1918

NOBEL LAUREATE

Fritz Haber

1868–1934

Following two years in which no Nobel Prize in chemistry was given, Fritz Haber was named to receive the prize for 1918. Because of the estrangements and travel problems deriving from World War I, the presentation of the prize to Haber and some other laureates did not take place until June 1920. That ceremony was unusual in that no member of the Swedish royal family participated, because of the recent death of Crown Princess Margaret. It was unusual as well, for a reason that will be discussed later, because the award to Haber generated considerable controversy, something rare in cases of the physical sciences. Fritz Haber was born on December 9, 1868, in Breslau (now Wrocław) in lower Silesia (now western Poland, but at the time, part of Prussia, the largest state in the German Reich). He died of a heart attack in Basel, Switzerland, on January 29, 1934, following a period of poor physical health coupled with intense emotional stress.

The citation for his Nobel prize was "for the synthesis of ammonia from its elements", but as this brief account of his career will reveal, his interests and accomplishments spanned a remarkably wide range of chemistry and physics. In his 1939 book, *The Social Function of Science*, J. D. Bernal declared Haber to have been "the greatest authority in the world on the relations between scientific research and industry." This may have been an overly generous summation, but it does direct attention to Haber's exceptional skill in spanning the sometimes

unbridgeable gap in the physical sciences between theory and application.

He was not a narrow specialist: As a young man, Haber acquired a classical education, with emphasis on literature and philosophy, and throughout his life he sustained an interest in and love of the humanities. He was a brilliant conversationalist and a fun-loving companion, often given to expressing his sentiments in light verse or to participating in fun-filled skits for the amusement of his friends and colleagues. Yet for all that, Haber's life was beset with, and unquestionably saddened by, a number of disappointments and tragedies that cannot have failed to darken his private life.

The first such tragedy, which occurred at the time of his birth, was the death of his young mother, who was also his father's first cousin. His father, Siegfried, a well-to-do manufacturer's agent and something of a public figure in Breslau, eventually remarried and had three daughters; he retained toward his son an attitude that has been described as severe and sometimes harsh. Young Fritz was provided with excellent preparatory schooling and then pursued his university training in the "nomadic" way then customary in Germany. It included a semester at Berlin, with instruction in chemistry from A. W. von Hofmann; a year and a half at Heidelberg, with chemistry from R. W. Bunsen; and then, after a period of military service, a year and a half at the Charlottenberg Technical College in Berlin. At this last institution Haber first undertook experimental chemical research, under the direction of Karl Liebermann. This work was in organic chemistry and culminated in a thesis submitted in 1891 for which, after the usual examination, he was awarded a doctorate.

Thereafter followed a period of seemingly aimless activity, quite out of character with his otherwise energetic and sharply focused career. In the span of just over a year he successively tried three industrial jobs, mostly in companies belonging to his father's friends. He then spent a semester at the Federal Technical College in Zurich where, under the guidance of Georg Lunge and to his subsequent great advantage, he learned much about the technological application of scientific principles. Then followed a disastrous few months of working in his father's business, after which he accepted a position as junior assistant to Ludwig Knorr, an aging professor at the University of Jena. Following a year and a half of uninspiring work there, he sought and eventually obtained in 1894 an assistantship in the department of Chemical and Fuel Technology at the Fredericiana Technical College in Karlsruhe. This proved to be the turning point in his career; he remained at Karlsruhe until 1911, by which time he had become a very eminent chemist worldwide.

His professor at Karlsruhe, Hans Bunte, had suggested as a topic of research the breakdown of hydrocarbons at elevated temperatures. Haber applied himself to this with skill and energy and within two years had entirely reshaped the interpretation of the thermal decomposition of such compounds and given new insight concerning the strength of bonds linking atoms in hydrocarbons. His work would come to be of great value in understanding the "cracking" of hydrocarbons during the distillation and other heat treatment of petroleum. By 1896 Haber could publish a habilitation thesis summarizing this work: "Experimental Studies of the Decomposition and Combustion of Hydrocarbons". On the strength of this, he was granted status as a *Privatdozent*.

Soon after his arrival at Karlsruhe, Haber struck up a warm friendship with Hans Luggin, a former pupil of Svante Arrhenius and the only physical chemist among Haber's colleagues. Physical chemistry was still then a comparatively recent extension of the subject, whereby chemical events could be rationalized through unifying theoretical principles, especially transfers of energy. Luggin was able to assist Haber in interpreting his experimental results with the hydrocarbons and thereby aroused the latter's interest in mastering the applications of physical chemistry. This proved to be work with an intellectual component that appealed more to Haber than synthesizing and characterizing organic compounds, and so he redirected his subsequent research efforts. Having at last found his true *métier*, Haber applied himself to the mastery of physical chemistry with an intensity and commitment not previously seen in his work but that would become characteristic of most of the rest of his career.

His new interest led to investigations in electrochemistry, of which the first concerned the reduction of nitrobenzene, a common organic substance, at the cathode of an electrochemical cell. Recent work by others appeared to have shown that a variety of different products were obtained thus, according to the conditions used. Haber was able to show, not only in this case but in general, that the reducing power of a cathode depended on its electrical potential, and that, by varying the latter in this instance, he could demonstrate the reduction of nitrobenzene in stages. He also showed that secondary (nonelectrolytic) reactions among the primary products formed by electrolysis accounted for some of the substances identified following the passage of current. Thenceforth, the control of cathodic potential was established as a requirement for carrying out specific reduction processes electrochemically.

In recognition of the value of this work Haber was promoted in 1898 to a professorship *extraordinarius* (comparable to an associate professorship). In the same year he published an important book, *Outline of Technical Chemistry on a Theoretical Basis*. The significance of this book is suggested by its title, in that it sought to provide a theoretical basis for many of the essentially empirical practices in new industries for carrying out chemical processes by the expenditure of electrical energy. It must be kept in mind that the generation and transmission of electric power on a scale sufficient for industrial purposes was not carried out until late in the 1880s, and thus that in 1898 "technical electrochemistry" was still comparatively undeveloped.

Of the numerous electrochemical researches conducted by Haber and his students, three others can be briefly mentioned here. One was a study of the reversible oxidation/reduction of hydroquinone/quinone, the balance of which was dependent on electrode potential and on hydrogen-ion concentration in solution. Based on this investigation later came, at the hands of Einar Biilman, the quinhydrone electrode as an indicator of hydrogen-ion activity. Another, which arose from Haber's studies of phase-boundary potentials, was the development of the glass electrode, which served the same purpose. The widespread use of the latter was delayed for want of a convenient device for measuring null-current balances, but Haber and Klemensiewicz carried out pH titrations with this device and a quadrant electrometer as early as 1909. The third important electrochemical investigation, which arose as an unexpected outgrowth of some inconclusive work on fuel cells, led to the development of an electrode responsive to gaseous oxygen. Haber immediately applied this to the study of combustion reactions and to the estimation of the free energies for oxidation for various elements and compounds. Free-energy values, through the application of thermodynamic reasoning, made it possible to evaluate the degree of completeness of chemical reactions.

Linked to this development in his experimental researches came Haber's next book: *The Thermodynamics of Technical Gas Reactions* (1905). It was widely acclaimed, and an updated English translation appeared three years later. Haber provided a clear exposition of thermodynamic theory and its application and a critical compilation of established thermodynamic data whereby yields of most technically important gas reactions could be calculated for a wide range of temperature. The authors of a later classic treatise on thermodynamics, G. N. Lewis and M. Randall, described Haber's volume as a "model of accuracy and critical insight."[1] Shortly after the publication of Haber's book, Walther Nernst, a fellow countryman, proposed what he called his "heat theorem". This principle made possible the calculation of the absolute value of free-energy change (and hence the yield) of a chemical reaction from measured thermochemical data. (See the chapter on Nernst, Nobel Laureate in 1920.) It is a fact that in Haber's book much of the evidence upon which Nernst based his conclusions was also discussed, but Haber was not prepared to make the leap of faith inherent in Nernst's proposals; for the English version of his book Haber did include an account of the heat theorem.

The work on gas reactions led directly to Haber's most celebrated achievement: the synthesis of ammonia from the elements. At the turn of the century, threats of a worldwide shortage of nitrogen compounds were circulating. Their importance as agricultural fertilizers had been appreciated since Liebig's time, and an increasing sophistication in weaponry was fueling demand for chemical explosives, which required nitric acid for manufacture. Many chemists were attracted by the possibility of converting ("fixing") atmospheric nitrogen into usable compounds, and a few such were produced but not by very practical methods. In 1904 Haber was engaged as a consultant for one such scheme and undertook to measure the equilibrium constant, which, at a particular temperature, enabled a calculation of the degree of conversion for the following reaction:

$$N_2(g) + 3H_2(g) = 2NH_3(g)$$

The slowness of the reaction required work at high temperatures, and it required a catalyst, for which he chose iron. The yields were disappointingly low and did not encourage further investigations. Two years later, Nernst calculated the equilibrium constant for the same reaction by means of his heat theorem; he found a value appreciably different from Haber's, and subsequently confirmed experimentally the yields of ammonia predicted by his calculations. Haber responded with a new series of improved measurements, the results from which were

[1]Lewis, G. N.; Randall, M. *Thermodynamics and the Free Energy of Chemical Substances*; McGraw-Hill: New York, 1923.

still at variance with the conclusions reached by Nernst. Neither of the Prussian prima donnas was disposed to give way to the other on the question of who was right in this case. Nernst argued, quite properly, that as his experimental studies had been made with the gases under pressure (about 50 times atmospheric) the resulting greater degree of conversion to ammonia should increase the certainty of his estimates of the equilibrium constant compared to Haber's, measured at atmospheric pressure. For him, as well, the integrity of the heat theorem could be at risk if his results were disproved.

But Haber refused to be talked down, and following a stormy session at a meeting of the Bunsen Society in Hamburg in 1907 at which Nernst had challenged his results publicly, he returned to Karlsruhe determined to have the last word. With the help of his assistant Robert le Rossignol, and his mechanic Kirchenbauer, an apparatus was built to conduct experiments at 30 atmospheres of pressure. His new measurements validated his earlier results at atmospheric pressure. Nernst, for once, was wrong and ultimately had to acknowledge an error in calculation. Haber and his associates had actually gone much further than merely gaining an intellectual victory. They had discovered catalysts other than iron, and they had literally built a machine capable of making liquefied ammonia on a continuous (not batch) basis. Eagerly the Badische Anilin und Soda Fabrik (BASF) took on the transformation of this laboratory prototype into industrial-scale production.[2]

Other work conducted by Haber at about the same time dealt with the water-gas equilibrium and with processes occurring in flames. As a homely example of the sort of system he examined, one concerned what takes place in the flame of the ubiquitous Bunsen burner. Here the familiar blue cone was unexpectedly shown to be the cooler part of the flame and to be made up of the gases inherent to the water-gas equilibria, in the proportions appropriate to the prevailing temperature. In the outer zone, the burning of hydrogen and carbon monoxide in the surrounding atmospheric oxygen provided most of the heat of the flame. Haber's numerous successes in the study of technically important gaseous processes by thermodynamic reasoning led to his appointment as professor and director of a new Institute of Physical Chemistry and Electrochemistry at Karlsruhe in 1906.

The year 1911 marked the establishment of the Kaiser Wilhelm Society for the Advancement of Science (which would later become

[2]Haber, 1971.

the Max Planck Society), comprising a number of research institutes, mainly in Berlin. These were to involve the cooperation of scientists, industry, and government in the prosecution of original research, with the obvious intention of sustaining for Germany the scientific and technological leadership achieved throughout the previous half-century. One of the institutes, proposed with Haber in mind as director, was for Physical Chemistry and Electrochemistry. Such an appointment could not fail to attract Haber's interests and enthusiasm, and so in 1911 he left Karlsruhe to immerse himself in the planning and specifying of the facilities for the new and prestigious foundation, the official opening of which took place in 1912. Once installed there, Haber had to finish odds and ends in the ammonia work and to resume studies begun in 1908 with G. Just, studies concerned with the emission of free electrons during certain chemical reactions. This kind of process focused on events taking place at the level of individual atoms and involved assumptions and explanations comparable to those introduced only a few years previously by Einstein to account for the photoelectric effect. Such work was later to earn worldwide acclaim for Haber's institute and to create the new subdiscipline of chemical physics.

But first came the Great War. When hostilities in Europe broke out on August 1, 1914, the German plan called for a quick attack to encircle Paris and to defeat France in a matter of weeks. By mid-September the plan had been thwarted, and the antagonists were reduced to the near stalemate of trench warfare. It soon became apparent that Germany was ill-prepared for a long struggle; the country lacked stocks of essential war materials and, being virtually surrounded in Europe, had no means of securing these. The ever-patriotic Haber had volunteered his own and his institute's services on behalf of the national struggle and was soon put in charge of mobilizing Germany's scientific and industrial resources.

One urgent problem was the production of nitric acid with which to manufacture explosives. The customary raw material had been sodium nitrate, of which the only significant source was Chile. Haber advocated and worked for much augmented production of synthetic ammonia by his own and other available methods, and he facilitated huge increases in the manufacture of nitric acid by the catalytic oxidation of ammonia. Most authorities agree that, but for this rapid expansion of the means for producing these chemicals synthetically, Germany's pursuit of the war would have foundered much earlier owing to a lack of explosives and essential agricultural chemicals.

Another part of Germany's war effort with which Haber's name has been inextricably linked, and for many people tarnished, was his involvement in the introduction of poison gas on the battlefield. The rationale for doing so was to try to break the deadlock of trench warfare. At first, lachrymators and irritant powders were dispersed from bursting shells, but then Haber proposed the use of chlorine gas liberated from cylinders at the battle line. This was first done in the second battle of Ypres, in April 1915. Inevitably, retaliation followed a year later when the French introduced phosgene for the same purpose. The gas respirator became an indispensable component of every soldier's kit, and the range of chemical agents introduced by both adversaries grew and grew. In 1916 Captain Haber was appointed director of the new Chemical Warfare Service of the Ministry of War, and his institute in Berlin was wholly involved in developing new and "better" poison gases.

The war dragged on until Germany finally capitulated late in 1918. It left in its wake a legacy of economic disasters, political upheavals, and unprecedented social changes. It also left Haber diminished in health and spirit, a condition from which he never fully recovered for the remaining 15 years of his life, yet in that period he continued to work hard for his country and for science. The terms of the Treaty of Versailles (1919) required Germany to make unrealistically large reparative payments to the countries violated. One consequence was that the German mark suffered almost uncontrollable devaluation in 1923, and because of that Haber's efforts to rebuild and broaden the scope of his research institute were delayed and limited. In due course, sufficient funding was provided to afford it a few years of glory before its key men were dispersed.

Linked to the problem of war reparations was a somewhat quixotic quest to which Haber devoted a great deal of time and effort throughout a period of almost eight years, the object of which was to extract a great quantity of gold believed to be dispersed throughout the oceans. He was convinced that this wealth could be extracted by chemical means and could be made available to his government to discharge its international obligations. He based his plans on a number of supposedly reputable analyses, but when the methods of recovery fell dramatically below expectations he was obliged to develop and perfect his own method of microanalysis. By this he was able to show that the true gold content of the oceans was about one-thousandth of the supposed value. The project proved to be a costly and unproductive adventure from which Haber emerged deeply chastened.

Readers with no more than a passing interest in the history of physical science will be aware of the dramatic changes brought about early in the 20th century by the recognition of the validity of quantum phenomena, the internal structure of atoms and molecules, the interpretation of atomic and molecular spectra, and so on. Little wonder then that the Kaiser Wilhelm Institute, into which Haber as director had brought promising new men after the war, became one of the important centers for further investigation of these new ideas. Among the prominent men conducting research there (during the periods indicated) were Herbert Freundlich (1919–1933), whose theoretical and applied work did much to rid colloid and surface chemistry of empiricism; Rudolf Ladenburg (1921–1931), a physicist of wide-ranging interests but principally remembered for his work on the effects of electronic excitation on the properties of gases; and Michael Polanyi (1922–1933) who made significant contributions, including the application of quantum theory, to the interpretation of chemical reaction rates. Haber himself, after the gold fiasco, carried out with K. F. Bonhoeffer a number of important investigations dealing with chemiluminescence in flames and its interpretation in terms of band spectra of molecules and radicals involved in or formed by the combustion process.

As well as the experimental work in progress in the Institute, a feature that never fails to be mentioned by all who experienced it was the fortnightly Colloquium. Accounts of work in progress in-house or lectures from invited speakers, many of whom were chosen from outside the Institute or outside physical chemistry, were presented formally. The level of the papers read was of such a high caliber that the meetings drew a wide audience from all the scientific establishments in the city. Haber had a rare genius for summing up or clarifying the discussion, and the events were lively and inspiring.

But all this came to an abrupt end in 1933 when Haber, Freundlich, and Polanyi tendered their resignations to protest against the zealotry of the National Socialist Party, which had come into power in January of that year. In April laws were enacted forbidding the employment of Jews in government establishments (except in some circumstances). Although a Jew, Haber actually qualified for exemption from this enactment, but he and his colleagues acted on a point of principle. It is now commonly agreed that this Nazi policy robbed German science of its indisputable world leadership prior to the 1939–1945 war.[3]

[3]Mendelssohn, 1973; Nachmansohn, 1979.

Haber left Germany in the summer of 1933. In London he arranged to meet Chaim Weizmann, the great chemist, Zionist, and future president of the State of Israel, with whom he discussed future plans. Weizmann already then had an interest in establishing a research institute at Rehovot in Palestine (now in Israel), and he suggested that a senior position for Haber could be created there. However, before a firm decision on that proposal was made, Haber spent the autumn of 1933 in the laboratory of Sir William Pope (who had worked with him in Karlsruhe). In January he set off for Switzerland, en route to Palestine and a decision about his future. Regrettably, he died of a severe heart attack in Basel.

As remarked previously, Haber's life was tinged with stress and sorrow. He married twice, yet each marriage ended in divorce because his almost obsessive commitment to his work appeared to rule out normal domestic relationships. He continued to see each wife on a friendly basis subsequently. His first wife (a chemist) bitterly opposed his promotion of poison gas, and finally in the spring of 1915 took her own life in protest. Not surprisingly, in view of the effort that he had invested, he took very hard his country's defeat in the war and all the ensuing difficulties. His receipt of the Nobel Prize in 1920 was the occasion for numerous protests and snubs. French laureates who were to have attended this postponed ceremony boycotted the event owing to Haber's presence there. In America a swarm of editorials and letters challenged the suitability of the award to Haber; the point of many of these protests was not the gas warfare, but the extended duration of the war made possible by the manufacture of nitric acid from synthetic ammonia. Many people (Rutherford, for example) continued to censure Haber for years. His failure to harvest gold from the oceans was a massive disappointment to him, but the ultimate sorrow must have been his decision to surrender the directorship of the research institute in Berlin, which literally had been created for him in 1911. Time and the horrors of a subsequent, even more deadly world war have largely dispelled such contemporaneous attitudes, and we are able today to see Haber as a man of rare scientific genius and integrity.

W. A. E. MCBRYDE
University of Waterloo

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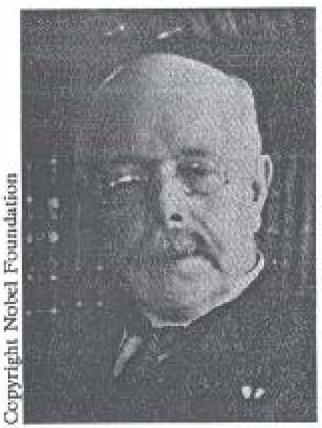
1920

NOBEL LAUREATE

Walther Hermann Nernst

1864–1941



In 1920 the Nobel Prize in chemistry was awarded to Walther Hermann Nernst. The citation for the Nobel Prize was "in recognition of his work in thermochemistry." On the basis of modern usage, the term *thermochemistry* too narrowly describes his interests and activities, which are more appropriately denoted by *chemical thermodynamics*. Actually, in his education and subsequent career he could justifiably claim as much affinity with physics as with chemistry, and certainly many of his pupils earned great distinction as physicists. Nernst, though a few years younger, fell in with a group of scientists—van't Hoff, Arrhenius, and Ostwald were the most evident leaders—who sought to embody chemistry with a theoretical basis, and by so doing created the new subdiscipline of physical chemistry. It was in this frontierland, in which chemists and physicists had found common ground at last, that Nernst was to apply his skill and imagination to formulate new ideas and in turn to attract new talent to share in the advance of physical science.

Nernst was born on June 25, 1864, in Briesen, a small town in what was then West Prussia and that now lies within Poland. He died on November 18, 1941, at his country estate "Zibelle", near Muskau in lower Silesia (also now part of Poland). His ashes were returned to Germany in 1949 and are buried in Göttingen. In the town where