottle". A terrible legacy of WWI.

5. Scientist, educator, human being

Haber was a scientist of great talent, versatility, and energy [16]. As we have seen, his doctoral work was in organic chemistry, but he quickly changed fields and engaged in other areas of chemistry and chemical technology. He carried out investigations and obtained important results in a variety of fields. In addition to the Haber-Bosch process, Haber's name has been retained in other named reactions. The *Born-Haber cycle*, developed by Max Born and Haber, is concerned with the formation of ionic crystals from the reaction of a metal (often a Group I or Group II element) with a halogen and is used in the calculation of lattice enthalpies, which cannot be measured directly [17]. The *Haber-Weiss reaction* was discovered by Haber and his assistant J. J. Weiss, an Austrian chemist [18]. The reaction, catalyzed by Fe^{3+}, generates hydroxyl radicals from hydrogen peroxide and superoxide ($\bullet O_2^-$) and can occur in cells and may therefore be a possible source of oxidative stress. In the field of inhalation toxicology, there is *Haber's Law*, a mathematical relationship between the concentration of a poisonous gas and the time the gas must be breathed to produce a given toxic effect [19].

In 1917 Haber initiated a program of pest control, i.e., the development of insecticides and pesticides, especially cyanide-based products, with the participation of scientists, industry, the military, and state authorities [20]. Haber led the program and played a decisive role in its development and success, and his institute was a major participant. There was in fact a critical need for pest control, in a variety of military and civilian settings. The work continued after the war and by the mid-1920s the operation had become a highly successful private company operating in many countries in Europe. By 1924 the company had developed an effective pesticide named Zyklon B, which contained hydrocyanic acid stabilized and adsorbed on a solid support. Importantly, a quick-acting warning agent was also included in the product in order to alert people to exposure [20].

As mentioned above, Haber was awarded the 1918 Nobel Prize for Chemistry for his ammonia synthesis. In addition, he received many prestigious awards and was honored by many scientific societies with medals, honorary memberships, etc.

By all accounts, Haber was an excellent teacher and research mentor. Scientists from many countries came to work with him and many spoke admiringly of his qualities as a teacher. He was a warm, generous, and devoted friend to many. His friendship with Richard Willstätter (1872-1942), the Nobel-laureate German chemist, was particularly close. Also noteworthy is the relationship between Haber and Einstein, a close but complicated friendship; the two men had similar backgrounds but radically different world view. For example, Haber was a fervent German patriot and deeply respectful of government authority while Einstein distrusted Germany and the powers of authority. Also, Haber ignored (until very late) the true character and implications of pervasive anti-Semitism in the society around him, in radical difference from the sensibilities of Einstein (and also of Willstätter). Nevertheless, despite such differences, and it is a poignant story, Haber and Einstein remained close friends to the end. It should be pointed out, however, that not everyone found Haber to be as charming as others claimed. For example, in Karlsruhe Staudinger described him as very impulsive and temperamental and later as "pompous and pontifical".

In his family life, Haber was less successful. His relationship with his father was tense. Siegfried wanted his son to join the family business but Fritz would have none of it. Moreover, the father resented his son's abandonment of the Jewish faith. In addition, as mentioned above, the psychological effect on Siegfried of his wife's death in giving birth to Fritz may have also played a role in the strained relationship between father and son.

Some aspects of Haber's conduct as husband and father were also troubled. As mentioned above, Haber and Clara Immerwahr married in 1901. In 1902 their son Hermann was born, and it was a difficult pregnancy and birth that left Clara exhausted. Soon afterward Haber left for a several-months-long scientific tour of the United States, to Clara's immense distress. Clara, an intelligent woman and a talented chemist, aspired to a career in science, but Fritz was unsympathetic and unsupportive of her desire for a life in chemistry. Gradually, Clara became depressed and bitter; in 1909 she expressed her distress at Fritz's domineering in a painful letter to her friend and doctoral-research director Richard Abegg [21]. When Fritz became involved in chemical warfare, their relationship further deteriorated: Clara was desperately opposed to her husband's work on poisons for war. In the middle of the night of May 1st-2nd, 1915, ten days after the first German chlorine attack at Ypres, Clara killed herself with Fritz's army pistol. She was found, covered in blood and dying, by 12-year-old Hermann.

Various interpretations of Clara's suicide have been given, but there is little doubt that her depression and suicide were at least in part rooted in her distress in the marriage, in Fritz's lack of comprehension and support for her career aspirations, and in her despairing opposition to Fritz's poison-weapons work. It is also relevant in this context that Fritz's and Clara's son Hermann committed suicide in 1946, and shortly thereafter one of Hermann's daughters, a young woman named Claire, also killed herself. Thus, three suicides in three generations.

Haber loved his son Hermann but his treatment of him was at times harsh. Hermann's dream was to become a lawyer, but Haber forced him to study chemistry and become a chemist. Hermann eventually did work in patent law but was never able to achieve his dream of becoming a lawyer. Haber ultimately conceded that forcing his son into chemistry had been a mistake.

In 1917 Haber remarried. His new wife was Charlotte (née Nathan), an intelligent woman who had no interest in science. They had two children, Eva (born in 1918) and Ludwig (1920-2004). The marriage became dysfunctional after a while; Charlotte felt unhappy because of Fritz's long absences and his domineering behavior, and there was also friction between Charlotte and Hermann. In 1927 Fritz and Charlotte divorced. As for the children from the second marriage, it appears that Haber was not very close to them and was perhaps even indifferent [22].

6. The rest of the story

On November 11th, 1918, the Armistice went into effect and the guns of WWI fell silent. WWI was a catastrophe of previously unimaginable proportions for humanity, including ca. 10 million military deaths and millions of civilian deaths. Moreover, the war was the likely cause of the "Spanish influenza" pandemic of 1918-19 which killed more than 50 million people, and a convincing case has been made that CWPs played a role in the emergence and spread of the virus of the pandemic [23]. Other consequences of the war included political and economic calamities and the irrational redrawing of some national borders, which in turn caused fierce ethnic or sectarian conflicts, some of which are still ongoing today. Examples in this regard that may be cited include, in the Middle East, the conflict in Syria; the civil war in Lebanon during recent decades; the struggle of the Kurds (dispersed in several countries in the region, e.g., Turkey, Iraq, Syria, Iran) for their unity and survival; the Shiite-Sunni conflict in Iraq; and, in Europe, the Serbia/Kosovo and the Serbia/Bosnia conflicts.

After its defeat in WWI, the German Empire collapsed, and in 1919 Germany became the Weimar Republic. In the wake of the war Haber appeared on the first Allied list of war criminals. He fled to neutral Switzerland, but soon the crisis passed and he returned to Germany. His patriotism undaunted, he now embraced the Weimar Republic and worked energetically to help rebuild German science and to assist German scientists in reconnecting with western colleagues after the alienation caused by the war; he vigorously promoted international scientific cooperation and worked tirelessly to reconvert his institute to fundamental chemical research and to build it into an internationally respected center of excellence in science. He succeeded eminently in many of these endeavors.

The Versailles Treaty of 1919, which settled the outcome of WWI, strictly prohibited Germany from undertaking CW-related activities of any kind, but such work nevertheless continued secretly, with Haber's participation. Some of this work resulted in the use of CWPs in Spain, the Soviet Union, etc. Another project Haber led – this one entirely legitimate –aimed to extract sufficient amounts of gold from sea water to pay off the exorbitantly high and crippling Allied war-reparations demands inflicted on Germany. However, Haber's studies found that the concentrations of gold in sea water had been overestimated in the literature by several orders of magnitude, which meant that recovery of gold in significant amounts was not feasible, and the project had to be abandoned.

On January 30th, 1933, Hitler became chancellor of Germany and less than two months later, on March 24th, 1933, the National Socialist (Nazi) party seized full control of power, unleashing the horrors of the 12-year Nazi nightmare. *Professor Doctor* Haber, a genius of German science, Lutheran, ardent German patriot, war hero, and great benefactor of Germany, became, practically overnight, just another Jew persecuted by a murderous regime. The Nazi reality in Germany had a deep effect on Haber, and unmistakable signs emerged that he began to rethink his life. In February 1933 (i.e., only days after Hitler's rise to power), he wrote to Willstätter: "I am fighting with diminishing strength against my four enemies – sleeplessness, the financial demands of my divorced wife, my increasing disquiet over the future, and the feeling of having made serious mistakes in my life". What mistakes? He did not explain, but some facts are known concerning changes in his outlook. For example, after life-long opposition to the Zionist movement and a dislike of its leader Chaim Weizmann, by 1933 Haber had changed his views, and a warm relationship developed between the two men. Haber even accepted Weizmann's invitation to work in a newly-created research institute in Palestine (but died before he could travel there). Another meaningful sign that Haber was rethinking his life was his last wish that his remains should be buried alongside those of his first wife Clara. Reacting to Haber's distress over the new situation in Germany, Einstein wrote to him: "I can imagine your inner conflicts. It is similar to having to give up a theory one has worked on all one's life. It is not so with me, because I never believed in it in the least".

On April 7, 1933, a new law went into effect in Germany for the "Restoration of the Civil Service" which required the dismissal from the civil service of Jews and other "undesirables". Haber, as professor, was a civil servant, but due to his frontline service in WWI, he was initially exempted from the stipulations of the new law for dismissal; however, he was required to dismiss the Jewish members of his institute. He resigned, taking early retirement. The Jewish members of the institute were of course dismissed, and Haber, to his great credit, exerted considerable efforts to find employment for them abroad.

But some ambiguities remained in Haber. When Hitler became chancellor of Germany, Einstein was traveling in the US. Einstein reacted to the rise of the Nazis by criticizing the regime for its cruelty and intolerance, criticism that created an uproar against him in Germany. In the Prussian Academy of Sciences, Max Planck (1858-1947, physicist, Nobel laureate 1918), one of the presidents of the Academy, informally polled the members of the Academy on the question of whether Einstein should remain member of the Academy. Most members, including, incomprehensibly, Einstein's close friend Haber, agreed with Planck's recommendation that Einstein should not remain a member, due to his "unpatriotic" criticism of the regime.

By the early 1930s Haber's health was in decline. He suffered from heart disease and was distressed by his inability, due to his failing health, to continue vigorous work somewhere outside Germany. In August 1933 he left Germany, accepting a visiting professorship at the University of Cambridge, England. He only stayed in England for a few months and in January 1934 returned to the continent. He was a broken man. On January 29th he died of a myocardial infarct in a hotel room in Basel, Switzerland. His remains are buried alongside those of Clara in a cemetery in Basel. A tragic end to the exalted life of a great figure of 20th-century chemistry.

A dreadful sequel to Haber's work concerns the pesticide Zyklon B developed in the early 1920s by the company that grew out of Haber's pest-control program (see above) [20]. Beginning in 1941, long after Haber's death, Zyklon B – without the warning agent – was used by the *SS* to murder more than a million victims in the gas chambers of the Holocaust, including some of Haber's own relatives. Some writers have held Haber responsible for the eventual use of Zyklon B in the Nazi extermination camps, but such accusations are entirely unjustified. Cyanide-based pesticides were developed before WWI in the US and subsequently in Germany because there was a considerable and legitimate need for pest control in agriculture and a variety of other settings. Moreover, it could not be suspected in the early 1920s that a vile regime that would rise to power in Germany in the 1930s would use a marketed pesticide as an instrument of mass murder in the 1940s. That said, however, there is little doubt that the massive use of CWPs in WWI was later a stimulating factor in the Nazi decision to employ poison gas for mass murder in the death camps. In this regard, it should be pointed out that hydrocyanic acid, the "active ingredient" of Zyklon B, was one of the CWPs used in WWI. Moreover, in the 1940s the Nazis also used another CWP of WWI, mustard gas, e.g., in the murder of Russian prisoners of war. In addition, another lethal gas, carbon monoxide (from truck exhaust), was used by the Nazis for mass murder in the Holocaust.

7. Assessing Haber

Haber was a scientific genius; he was endowed with exceptional scientific versatility and a superb capacity to combine theoretical science with technical application; he had seemingly unlimited energy for work; he firmly believed that science could solve many problems of society; his organizational abilities were remarkable; his excellence as a teacher was legendary; his outstanding skills as research mentor attracted students and scientists to his laboratory from numerous countries; many of his friends, students, associates, and colleagues expressed great respect, affection, and admiration for him for his support, concern, and friendship; he was tireless in promoting international science; he exerted considerable efforts to find work abroad for the Jewish members of his staff dismissed by the Nazis; etc. All of this clearly attests to an outstanding scientist of unique abilities and a human being with admirable qualities.

And yet, there is also considerable evidence of seriously negative facets in Haber's character and conduct. His obsessed patriotism, fanatical nationalism, and rigid Prussian militarism (Figure 5), fixations which underlay some of his deplorable actions, are troubling. His decision to inflict CWPs on humanity raises grave questions about his character and judgment. In this regard, he denied the clear prohibition of CWPs by The Hague agreements, and he did not acknowledge the appalling suffering the victims of his CWPs had to endure. It is also disturbing that after WWI Haber engaged in secret work on CWPs, in violation of the prohibition by the Versailles Treaty. Finally, for all his genius Haber entirely misjudged the promise and potential of CWPs: despite his adamant predictions, CW did not provide strategic advantage, did not produce victory, did not shorten the war, nor did it stop the carnage.

Thus, Haber is both an admirable and a troubling figure, with both laudable qualities and serious faults. Not surprisingly, opinions on him in the literature vary widely, from overall very positive evaluation to severe condemnation. In their essay on Haber [9], Hoffmann and Laszlo draw attention to the widespread tendency today to judge historical personalities, including Haber, "in context", that is, from the standpoint of the society and period the individual lived in rather than from the perspective of the present. Hoffmann and Laszlo warn that in-context assessment may, in their words, "become a smokescreen for relativism, and especially for moral relativism". Moral relativism is a philosophical view which holds that moral values are *relative* and particular to the specific time, society, and culture, i.e., that general or universal moral standards cannot be applied in judging human conduct in any individual case. An unfortunate result of moral relativism is its propensity at times to absolve individuals of transgressions considered execrable according to widely accepted moral standards. Hoffmann and Laszlo refuse to engage in in-context judging of Haber and conclude that he did not have the sensitivity and courage to take a moral stand and that therefore it should not come as a surprise if history judges him as morally lacking, regardless of his outstanding achievements as a scientist. Supporting these conclusions by Hoffmann and Laszlo is the crucial fact that *some* scientists of Haber's time and place did have the comprehension and courage to take a moral stand and resist the madness, e.g., Einstein, Staudinger, and Born.

To understand Haber, we search for the roots and foundations of his conduct and character. Clues to his personality and behavior have been sought from psychological factors connected to circumstances of his birth, upbringing, family relationships, etc. [3, 8, 9], but such analysis is inherently difficult and has not produced significant insights into Haber's thinking or actions. Potential influences on Haber's character by historical factors and economic, political, and social conditions in Prussia and Germany have also been discussed [6, 24]. Finally, Smil has provided a relevant comment on the difficulties inherent in attempts to understand Haber: "We have his scientific writings, his patents, his lectures on science and research management, many of his letters, numerous recollections of his colleagues and students, and the memoirs of his second wife. But we will never know the actual mix of motives that animated his life and the deepest feelings that marked both his ascents and falls. Only in a few of his letters did he offer unguarded self-appraisal. Everything else, including his feelings about the suicide of his first wife, he kept to himself. We will never truly know him." [25].

In conclusion, Fritz Haber's work has had both immensely beneficial and gravely injurious consequences for humanity, and his life was a stunning mix of triumph and tragedy. We remember him as a great, flawed, and enigmatic figure of 20th-century chemistry and history.

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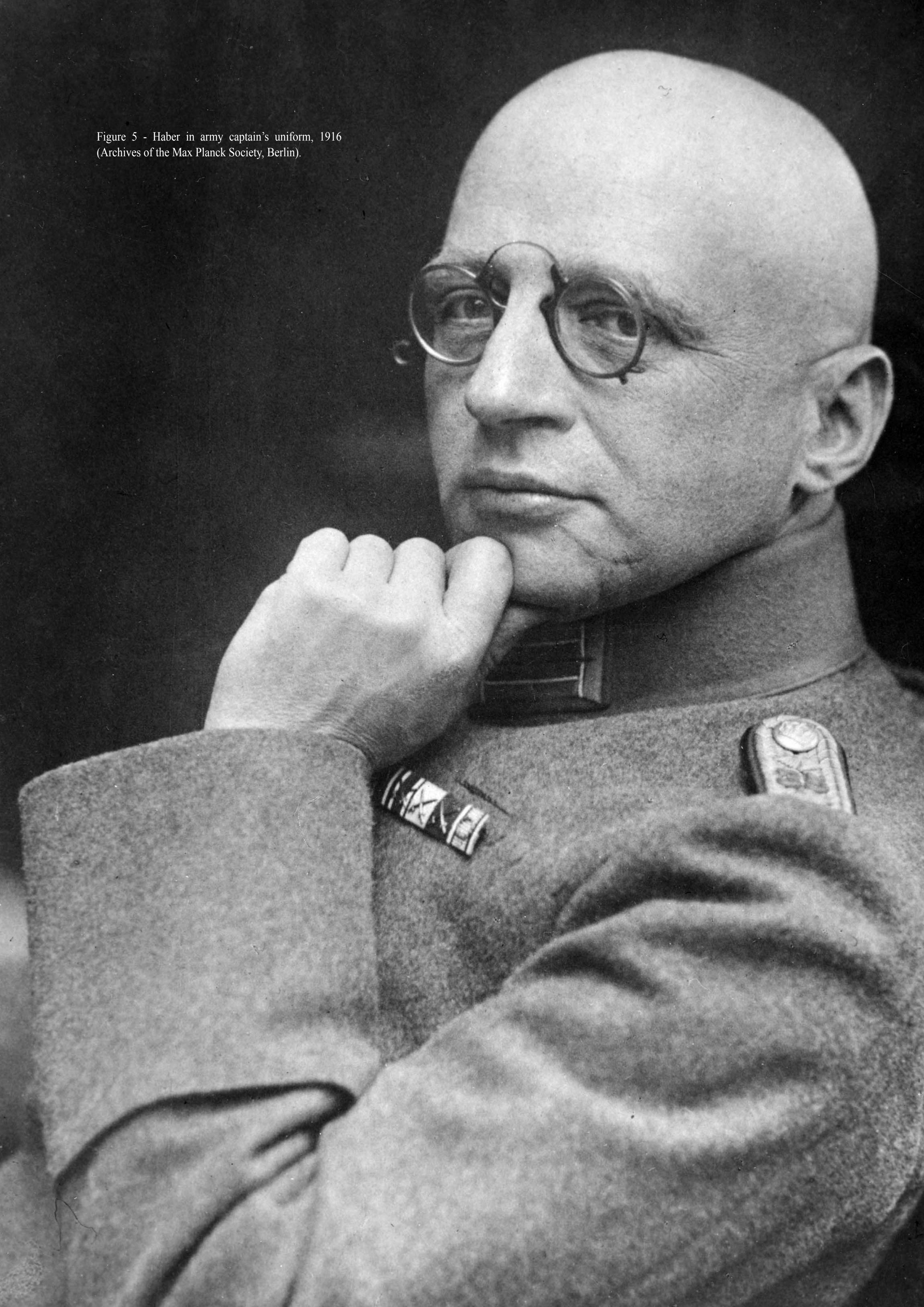

Figure 5 - Haber in army captain's uniform, 1916 (Archives of the Max Planck Society, Berlin).

Fritz Haber

Inventa un catalyseur pour extraire des km cube
D'azote de l'air. il fixa le gaz
Sur des copeaux de fer ; les industries allemandes
Déversèrent des tonnes d'ammoniac,

Et d'engrais, des mois avant que les lignes maritimes
Du salpêtre et du guano chiliens ne soient coupées,
Juste à temps pour entreposer poudres et explosifs
Pour la Grande Guerre. Haber savait comment les catalyseurs

Fonctionnent : un catalyseur n'est pas innocent, non,
Il collabore pour éventrer la barrière ou saper
Quelque colline critique, pour tendre des mains moléculaires
Aux partenaires au stade le plus difficile

De la réaction, les rapprochant, facilitant
La conclusion et la rupture des liaisons.
Le catalyseur, régénéré, s'empresse de s'entre-
mettre aussitôt ; une livre bon marché du

Fer bichonné par Haber peut produire un million de livres
D'ammoniac. Son excellence le conseiller Haber du Kaiser
Wilhelm Institute s'imagina en catalyseur
Pour finir la guerre ; ses armes chimiques

Apporteraient la victoire dans les tranchées ; brûlures
Et cancers du poumon valaient mieux que balles
Explosives, ou shrapnel. Lorsque ses hommes dévissèrent
Les bouchons des caissons de chlore, et que le gaz verdâtre se répandit

Sur l'aurore des champs d'Ypres, il prit soigneusement
Des notes, oubliant les lettres sombres de sa femme.
Après la guerre, Fritz Haber rêva à Berlin
De mercure et de soufre, l'œuvre alchimique

Précipitant le monde, se changeant eux-mêmes.
Il se demanda comment extraire les millions
D'atomes d'or de chaque litre d'eau,
Transmutant la mer en la pile de lingots

De la dette de guerre allemande. Et bien, le monde,
Il changeait ; à Munich, on pouvait entendre
Les bottes des chemises brunes, on payait
Un milliard de marks pour manger. Un catalyseur

C'est ce qu'il trouverait à nouveau, et trouva - lui-même
À Bâle, ville étrangère sur les rives de son
Rhin, il se retrouva, son excellence
Haber le protestant, maintenant le juif Haber, dans la ville
Du roué Paracelse, un homme altéré et mourant.

Roald Hoffmann, extrait de *Memory Effects*,
Calhoun Press : Chicago, 1999, pp. 76-77.
Traduction de Brigitte Van Tiggelen,
publiée avec la permission de l'auteur.

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[22] In a telephone conversation in August 2010, Haber's daughter Eva Lewis expressed to the present author that her father had been a distant and indifferent figure in her and her brother's lives, and she added, "We hardly ever saw him". Very recently Eva expressed similar sentiments to another interviewer, see: Everts S., Who was Fritz Haber? *Chem. & Engin.* News, **2015**, *93(8),* p. 18. See also: Charles D., *Master mind: The rise and fall of Fritz Haber, the Nobel laureate who launched the age of chemical warfare*, HarperCollins, **2005**, p. 214.

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