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Military Strength and Science Come Together: The Kaiser's Chemists at War

With deepest thanks to our Imperial Lord we may praise the fate which allowed the Kaiser Wilhelm Society to arise at just the right time. . . . Create, organize, discipline: in this triad of German spirit and German labor, military strength and science come together.
—Adolf von Harnack, Annual Report of the Kaiser Wilhelm Society, April 1916

In short, modern warfare is in every respect so horrifying, that sensible people can only regret that it draws its means from the progress of the sciences. I hope that the present war will teach the peoples of Europe a lasting lesson.
—Emil Fischer, December 1917

"The outbreak of war overtook us like a natural disaster," Willstätter wrote later.[1] In the first few days of August, the timetables of the Schlieffen Plan pulled most of the bright young chemists from their quiet laboratories and sent them out to chase the dream of victory on the fields of Belgium, France, and Russia. Emil Fischer took what was in those days an unusually realistic view of the war, fearing that Germany's opponents were strong enough to prolong the war into the next summer; after the Schlieffen Plan died at the Marne, he extended his prediction to at least one to one and a half years. His expectations corresponded to the most pessimistic assumptions of the group around Walther Rathenau and Karl Helfferich, with whom Fischer was to agree in other areas as well.[2] Nevertheless Fischer had come to accept the war as an inevitable response to the military threat from abroad, especially from the East. If Germany must fight, he reasoned, it was better to do so before the foe grew even stronger. His reasoning, evidently influenced by exaggerated reports in the German press that summer, approached the idea of "preventive war" circulating among leading circles of the German government and military during the early part of 1914, rather than the "defensive war" line with which the war

was officially justified in August.[3] Under the circumstances Fischer and his colleagues found no joy in contemplating their nearly deserted laboratories and lecture halls. Instead they sought out ways to make themselves useful in the war effort.[4] In so doing they discovered that science, and especially chemistry, could play a vital role. The era of the total war was at hand.

In the Service of National Propaganda: Defining Aims and Means

The pressure of events soon obliged Fischer to abandon the illusion that scientists might somehow continue to enjoy a feeling of international solidarity above the conflict. Reluctantly he put aside his correspondence with erstwhile friends on the other side, though he took the opportunity to send Sir William Ramsay greetings via a Swiss scientist when Ramsay asked for help in locating a relative missing in action.[5] As passions on both sides heated up, Fischer and other prominent scientists nevertheless successfully resisted proposals to retaliate against scholars on the other side, either by striking their names from the lists of honorary members of German organizations or by returning scientific honors to the foreign organizations that had conferred them.[6] "You cannot do anything, gentlemen," Einstein recalled Fischer telling the Berlin Academy at one point, probably in July 1915. "Science is and remains international."[7] Yet Fischer had been dealt a hard blow by his old friend Ramsay's vitriolic attacks on German chemists and the German chemical industry in the spring of 1915. With regret Fischer observed that Germany's opponents, like many of his own colleagues, lacked his enthusiasm for scientific supranationalism.[8]

One German scholar whom Fischer scorned for ultranationalism was Wilhelm Ostwald, a leader of the Monist League, which before the war had been pursing a left-liberal campaign of anticlericalism in Germany. Ostwald had even stood on the same platform with Karl Liebknecht, the revolutionary Social Democrat, to promote a "mass strike against the State Church," a movement to strangle official religion by having people renounce their confession (confessionless people paid no church tax).[9] Ostwald then considered himself an internationalist, if not a socialist, and he was involved in various international scientific and intellectual organizations. At Ostwald's suggestion, Ernest Solvay, the Belgian industrialist who had just sponsored the first international conference of physicists, had just agreed to provide the capital for an international chemical laboratory in connection with the recently organized International Association of Chemical Societies (to which Ostwald belonged as a German representative). The initial plans were being made when the German armies marched into Belgium, after which the outraged Solvay excluded the Germans.[10] Ostwald meanwhile drowned his internationalism in patriotic

enthusiasm, transforming his anticlerical "Monistic Sunday Sermons" into nationalistic outpourings in support of the war effort and eventually of a peace of conquest. Perhaps his Baltic German origins helped to sharpen his feelings against the Russians. Adolf von Harnack, who was also an Easterner, eventually reacted in this way and by 1917 supported "the most extensive goals" of German war aims "by way of 'liberation' in the East."[11]

In January 1915 Emil Fischer was to write a sharply worded letter to Professor Peter Klason in Stockholm, complaining about Ostwald's Monistic activities there and his unofficial peace proposals. These, along with the public pronouncements of other German scholars, damaged the German cause as Fischer saw it by creating the appearance that "Germany pursues boundless plans. That is all nonsense." In this as in other letters to neutrals, Fischer spoke out for German moderation and for the rationality of the great majority of the German people.[12]

The need to convince the neutrals of Germany's essential righteousness placed Fischer among the ninety-three scholars, scientists, and intellectuals who signed Ludwig Fulda's manifesto "To the Civilized World" in October 1914. In the interest of solidarity Fischer aligned himself with Ostwald, Adolf von Harnack with Ulrich von Wilamowitz-Moellendorf, Richard Willstätter with the anti-Semitic physicist Wilhelm Wien, and all aligned themselves with the cause of German militarism. It was a step that many of them later had cause to regret. After the war Fischer even circulated a countermanifesto among the original signers.[13] As Willstätter recalled, "The professors were convinced that Germany bore no responsibility for the war and that war had taken it by surprise. . . . The war appeared to us to be a defensive one. The search for causes and connections went no deeper."[14] Let the manifesto speak for itself: "*It is not true* that Germany is guilty of having caused this war . . . that we trespassed in neutral Belgium . . . that our troops treated Louvain brutally . . . that our warfare pays no respect to international laws. . . . *It is not true* that the combat against our so-called militarism is not a combat against our civilization. . . . Were it not for German militarism, German civilization would long since have been extirpated. . . . The German army and the German people are one."[15]

A sizable contingent of those who subscribed to these sentiments had also been active in the establishment of the Imperial Chemical Institute Association, the Kaiser Wilhelm Society, and its various institutes. All three authors of the original Imperial Institute memorandum were there, Walther Nernst signing in addition to Fischer and Ostwald. Among the others, Fritz Haber signed as well as Willstätter; Paul Ehrlich and Carl Engler were on the chemical institutes' advisory board. Two other directors of Kaiser Wilhelm Institutes, Max Rubner and August von Wassermann, added their names. While four of the six active directors of Kaiser Wilhelm Institutes joined the proclamation, only one other chemist's name appears among the ninety-three: Fischer's mentor Adolf von Baeyer, whose father had been a Prussian general. These men were indeed the "Kaiser's chemists."

Emil Fischer did not merely subscribe to Fulda's manifesto, he distributed it to neutral colleagues abroad—though perhaps not quite so enthusiastically as Ostwald, who ordered one hundred copies through Fischer in October.[16] Unfortunately Fischer soon discovered that the effect was as much negative as positive.[17] Needless to say, the scientists in countries opposed to Germany reacted with outrage. The result that Fischer had sought to avoid now came to pass. French scientific organizations cut their ties with the Germans, dropping German honorary members from their rolls. "My French colleagues never forgave me for having been one of the signers of the Proclamation of the Ninety-Three," Willstätter recalled.[18] Few seemed able to resist the passions unleashed by the conflict; when Albert Einstein circulated an alternative proclamation with pacifist and internationalist sentiments, he got only four signatures, including his own.[19]

The illusions that led the German middle classes to support this war had captured Fischer as well as Ostwald and his more chauvinistic colleagues, less fanatically perhaps but just as surely. Carl Duisberg had written Fischer in August 1914, full of pessimism because the government's policy of embargo on dyes and drugs had cost his industry its world economic dominance, which might take another decade to restore, but equally filled with outrage against the British, "who are chiefly to blame for all the misery."[20] Fischer in reply forecast a long and bitter economic as well as military struggle, but with one consolation when it was all over. Germany could then create a continental bloc capable of competing with the United States. This was the war aim for which Emil Fischer, like so many of his colleagues, was to expend his talents and energies during the next few years. Essentially the same idea was at the basis of the war aims program that Chancellor Bethmann-Hollweg and his circle, including Walther Rathenau in particular, worked out during August and September 1914.[21] One of the salutary attractions of such a *Mitteleuropa* dream for the German scientists might well have been that if a political-economic unit emerged from the war capable of generating revenues on the same order as American capital, then the fund-raising woes they had been experiencing for the previous decade would finally be over. Whether or not "unlimited possibilities" in chemistry might require imperial conquests after all, however, it quickly became obvious that the conquests would require chemistry.

In the Service of the War Economy: Facing the Crisis in Raw Materials

Initially the war brought research in Germany nearly to a standstill. Two of the four main teaching sections of Fischer's institute were closed in the fall semester, and his own private laboratory was all but deserted. Fischer had just one regular private assistant and four coworkers—including two older men and one woman—where before he would have had several times as many. Overall, Fischer estimated in November that the scientific institutes held only about one-third their normal capacity of students.[22] The pause in German science would allow the United States to take the lead, Fischer told an American chemist.[23]

In the early days of the war the same story had been true of the Kaiser Wilhelm Institutes, with what Richard Willstätter recalled as the "devastation of scientific life at Dahlem."[24] Most of the students and assistants went to war. Thus Fritz Haber's institute, apparently one of the hardest hit, lost all but five members of its staff.[25] Beckmann's institute lost Otto Hahn and many assistants.[26] Under the circumstances, those remaining naturally looked for ways to use their scientific talents in war work. Fritz Haber and Richard Willstätter asked Adolf von Harnack in the first days of August whether the government might need them. Harnack inquired but, as Willstätter recalled, "no use could be made of us." To Willstätter this reflected the lack of technical imagination that the social outlook of the Prussian army had produced at the top of the military hierarchy. Initiatives in the application of science to military problems were to come from outside the military bureaucracy.[27] Emil Fischer was one of the scientists most prepared to participate. While the transition from peace to war may have been traumatic for him, it was not illogical, as he was to acknowledge in November 1914 to a former subordinate then in the army. "I am actively engaged in the business of war. No wonder, because our science interacts very strongly with economic as well as military life."[28]

The administrative committee of the Kaiser Wilhelm Society conferred on August 12, 1914, with the directors and senior members of the institutes, with the society's two principal architects in Berlin, and with two representatives of the Prussian Education Ministry. How, they asked, was the society to act in the war? It was agreed that the institutes should try to pursue their original aims as far as possible within their original budgets, paying salaries to those staff members in service. The society would continue to construct institutes already begun. "It was also indicated," according to the official minutes, "that individual institutes had already begun to take up the solution of questions which would be of direct significance for the war." The administrative committee authorized Wassermann an unlimited budget for biomedical work that he had undertaken in his institute on behalf of the War Ministry, but for the time being it left initiatives to the individual directors rather than attempting to develop a coordinated strategy for war-related research. Prepared by years of struggling to justify their own institutes, the society's chemists already realized how they might be most useful; "Dr. Emil Fischer, Dr. Beckmann, and Dr. Just [representing Haber's institute for physical chemistry] spoke of new problems presented to chemical and physical research by the complete alteration of our raw materials supply."[29]

The problems arose from the illusion that the war would be over in a few months, an illusion that had made it easy to neglect economic preparations before the war began. Of course it had also been a politically necessary illusion, since any other expectation would have implied a lack of confidence in the army while necessitating a greater degree of peacetime bureaucratic involvement in economic planning than the businessmen or even the military authorities were willing to accept.[30] The Imperial German government had of course made some preliminary decisions regarding the wartime trade policy in strategic raw materials, but they do not appear to have been consistent. Thus in 1911 the Schlieffen Plan had been modified to omit the originally intended invasion of the Netherlands. The latter, a major European inlet for overseas raw materials such as oil, was then supposed to be "a country whose neutrality allows us to have imports and supplies," in General Helmut von Moltke's words.[31] Yet the government also made a decision to impose an embargo on products like organic chemicals as well as potash, in which Germany held a near world monopoly. Although damaging to the enemy in the short run, in the long run it was counterproductive—as Emil Fischer foresaw—because it seriously damaged German trade and provoked retaliation from the neutrals. A partial relaxation of the embargo soon followed, especially on behalf of the United States, but within a few months after the outbreak of war, the British blockade would almost wholly cut off trade again.[32]

It is clear that the Kaiser at least took an interest in the Kaiser Wilhelm Institute for Coal Research and in Fritz Haber's ammonia synthesis,[33] but despite the views of Germany's foes, it does not appear that before the war either the military authorities or the government bureaucrats responsible for economic planning systematically examined ways to use chemical substitutes for imported raw materials that might be cut off in time of war. If the problem was considered at all, its solution was left up to private industry.[34] Fritz Haber, on the other hand, had a long-standing interest in the question and the possible uses of chemistry in time of war. Willstätter recalled later that Haber was one of the few professors who as early as 1909 "spoke of the relationship of chemistry to war and emphasized that it is coal for which countries will wage war."[35] He had even tried to establish

a connection with the Prussian War Ministry when his Kaiser Wilhelm Institute for Physical Chemistry opened in 1912, but the ministry rebuffed him.[36]

The ministry's attitude began to change rapidly after the war began. By mid-August the shortage of vital imported light metals became obvious, especially copper for the electrical industry and for the production of brass shell-casings. The Th. Goldschmidt chemical firm in Essen had already requested and received an exemption from military service for its research director, Friedrich Bergius, one of whose projects was to attempt to produce synthetic oil from coal. On the day after the war conferences in the Kaiser Wilhelm Institute, Walther Rathenau was commissioned to set up and direct the ministry's War Raw Materials Department, which he had himself proposed.[37] Both Emil Fischer and Fritz Haber were to work with this department on the raw materials problem during the next few months.

Within a week after the military reverse at the Marne, Emil Fischer approached Francis Kruse for help in bringing the Kaiser Wilhelm Institute for Coal Research into the war effort.[38] To do this he had to get Franz Fischer, who had been conscripted at the beginning of the war, back from the Russian front. When Kruse could make no impression on the military authorities, Emil Fischer was obliged to use the Kaiser's influence via Valentini's civil cabinet, which in October contacted the military cabinet to set in motion the relief of Fischer and various subordinates. During the fall and winter they began to come back to Mülheim.[39] Franz apparently took charge of his institute again in late November, when Emil wrote to advise him on the institute's wartime program. The first task would be to coordinate between the War Ministry and the cokeries, giving them technical assistance where necessary to keep up their production of by-product ammonia for explosives and fertilizers.[40] A second task was to find a substitute source for the sulfates normally extracted from imported Spanish pyrites to produce sulfuric acid, the most important industrial reagent. Perhaps by-products from other processes such as coking or the manufacture of explosives could be applied to this purpose.[41] (Eventually gypsum was chosen as the most likely source.) By 1916 the institute would also be working on the synthesis of gasoline from coal and the extraction of oil from coal tar, in accordance with the program that Emil Fischer had outlined in 1912. In 1915 Fischer had already recommended that the government support Bergius's work on the same problem.[42]

Well before Franz Fischer had returned from the front in 1914, Emil Fischer had been working to encourage the output of ammonia and other coking by-products. On September 22, 1914, the coal producers assembled in Essen to hear Fischer presenting the ugly numbers that added up to a critical gap between production and requirements for toluol (for

TNT), ammonia, nitric acid, gasoline and oil, coal and coke. The most serious problem was contained in the fact that whereas Germany normally produced 360,000 tons of ammonium sulfate per year, accounting for about two-fifths of German consumption of nitrates, production had been halved since August simultaneously with the drastically increased military demands for nitrates and the cutting off of overseas imports, which normally accounted for more than half the German consumption. Synthetic sources covered less than a tenth of German needs in 1913. The BASF had promised to produce 30,000 tons of synthetic ammonia by the Haber-Bosch process in 1914 (by the end of the war its annual production would reach 200,000 tons or half of Germany's needs) and the Lothringen Mining Company was using the process developed by Wilhelm Ostwald to produce a small quantity of nitric acid from ammonia contained in coking gas. All these capabilities would have to be expanded as rapidly as possible if the German military machine were not to grind to a halt within a few months for lack of explosives. On October 1 Fischer reported in detail to the Prussian War Ministry on the situation.[43]

At the meeting in Essen, Fischer asked Carl Duisberg to bring the BASF into contact with the acting director of the coal research institute, Professor Hilpert, so that the latter could get information on the development of processes for oxidation of ammonia to nitric acid for explosives. The BASF was experimenting with a process that would compete with Ostwald's Lothringen process, and it naturally wanted to protect its investment. At first its directors refused to see Professor Hilpert, but at Duisberg's urging they finally agreed to receive him.[44] The work of coordination began.

In the following weeks Emil Fischer held a lively correspondence on the ammonia question with scientists and industrialists including August Thyssen, Fritz Haber, Carl Bosch of the BASF, Dr. Adolf Haeuser of Hoechst, Carl Duisberg of Bayer, Gustav Krupp von Bohlen, Walther Rathenau, and Gustav Aufschläger, presiding over the newly established War Chemicals Company.[45] In December he mediated between Rathenau and Haber, in order to settle a difference of views on the raw materials problem so that the common work could continue.[46]

The coordination of ammonia production was in part spurred on by Wichard von Moellendorf, an apostle of state-capitalist enterprise who was one of Rathenau's subordinates in the AEG and then in the War Ministry. Moellendorf, from whom the idea of a war raw materials department is said to have stemmed, apparently hoped to use the ammonia program as a precedent for wide-ranging military and bureaucratic coordination of the war economy.[47] By 1916 the interaction of bureaucrats with industrialists would reach a degree such that Adolf von Harnack could proclaim the ultimate replacement of private enterprise by a "mixed," state-capitalist economy. It was not a conclusion with which Emil Fischer

could agree, despite or perhaps because of his participation in the programs that made such a goal possible. He was particularly disappointed in the shortcomings of the Imperial Office of the Interior with regard to economic mobilization for war. Harnack's criticism of private enterprise for war profiteering added insult to injury for the business members of the Kaiser Wilhelm Society, who forced Harnack to issue an eventual retraction.[48]

The chemists' successes led to the Kaiser Wilhelm Foundation for Military and Technical Sciences (*Kaiser-Wilhelm-Stiftung für Kriegstechnische Wissenschaften*), established at Haber's initiative with the support of Koppel and Friedrich Schmidt in 1916, and in 1917 attached to the War Ministry. This organization had no research facilities of its own; rather, it was intended to promote and coordinate war-related work by scientists in academic institutions as well as in the Kaiser Wilhelm Institutes. Fischer and Haber took leading roles in the organization, Fischer as the head of the foundation's Expert Committee I, one of six in various areas. His responsibility was to coordinate the work of seven other chemists dealing with problems in the production, use, and substitution of munitions, foodstuffs, and related war materials.[49]

By the end of 1917 Fischer was to perform the following militarily significant services: experiments on explosives and gas bombs, on the deodorizing of corpses, on the utilization of fatty acids as food, on synthetic tanning agents, on the use of straw as fodder, and on alternate sources for sugar. Other chemists in the Kaiser Wilhelm Institutes followed Emil Fischer's lead and the model of the successful Haber-Bosch ammonia synthesis in attempting to develop chemical substitutes for essential products in short supply. Thus the German *Ersatz* program was born. Ernst Beckmann, for example, belonged to a committee for substitute textile materials and explored the refinement of straw for fodder, though without much success.[50] Other projects were apparently undertaken more in the sense of private business ventures. Into this category might be placed Richard Willstätter's research, in cooperation with the Th. Goldschmidt firm in Essen, which led to a process for producing dextrose sugar from wood cellulose as a means of increasing the food supply.[51]

Naturally a great deal of work was done in industry as well as by individual academic scientists outside the Kaiser Wilhelm Institutes. Only a general impression can be given of these efforts to develop substitutes for strategic materials through chemical synthesis. For the most part, the time and resources were too short to produce adequate *Ersatz* materials, except for those derived from processes (like Haber-Bosch) perfected before the war. Even the Bayer firm's synthetic rubber process, developed before the war but abandoned as too expensive, could not fully meet German needs.[52] The Bergius coal-oil conversion process, also patented

but not developed before the war, was never brought into production, and the German government lost interest in it toward the end of 1917 as sources in the East were secured through conquest.[53] As the exigencies of war fostered coordinated research in entire branches of German industry, however, the Kaiser Wilhelm Institute for Coal Research became the model for many similar research centers for strategic materials after 1916: a second coal institute in Silesia, an iron and steel institute, a nonferrous metals institute, a synthetic textile chemistry institute, and a leather institute. None actually opened, except on a small scale in provisional rooms, until 1921–22.[54] Thus although they were too late to affect the outcome of the war, the war accelerated their creation and hastened the integration of industry, science, and military strategy.

In the Service of Weaponry: The Origins and Dilemmas of Chemical Warfare

Whereas the work of the Institute for Coal Research and its analogues was to be mainly in the area of strategic minerals, the Dahlem complex gradually assumed the character of a research center for tactical military science and technology. The man who took the lead in this area was Fritz Haber. Despite his earlier rebuffs, Haber was determined to play a significant role in war work. In a logical outcome of his prewar research, he began by embroiling himself in the ammonia question, in which he also represented the BASF on occasion in the War Ministry. The logic of *Ersatz* led to problems of munitions, and eventually to poison gas. Eventually Haber, who because of his Jewish origins could not obtain a commission in peacetime, headed the section in the War Ministry dealing with all phases of gas warfare, but he was never promoted above the rank of captain. His opposite number in the British Army, also a professional chemist, was made a general.[55]

The bankrupt Schlieffen Plan catapulted the German high command into a situation on the Western front without any precedent in their military traditions. With their lines thinly held and reserves of munitions used up, they confronted an unbroken line of trenches against which conventional weapons "often failed completely. A weapon had, therefore, to be found which was superior to them but which would not excessively tax the limited capacity of German war industry in its production."[56] In other words, innovation in weaponry arose not simply from the unforeseen tactical problems of trench warfare, but also from the crisis in strategic raw materials that produced the *Ersatz* program. Thus the new chemical weapons were to be *Ersatz* themselves—a substitute for conventional munitions. Recognizing this, the generals swallowed their pride and turned to the scientists whose offers of help they had earlier spurned.[57] Haber and

other chemists, including Carl Duisberg and Walther Nernst, were asked to devise means of chemically clearing the trenches. In October and November 1914, while Haber's institute was trying unsuccessfully to discover a more powerful explosive for artillery shells, Duisberg and Nernst, using the Bayer facilities, developed various grenades, shrapnel shells, and firebombs. Very early, they began to study nonlethal irritants like sneezing gas or tear gas, which seemed to be acceptable under the international Hague Conventions of 1899 and 1907. Duisberg and Nernst thus developed a gas-filled shell intended to make the enemy trenches uninhabitable only long enough to clear the way for the German shock troops. In the fall and winter of 1914, both sides used such substances in limited quantities, but with no obvious military success.[58]

Chief of staff General Erich von Falkenhayn was disappointed. Although he ordered production of the tear gas shells in December 1914, he also asked the German scientific experts to produce a shell that would either kill or permanently sicken the enemy, forcing them to clear their trenches for an extended period of time after a bombardment. Duisberg believed that if the problem could be solved at all, it would require the cooperation of "all suitable forces in the German Empire," including the chemical institutes in Dahlem. He asked Falkenhayn to consult Fischer, in the hope that Fischer would convince the military authorities not to pursue the task. Fischer was indeed dubious, out of his fear of shortages in raw materials. If the other side could outproduce Germany, the weapon would cut the wrong way. Yet when Duisberg learned that Fischer knew of a substance—probably phosgene—which would kill "even in extraordinarily great dilution," he was all in favor of trying it. Within two weeks Duisberg had set his staff to work on improving the production of phosgene, and by February the Germans had begun to test it in mixtures with tear gas. Initially, however, this extremely deadly gas was not yet available in sufficient quantities or with the proper equipment to use it in combat and protect advancing German troops.[59]

In Dahlem, after a disastrous accident that killed one of his assistants, Fritz Haber had come up with the simple, ingenious solution that induced the Kaiser to break with military tradition and give him a captain's rank: poisonous chlorine gas, to be released under proper wind conditions from canisters in the German lines. The prevailing winds on the Western front went the wrong way, however, which led Fischer to wish Haber "failure from the bottom of my patriotic heart; for if he succeeds, the French will soon figure it out and then turn the tables, which will be very easy for them to do." Duisberg agreed, but the German high command disregarded these doubts, as well as possible objections on the basis of international law or their own discomfort with an "unchivalrous" weapon. Their main question was not whether, but only how soon the English

and French could develop the technical facilities that would allow them to "turn the tables." When Duisberg estimated the time at five or six months, Falkenhayn agreed to an "experiment," code-named "Disinfection." Haber told his colleagues in Dahlem that poison gas was more humane than high explosive, and that it might even save lives by shortening the war.[60]

As Fischer had foreseen, wind conditions proved to be a key limitation, causing weeks of delay in the spring of 1915 and the repeated abandonment of planned attacks. Other practical problems also arose, and for some time the gas canisters caused casualties only to the Germans themselves. Perhaps out of frustration, Falkenhayn began shifting his reserves to the Eastern front on April 17 for a major campaign in Galicia. Then, on April 22 before Ypres, "Disinfection" finally worked, producing initial success far beyond what anyone expected; but given the change of plans and lack of reserves and munitions, it could not be followed up by any sort of large-scale offensive. The generals had thrown away the unique psychological and tactical advantage of attacking an unprotected, unprepared enemy.[61]

Allied retaliation came five months later, right on schedule, but even less effective than the initial German attacks.[62] For the remainder of the war, gas weapons became increasingly more sophisticated as both sides raced to find new solutions to the trench warfare problem. Haber continued to lead the German chemical warfare unit, and he gradually expanded the group under his command.

By 1917 Haber had 1,500 people on his staff, including 150 scientific workers in a wide variety of fields who had been recruited, drafted, or militarily reassigned from other positions. All the Kaiser Wilhelm Institutes in Dahlem as well as some other academic facilities set aside space for his work, and his total budget was fifty times that of the prewar Kaiser Wilhelm Institute for Physical Chemistry. Centralization made not only for greater efficiency, but also for the greater secrecy that the military authorities wanted, as they distrusted scientists in the academic institutions. Militarily, the relative isolation of Dahlem and its wealth of talent and facilities for interdisciplinary biological, medical, and chemical research thus made it an ideal place to work on the complex problems of gas warfare, even though its transformation into a military research center was "a purely wartime measure" that was not intended to be permanent.[63]

The organization also placed perhaps too much responsibility on Haber himself. As an academic chemist and specialist in physical chemistry used to directing a relatively small, autonomous institute, managing an operation of this scale and diversity gave Haber some serious problems that he was not fully able to solve. Although he was good at organizing and planning the war effort, he had difficulties dealing with some of his

colleagues, perhaps owing to some of the same problems that had divided him from Beckmann, or Beckmann from Willstätter. Yet his biggest problems arose from inability to delegate sufficient authority to his subordinates. As with many German full professors directing big institutes before the war, Haber thus wasted much of his prodigious energy, and toward the end of the war a sense of the approaching disaster helped wear him down. He also had to live with the tragic memory of his wife's suicide in the spring of 1915. She had shot herself with his service revolver, perhaps in part out of despair over Haber's role in developing gas warfare.[64]

Haber and his group nevertheless achieved a great deal, and they kept the lead in what became a race to develop and introduce new defensive measures and new forms of poison gas. On the defensive side, he enlisted his friend Richard Willstätter to solve the problem of developing an effective military gas mask. Before leaving Dahlem in 1916 to take over Baeyer's place in Munich, Willstätter devised a three-layer filtration drum using charcoal and other chemicals. Further study of charcoal filtration led to "one of the few positive results of chemical warfare."[65] On the offensive side, once the munitions crisis had passed by mid-1916 or so, Haber abandoned his own idea of cloud attacks to introduce a variety of gas shells as more effective weapons, and by mid-1917 his group was introducing compounds like mustard gas and arsenicals that worked in ways very different from the earlier cloud gases.

The work involved a combination of his own physical chemistry, inorganic chemistry, physics, physiology, and—not least—the traditional organic chemical syntheses that Germans did so well, but that must have seemed both boring and trivial to the physical chemist in Haber. Nevertheless he was open to suggestions from organic chemists, such as the study of arsenicals proposed in 1916 by Emil Fischer. Fischer's knowledge of the literature was an important factor, because the most successful chemical weapons, like mustard gas, had been discovered in prewar research for peaceful purposes. To make the research more purposive and provide a way of screening the hundreds of compounds resulting from the synthetic work, Haber introduced a degree of quantitative precision in the shape of a formula for calculating and comparing the toxicity of gases. His assistants must have sacrificed hundreds of hapless cats in systematically testing the potential killing agents. The system resembled the way the big industrial firms found new dyes or drugs, but the difficulties of working with the military probably made it less efficient and more frustrating, hence more "amateurish," not unlike the earliest, trial-and-error days of industrial research. In the case of the arsenicals, this led to premature and thus ineffective use, before fundamental problems had been solved. Consequently, all the available reserves of arsenic in Germany were wasted on

producing a weapon that could not work or, if it had, might have endangered the German troops themselves.[66]

Overall, however, the Germans had the advantage in the gas war until their final collapse, and for this Haber and his Dahlem group deserve much of the credit. On the other hand, they never produced a decisive breakthrough (though they may have contributed to the Russian collapse), and like the other applications of chemistry on the German side, gas may well have helped to prolong the war and intensify its horrors.

An anti-German work written after the war remarked on the apparent ease with which the great German organic chemical concerns were able to convert from peacetime products to the mass production of chemical weapons, from which the author concluded that it was "the critical factor in this new method of war which almost led to our downfall."[67] The great diversity of German organic chemical production favored flexibility. It turned out that many of the intermediates used for dyes and drugs could just as easily produce explosives and poison gas; hence Germany, or indeed any nation with an advanced chemical industry, could never be absolutely "disarmed." Chlorine and phosgene, the two earliest German gas weapons, were both produced in large quantities by Bayer and the BASF before the war. Later, more complex agents required greater changes in plant, but the process of innovation did not essentially differ from the introduction of any new dye or drug, while it did make use of excess capacity resulting from the wartime blockade. Mustard gas could be derived from an intermediate used by the BASF to produce indigo, and Hoechst was familiar with arsenicals from producing the antisyphilis medications developed by Paul Ehrlich. With few exceptions the gas war put no serious strains on German chemical production. Fischer's early pessimism seems not to have been justified in this respect; although Willstätter believed that "lack of raw materials" limited the German advantage, they were still able to outdo their opponents in producing offensive weapons. The real limitation came in producing gas masks, because the Germans had no good substitutes for rubber and cotton.[68]

Thus Duisberg's original worries about the war being bad for business were to prove wholly unfounded as long as the war lasted. Duisberg himself acknowledged that his industry did well in the war, not only in respect to poison gas but also regarding explosives production. The dye industry by the end of the war was down to 5 percent of its prewar dye production, but it produced 80 percent of all explosives used in the German army. Moreover, he noted that during the war the character of his industry's research interests had shifted decisively in the direction of inorganic chemistry. The unusual demands of the war, which had brought dramatic increases in the production of chlorine, sulfur, nitrates, and

other inorganic substances, led the dye companies to invest heavily in these areas and hire large numbers of inorganic experts for them. In peacetime these facilities would not be dismantled, but instead shifted to commercial research and production. Duisberg now estimated that only two years would be required to restore the prosperity of the industry. Hence the war had completed the process of modernization and diversification begun at the turn of the century. His pessimism thus gave way to cheerful optimism, becoming all the greater as he achieved his dream of a nationwide chemical concern, the "Expanded I.G.," in 1916.[69] The chemical industry too had demonstrated its "unlimited possibilities" through war, and the challenges of the war had proved the correctness of the original premises of the proposal for an Imperial Chemical Institute, whereby Fischer, Nernst, and Ostwald had sought more support for research in the nonorganic subdisciplines of chemistry.

A New Symbiosis Defined, 1915–1917

Before the war Adolf Harnack had written of the relationship between *Wehrkraft* and *Wissenschaft*, military strength and science, "the two strong pillars of Germany's greatness."[70] In 1916, in the annual report of the Kaiser Wilhelm Society, Harnack returned to this theme from a new perspective.

> "But our enemies, by their surprise attack, achieved something quite unexpected and, for them, unwelcome: *they brought German science and military strength as close together as possible*. Of course we knew all along that these two pillars . . . , deep down, have a hidden connection; but we did not know that this connection is so immediate that military strength can be directly promoted by science and constantly open new connections with it. . . .
>
> "With deepest thanks to our Imperial Lord we may praise the fate which allowed the Kaiser Wilhelm Society to arise at just the right time. . . . *Create, organize, discipline*: in this triad of German spirit and German labor, military strength and science come together."[71]

Before the year was out, the government awarded Adolf von Harnack the Iron Cross. Emil Fischer had already received his in 1915. At that time he too had expressed similar sentiments in thanking the Prussian government: "One could say that the unity of science and technology, which has become a tradition in chemistry, has again proved itself in the most brilliant fashion during this most difficult time. I consider the award given me to be a recognition of the services to warfare which scientific chemistry has provided behind the fighting front, and for this reason the medal is especially valuable to me."[72] Haber too was happy to see that the old prewar "wall" between academic and military circles had fallen, and in 1917 he hoped that the Kaiser Wilhelm Foundation for Military and Technical Sciences would help to "create a permanent connection" between them. That was in fact Koppel's express purpose in establishing the foundation.[73]

Thus the instruments were fully in place for integrating German science into the war effort; among those instruments the Kaiser Wilhelm Institutes and the leading scientists associated with them played a crucial role both in developing weapons and in coordinating the use, conservation, and substitution of strategic raw materials. Of course similar organizations were created in all the major belligerent nations. What is unusual about the Kaiser Wilhelm Institutes is that they had emerged before the war began, in an atmosphere of intense international competition that was beginning to shape scientific research into the cold-war style of a half-century later.

In 1917 the Prussian War Ministry sought to confirm the pattern of scientific weapons research established within the Kaiser Wilhelm Society by offering to support a permanent Kaiser Wilhelm Institute for Gas Research, to be connected with the Kaiser Wilhelm Foundation's expert committee on gas warfare. The other Dahlem institutes would be freed to revert to their original scientific work after the war, but the experience and the German advantage would not be lost. Because peacetime applications like pesticides were expected to emerge from the new institute, other sources of support might include the Education Ministry and the Agriculture Ministry. Haber worked out the details, emphasizing that there would have to be two sections. The one directly administered by the War Ministry could handle technical problems of specifically military value, but those of more general and fundamental interest would have to be approached in "free scientific activity" by a "research center for applied science," the Kaiser Wilhelm Institute for Applied Physical and Biochemistry. Again he emphasized the need "to strengthen the connection between national defense and science, whose irreplaceable significance we have learned in so many different areas in this war."[74]

Yet permanent institutions integrating science with the military could not fully entrench themselves in a Germany that was about to lose its first total war. The ambitious plans of 1917 receded as Germany crumbled, and just before the collapse the leaders of the Kaiser Wilhelm Society agreed not to establish a separate institute for gas research.[75] Although up to 1916 there had been few chinks in the wall of support among German scholars for the German war effort, the iron crosses and the chauvinistic statements of the early years of the war were not the last word. Emil Fischer, a pillar of militarized science in himself, weakened in 1917 after contemplat-

ing the useless deaths of his two younger sons. Overwhelmed by the ongoing horror, he put aside nationalistic shibboleths, reevaluated his own role and that of science in the war effort, and prepared himself to reject the Kaiser and political system that he had served so ably, but which could not halt the insanity. In December 1917—in the shadow of the Bolshevik Revolution in Russia—Fischer reflected that although unlike Haber and Nernst, he had held back from a major part in the development of poison gas, it really did not matter. High explosive—a fruit of his own organic chemistry—caused no less gruesome a death. "In short, modern warfare is in every respect so horrifying that sensible people can only regret that it draws its means from the progress of the sciences. I hope that the present war will teach the peoples of Europe a lasting lesson and bring the friends of peace into power. Otherwise the present ruling classes will really deserve to be swept away by socialism."[76] Before the war, Fischer would have found the last statement unthinkable; it sounded more like the radical Social Democrat Karl Liebknecht, who as a member of the Prussian House of Deputies in 1911 had criticized the Kaiser Wilhelm Society for standing "too much under the protectorate of an all too highly placed personage. . . . Gentlemen," he had warned, referring to the authorization of court uniforms for the members of the Kaiser Wilhelm Society, *"science and research in uniform have hardly ever done good."*[77]

Epilogue: the Fate of the Kaiser's Chemists

Pleading illness, Emil Fischer scaled back his war work in 1918; after the Kaiser's departure Fischer sent a friendly letter to Leo Arons, the physicist whom the Kaiser had purged from Berlin University two decades earlier for Social-Democratic activism, and who was now calling upon German professors to cooperate with the new regime.[78] But the war's wounds went too deep, and the ensuing revolutionary violence as well as the potential economic consequences of socialism were too frightening; within a few months an acute illness diagnosed as intestinal cancer led Fischer to an apparent suicide,[79] a broken man in a Germany that was disarmed but not truly demilitarized, reluctantly republican but backing away from a brief flirtation with socialist revolution. He could not know how quickly the lesson he had learned would be forgotten.

The other two initial proponents of the Imperial Chemical Institute, Wilhelm Ostwald and Walther Nernst, also regretted their participation in the war's excesses and hoped for better from a more democratic system; neither regretted the Kaiser's fall. Nor did either scientist find much attraction in chemical research after the war. Until his death in 1932 Ostwald promoted a theory of color harmony that he had developed, while Walther

Illus. 9-1. "Science in Uniform": Fritz Haber (pointing) among the German gas troops, probably around 1916–1917 (Max-Planck-Gesellschaft Photo Archive)

Nernst returned to his first love, physics. In 1920 Nernst finally won the Nobel Prize for his heat theorem; two years later, having struggled for so long to achieve an Imperial Chemical Institute, he gained the satisfaction of becoming president—of the old Imperial Physical and Technical Institute. Yet he found it a hopeless place to do research; aside from the financial problems of the postwar era, the earlier complaints about bureaucratization turned out to be valid. After just two years of frustration, Nernst went back to the university. In 1933 he responded to the advent of National Socialism and the dismissal of his Jewish colleagues by retiring to a provincial estate, where he became increasingly disaffected (two of his daughters had married Jews and were forced to emigrate) until his death during the Second World War.[80]

Nernst and Ostwald had had the satisfaction of seeing what Emil Fischer could not: in 1920 the Weimar Republic, its military expenditures almost eliminated by the Treaty of Versailles, could finally afford to create a National Chemical and Technical Institute. The government did not even need to build a new laboratory, because one was already available. The new institute was the old Prussian Military Testing Office under a different name. During the late 1930s it began again to devote facilities to military research, however, and the defeat in 1945 again brought its dissolution.[81]

Ernst Beckmann, who might have become the president of an Imperial Chemical Institute, endured a few frustrating years after the war as director of the Kaiser Wilhelm Institute in Dahlem. At the end of his scientific creativity, he was reduced to seeking advice from the business sponsors of the institute as to what research areas to explore. Carl Duisberg treated Beckmann's request with contempt and was no doubt happy to see him retire in 1921. Two years later, Beckmann was dead.[82]

After the Kaiser's fall, Fritz Haber's institute had also been reconverted to peacetime scientific research, and it was finally integrated into the Kaiser Wilhelm Society after the postwar financial crisis destroyed the capital of the Koppel Foundation. It attracted an outstanding staff and by the mid-1920s became the scene of perhaps the most intellectually exciting, wide-ranging, and open colloquia in Germany. In 1918 Haber had won the Nobel Prize for his ammonia synthesis (despite outcries from critics who associated him with poison gas), and his mind was sharp enough and his interests broad enough—including biology[83]—to make him Emil Fischer's heir-apparent as scientific leader of the Kaiser Wilhelm Society; he had also helped to organize the "Emergency Community of German Science" to deal with the postwar inflation by administering grants to needy researchers. Unfortunately, the influence of men like Carl Duisberg, who vehemently opposed hiring a physical chemist to fill Emil Fischer's chair, had deprived Haber of the chance to use his talents to best advantage within the university itself.[84] Yet Haber loyally served the Weimar Republic, trying for example to extract gold from seawater in order to pay reparations. With the coming of the National Socialist regime, Haber's military service would have entitled him to continue as director despite his Jewish origins. But Haber, whom 1933 broke as much as the war had broken Fischer, resigned his position and left the country, dying within a year. By then the new regime had initiated the remilitarization of his institute; one of the party hacks who now occupied it specialized in gas warfare.[85]

In 1942 Haber's friend Richard Willstätter also died in exile, having fled to Switzerland in 1939. Yet in a sense he had begun his own exile much earlier. After winning the Nobel Prize for 1915 and then refusing to accede to Duisberg's pleas to come to Berlin in 1919, on the grounds that his work in Munich was not over, in 1924 he had resigned the Munich chair in protest against his faculty's surrender to anti-Semitism in professorial appointments. Willstätter henceforth refused to work in a public or corporate research position, or even to set foot in what had been his private laboratory. Yet he also refused to leave Germany until the last possible moment, regardless of the many opportunities presented him. Instead he directed a single assistant from his home by telephone, with less than optimal results. To a Jewish scientific contemporary who believed that the researcher's highest duty was to science, Willstätter's principled attitude produced an incomprehensible result, "the self-destruction of a great genius."[86]

The last and youngest of the Kaiser's chemists was Otto Hahn, who went on to become director of the Kaiser Wilhelm Institute for Chemistry and eventually, after the Second World War, president of the Max Planck Society for the Advancement of the Sciences, successor organization to the Kaiser Wilhelm Society. Although he too had resigned his position at the university after Hitler took power, Hahn remained at his post in Dahlem even as his old scientific partner, Lise Meitner, was forced into exile after the annexation of Austria in March 1938. In the Kaiser Wilhelm Institute for Chemistry, Hahn and his associate Fritz Strassmann went on to provide, in the fall of 1938, conclusive experimental evidence of a puzzling phenomenon that Meitner and her physicist colleagues soon identified as nuclear fission in uranium atoms. The proof had required precise quantitative microanalytic techniques,[87] just the sort of thing that the Imperial Chemical Institute had originally been intended for. Emil Fischer's old vision of the "unlimited possibilities" in modern science to be opened at Dahlem had also found its most spectacular confirmation, followed all too swiftly by another horrifying lesson in the effects of "science in uniform." This time, however, the uniforms would be American.