

History of Science

Jon Agar, *Science in the Twentieth Century and Beyond*

David Knight, *The Making of Modern Science*

SCIENCE IN THE TWENTIETH CENTURY  
AND BEYOND

JON AGAR

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## SCIENCE AND THE FIRST WORLD WAR

Like other volunteers at the outbreak of the First World War, many scientists wanted to fight. Some, such as Henry Gwyn Jeffreys Moseley, were recruited direct to the front line, employed as soldiers.<sup>1</sup> Born in 1887, Moseley came from an influential Manchester landowning family, several of whom had been scientists: one relative taught natural philosophy at King's College, London, while his father, a zoologist, had travelled on the *Challenger* expedition and become Linacre professor of human and comparative anatomy in Oxford.<sup>2</sup> Harry Moseley had studied physics at that university, achieving a modest second-class degree in 1910, before joining Rutherford in Manchester as a demonstrator of experiments. His research, first in collaboration with another scientific scion, Charles Galton Darwin, turned to the new field of X-ray science. This was expensive research, slightly aside from Rutherford's main lines of inquiry. The great physicist needed persuasion. His trust was soon vindicated when Moseley, building on the work of William and Lawrence Bragg at Leeds University, used the father and son's design of X-ray spectrometer to record five sharp X-ray emission lines from platinum.

Following his return to Oxford in 1913, Moseley's research programme was clear: to measure the spectra of emission lines when the platinum target was replaced by other elements. Nevertheless, there were many practical obstacles: he had to beg scarce laboratory space as well as equipment – a Gaede pump from Balliol and Trinity's joint laboratory, a spectrometer from the Clarendon; he was reliant on expert glass blowers to produce the bespoke X-ray tubes he required; and the rare earth elements had to be secured through the networks of scientific cooperation that supported European physics. After begging equipment and several months' toil in the laboratory, Moseley had

measured the K and L emission line frequencies of X-rays produced by elements from the light (aluminium) to the heavy (gold). Plotting the square root of the frequency against an integer allocated to each element produced, on one page, readable at a glance, a remarkable graph: the elements arranged on straight lines, with a few odd gaps.

Moseley's interpretation was as follows. The integer, which increased from the lightest (aluminium, 18) to the heaviest (gold, 92), was the atomic number, or number of positive charges in the atom. When the number was construed as the number of electrons normally filling the orbits of an atom, the relationship between frequency and atomic number seemed to make sense according to Bohr's theory of atomic structure, which in turn garnered support. (The Oxford physicist Frederick Lindemann disputed this contribution.) Moseley's results also helped resolve the 'riddle of wrong positions' in the periodic table, for example providing new justification for the relative placing of iodine (53) and tellurium (52),<sup>3</sup> as well as swapping the positions of cobalt (27) and nickel (28). Finally, the gaps, at integers 43, 61 and 75, suggested the existence of as yet undiscovered elements with these atomic numbers (later found and named technetium, promethium and rhenium). Applying Moseley's results in reverse provided a means of discovering the elemental make-up of an unknown sample. X-ray research, so dependent on the working world of industry, would return the favour by providing a major technique of analysis in the form of this non-destructive X-ray investigation of materials.

When war was declared in 1914, Harry Moseley was in Australia, where a meeting of the peripatetic British Association for the Advancement of Science was under way. He rushed back to England, was granted a commission in the Royal Engineers and later was made a signalling officer of the 38th Brigade of the First Army. He left in June 1915 for the Dardenelles, where an ill-prepared invasion of Turkey via the beaches of Gallipoli was being planned. On 10 August 1915, only a few days after landing at Suvla Bay, while telephoning an order to his division, Moseley was shot in the head by a Turkish sniper. He died instantly.

Just as the death of the war poets Rupert Brooke, Isaac Rosenberg and Wilfred Owen came to stand for the untimely slaughter of young artistic talent, so the death of Moseley was held by contemporaries to be a wasteful sacrifice of the brightest and best in science. 'To use such a man as a subaltern', bewailed Rutherford, was 'economically equivalent to using the *Lusitania* to carry a pound of butter from Ramsgate to Margate.'<sup>4</sup> The American Robert Millikan called Moseley's death 'one of the most hideous and most irreparable crimes

in history'.<sup>5</sup> George Sarton, the Belgian historian of science who had fled the war, emigrating to the United States, wrote that Moseley's death represented the tragic fate of 'genius':

It must necessarily occur that men of genius die before having been able to justify themselves and to give out the treasures that were in them, and these are perhaps of all events the most tragic. Just think of the loss which mankind is thus suffering, for in the last analysis everything great and really worthwhile is due to the genius of individuals – and think also of the pity of having been called to the human stage to play an exceptional part and being swept off before having begun. The tragedy thus is not to die young but to die before having done what one was prepared to do.<sup>6</sup>

'Moseley's death', Sarton consoled, was 'tragic enough', but 'our grief is assuaged by the thought that his fame was already established . . . that his memory will be green forever. He is one of the immortals of science . . . He died in beauty', his death a 'consecration' of individual genius.<sup>7</sup> The glassware of his experiments, once temporary assemblages, became treasured relics of a secular saint. (Some of the apparatus can be seen in the Museum of the History of Science in Oxford.)

But science's role in the First World War was not, primarily, as a sacrificial victim, nor was it best characterized as the contributions of individual genius. Instead, along with all other factors in the economy deemed to be strategically important, science was collectively mobilized in an increasingly organized fashion. Rutherford's lament reveals far more of contemporary attitudes than Sarton's conventional elegy: the waste of Moseley was a waste of resources. Just as great civilian steamers should be requisitioned as supply ships and used in the most efficient manner, so scientists should be organized and put to work. Moseley, who had been offered scientific work at home, chose to fight abroad, responding to a patriotic fervour he shared with many young men in 1914. The complaint was not that bodies should be sent to the front to fight and, if necessary, die, but rather, by putting his brain in the line of fire of a Turkish bullet, it was not being deployed efficiently or effectively enough.

### Organizing science for war

Historians agree that the First World War accelerated a trend towards increased organization in the modern world. As hopes for

a quick conflict faded, so states found that they had to improvise a constant state of war preparation. Armies in the field had to be fed, equipped, trained, healed and buried.<sup>8</sup> This situation favoured large-scale industrial manufacturers, with which states learned to liaise, plan and coordinate. It also encouraged state intervention in matters of health, food supply and childcare. Furthermore, all sides were afflicted by shortages of key strategic materials. We will shortly see perhaps the most famous case: how the Royal Navy blockade of the Chilean nitrate mines prompted the German mass production of artificial ammonia and nitrates through the Haber-Bosch process. Likewise, Britain, France and the United States were cut off from high-quality optical glass (used for gun sights), synthetic dyes (used to dye soldiers' uniforms) and a host of other products of Germany's peerless chemical industries. German dominance of pharmaceuticals, another aspect of the strength in chemicals, created alarming shortages on the outbreak of war; the painkiller acetanilide, for example, rose in price from 20 cents a pound to nearly \$3, while the fever-reducing medicine antipyrine went from \$2 to \$60 a pound.<sup>9</sup> These shortages in turn encouraged strengthened industry-academic linkages in the United States.

The overall process, argues historian William McNeill, was to encourage large-scale industries, often in the form of state-orchestrated national cartels, to manage innovation, with two very important consequences: the mass production of nearly everything and the institutionalization of planned invention. In general, the First World War intensified the organizational revolution – a gathering concern for scale, organization and efficiency that was discernible in the mid- to late nineteenth century, as described by Robert Wiebe, Alfred Chandler and Louis Galambos.<sup>10</sup> However, this increase in organization and management of innovation was not imposed on science from above, but was also called for from below, as the following case studies of scientists in Britain, the United States and Germany will show.

Since science does not exist independently of the working world, scientists have always had to justify their activities to political powers and social institutions to garner 'good will, patronage and cooperation'; from the 1870s, argues historian Frank Turner of the British 'public scientists' who led such justification, the rhetoric shifted 'from the values of peace, cosmopolitanism, self-improvement, material comfort, social mobility, and intellectual progress towards values of collectivism, nationalism, military preparedness, patriotism, political elitism, and social imperialism'.<sup>11</sup> There were several causal factors

behind this shift, including perceived failures of government support for science education and trepidation at the success of the anti-vivisectionist movement, but, perhaps most importantly, the demonstrable advance of Germany as an industrial nation and imperial threat. Specifically, the army and navy, the largest and most generous state sponsors of science in Britain,<sup>12</sup> were targeted by organizations such as the British Science Guild, a body set up in 1905, the purpose of which was

to stimulate not so much the acquisition of scientific knowledge, as the appreciation of its value, and the advantage of employing the methods of scientific inquiry, the study of cause and effect, in affairs of every kind . . . [for example the problems of] the statesman, the official, the merchant, the manufacturer, the soldier and the schoolmaster . . . [The] value of a scientific education lies in the cultivation which it gives of the power to grasp and apply the principles of investigation employed in the laboratory to the problems which modern life presents in peace or war.<sup>13</sup>

A British Science Guild prize question of 1910, set against the background of a dispute over rearmament, specifically the order of Dreadnoughts for the navy, asked for essays on 'The best way of carrying on the struggle for existence and securing the survival of the fittest in national affairs' – for example, 'whether a system of party government is sufficient to secure all the best interests of the State in those directions in which brain power and a specific knowledge are needed . . .'.<sup>14</sup> Norman Lockyer, editor of *Nature*, prime mover of the British Science Guild, who had lectured the British Association on 'The influence of brain power in history', urged the mobilization of science. In October 1914, *Nature* editorialized that 'This war, in contradistinction to all previous wars, is a war in which pure and applied science plays a conspicuous part', and throughout the war public scientists charged the government with inadequate attention to science and scientists. No wonder Moseley was made into a symbol of waste.

But how did practice compare to rhetoric? In Britain, as the hopes for a quick victory faded, confirmed by the disaster at Gallipoli, the public scientists stepped up their pressure, clamouring for greater direction (and offering, of course, themselves as guides). In June 1915, H. G. Wells wrote to *The Times* in protest against the 'very small part we are giving the scientific man and the small respect we are showing scientific method in the conduct of war'; Sir Philip Magnus, an expert on education, chimed in: 'Our scientific men are in no way inferior to those of Germany, but they work independently and are not in close

co-operation'; while electrical engineer and the inventor of thermionic rectifier, John Ambrose Fleming, echoed the sentiment: 'There is no want of ability, but there is an entire absence of external directing power.'<sup>15</sup> The government responded to these complaints in July 1915, when two advisory boards of civilian scientists were set up, one for the War Office and one for the navy.

These boards provided a route by which civilian scientists could contribute to the organized war effort. Their establishment was a defensive sop to public pressure, as the first lord of the Admiralty, Arthur J. Balfour, of scientific stock himself, privately acknowledged ('Although I attach no very great value to public sentiment as such . . . the establishment of a Board . . . [would] do much to satisfy public demand').<sup>16</sup> In fact the armed services, and especially the navy, had long-standing intramural traditions of technical expertise and innovation (witness Admiral Jacky Fisher's Dreadnoughts). To a great extent the civilian public scientists were not required.

Nevertheless, a civilian science body such as the Royal Navy's Board of Invention and Research is interesting to us for three reasons. First, the creation of the board, and the arguments that supported it, are evidence for the First World War as intensifying the trends towards greater organization of research, towards the management of strategic resources such as science and scientists. Likewise the frequent complaints that the various research branches of government were duplicating military work – 'several or all of them, . . . working on the same problems, with incomplete knowledge, or none at all, by each of them of what the others are attempting or have accomplished' – should be taken as evidence for the trend towards increased organization and management rather than merely complaints about inefficiency.<sup>17</sup> Second, the board was significant for what it achieved, in particular innovating techniques of anti-submarine defence. Finally, the involvement of civilian scientists via the board is interesting when compared to similar trends and tensions in other countries.

The board, chaired by the great enthusiast for naval invention Admiral 'Jacky' Fisher, was composed of some of the most eminent scientists and engineers in civilian life: physicists such as J. J. Thomson, Ernest Rutherford, William H. Bragg and Lord Rayleigh, chemists such as George Beilby (inventor of a cyanide production process, critical to gold extraction), William Crookes and Percy Frankland, and engineers such as Charles Parsons (inventor of the steam turbine), electrical engineer William Duddell and metallurgist Henry Carpenter. But the navy's problem was not lack of ideas, but too many. Not only were the in-house technical experts pushing ideas

but many suggestions were flooding in from outside. The board therefore was useful to the navy not just as a means of tapping eminent civilian scientific brains, but also for screening out the public wheat from the chaff. Between July 1915 and December 1916 the board considered almost 20,700 inventive ideas; by mid-1917, the figure had reached 40,000.<sup>18</sup>

The board considered inventions relating to many branches of warfare, including aircraft, balloons, the construction of ships, torpedoes, the storage of oil and the saving of lives. But by far the greatest number of ideas were responses to the greatest threat of the war: the submarine. Contrary to international law and the Hague convention, submarine warfare was practised by both sides (indeed, Fisher had been instrumental in building up the British experimental fleet), but in 1915, when Germany declared merchant shipping as legitimate targets, and especially following the sinking of the ocean liner *Lusitania* in May 1915, the submarine was established as a terrifyingly effective weapon of war. The unprecedented loss of shipping would justify some unusual scientific responses, among them the conditioning of sea lions, in a manner akin to Pavlov's dogs, to locate U-boats.<sup>19</sup> The successful techniques were, if anything, just as outlandish. In-house naval research, at HMS *Vernon*, developed torpedoes, while the Board of Inventions and Research began developing underwater acoustic – hydrophone – methods to listen out for the chug of the U-boats' engines. In 1916 this work, directed by the physicist William H. Bragg, pushed the limits of detection out to 4 miles and began to improve methods of determining the direction of the submarine. Staff and resources grew. The civilians made a small but significant contribution to the greater research and development being conducted by the Admiralty in general, and the Admiralty's Anti-Submarine Division in particular.

Furthermore, the organization of research was transnational. From March 1915, Paul Langevin in France developed the idea of using sound detection to locate submarines by drawing upon an effect he had studied in Paris under Pierre Curie: the capability of quartz crystals to produce tiny currents of electricity when put under pressure.<sup>20</sup> Since sound is a pressure wave, this piezoelectric effect could be the basis of a sound detector. Quick results were achieved in France. In 1917, work by two Rutherford students, the Canadian Robert W. Boyle and the British mainstay of acoustic detection, Albert Wood, took the French ideas and experimented with detection by measuring ultrasound echoes. Cooperation with the French turned this experiment into ASDIC, an early form of sonar. ('ASDIC' does not stand

for Allied Submarine Detection Investigation Committee, a story invented in the 1930s, but the moniker contains a truth.)<sup>21</sup>

The board, a body independent of the Royal Navy, inevitably met with distrust and opposition and was eventually all but dissolved in 1917.<sup>22</sup> The record of the Munitions Inventions Department, set up in 1915 to play a similar role for non-naval military invention, reveals the same tensions.<sup>23</sup> Nevertheless, these tensions are best seen as the usual organizational friction rather than resistance to science. The channels of scientific advice were retained, even as the Admiralty reverted to the intramural invention it preferred.

The story of the relationship between the civilian scientists and the British military had direct parallels in the United States. Furthermore, as historian Daniel Kevles has shown, the Great War became a moment when an older, highly successful tradition of innovation was challenged by a newer, science-based one; the challenge is best seen in the contrast between the Naval Consulting Board and the National Research Council.<sup>24</sup> Before the First World War, American military laboratories concentrated on 'simple testing of materials and devices' and the 'cut-and-try improvement of guns, cannons, engines and gadgetry', while civilian inventors and industrial firms were looked to as the source of new weapons.<sup>25</sup> Elmer A. Sperry, for example, had provided the gyrostabilizer technologies that the US Navy had introduced in 1912; during the First World War the links between the Sperry Gyroscope Company and the US Navy intensified to such an extent that the historian Thomas P. Hughes spies a well-formed 'military-innovation complex' in operation.<sup>26</sup>

Following the sinking of the *Lusitania*, the secretary of the US Navy, Josephus Daniels, oversaw the appointment of a Naval Consulting Board. His plan was to channel the enthusiasm and ideas of independent inventors – Elmer Sperry, Leo H. Baekeland (the inventor of bakelite plastics), Frank J. Sprague (electric transport) and, particularly, the great Thomas Alva Edison, installed as the board's leader. Despite the presence of Willis R. Whitney, of General Electric, home of the influential corporate laboratory, the members of the Naval Consulting Board saw military invention as the preserve of engineers, and the board itself as a clique of the nation's 'very greatest civilian experts in machines'.<sup>27</sup> Physicists, and other professional scientists, were to be excluded, 'because', explained Edison's chief engineer of the great man's motives 'it was his desire to have this Board composed of *practical* men who are accustomed to *doing* things, and not *talking* about it'.<sup>28</sup>

The physicists' response was led by George Ellery Hale. Hale was

a past master at persuasion – we will see the results of his success in converting the industrial wealth of philanthropists into funding for American science in a later chapter. In 1916, Hale was not only one of the world's leading astrophysicists and director of the Mount Wilson Observatory in California (see chapter 8) but also a reforming president of the National Academy of Sciences. The Academy was an odd, anomalous, almost moribund body: 'a private organisation with a federal charter, created in the middle of the Civil War to provide expert advice to the government'; Hale sought to make it more relevant, cooperating with other bodies, dispensing grants to young researchers, but his attempt to persuade the Carnegie Corporation to pump the grant scheme failed, and he was on the look out for other patrons.<sup>29</sup>

A week after Woodrow Wilson issued a final ultimatum to Germany, in April 1916, Hale was at the White House pitching an idea. His proposal was for a National Research Council – a body of scientists drawn from academia, industry and government that would encourage pure and applied research for 'the national security and welfare'. It would be run under the National Academy of Sciences, breathing life into the old institution. While the pacifist psychologist James McKeen Cattell described it as 'militaristic', and the US Navy ignored it in favour of its Naval Consulting Board, Hale's creation of the National Research Council on 9 June 1916 drew warm applause.<sup>30</sup>

The differences in constitution and values between the Naval Consulting Board and the National Research Council are best illustrated in the bureaucratic turf war fought over anti-submarine defence. U-boats were devastating Atlantic traffic, and formed the greatest threat to American supply to support intervention in Europe. While merchant shipping losses dropped by a third following the adoption of Admiral William S. Sims's convoy proposals, U-boats still sank hundreds of thousands of tons. The Naval Consulting Board, in the absence of its own workshop (a proposal for a laboratory was held up by a dispute over 'purpose, control and location'), authorized the Submarine Signal Company to establish an official experimental station at Nahant, Massachusetts, to be shared with General Electric; again academic physicists were excluded, this time on the grounds that they would 'complicate the patent situation'.<sup>31</sup>

The National Research Council responded by enthusiastically receiving an allied British–French scientific mission that passed on devices for submarine detection. These instruments were demonstrably better than developments at Nahant, and Hale and Robert

Millikan successfully persuaded the US Navy to set up a second laboratory, at New London, Connecticut, that would be staffed by physicists and build on the French-British inventions. Research and development at both Nahant and New London led to successful anti-submarine methods. Nevertheless, it was New London 'which steadily acquired more equipment and more physicists [and] was by the spring of 1918 virtually absorbing Nahant', as in turn the National Research Council was 'overshadowing' the Naval Consulting Board.<sup>32</sup> The stock of physics was rising, that of the independent-inventor engineers falling.

Physicists demonstrated their usefulness to military patrons in other fields too. For the American Expeditionary Force, Augustus Trowbridge and Theodore Lyman, for example, tested varieties of sound ranging equipment (for locating the position of enemy artillery), as well as flash ranging techniques.<sup>33</sup> Another consequence of the mobilization of civilian science was that military research projects began to filter into the academy: in the United States forty campuses hosted highly secretive military research 'under the constraint of tight security regulations for the first time in American history'.<sup>34</sup> Overall, the Edisonian model (independent invention, backed by workshop laboratories) failed where the Hale/Millikan model (incremental physicist-led invention, planned in a manner following the pattern of the corporate laboratories) succeeded. 'For thoughtful military observers, concludes Kevles, 'the meaning of it all . . . was clear: The advance of defense technology required the organized efforts of scientists and engineers' drawing on 'fundamental physical truths and engineering data'.

In Germany too the First World War promoted the militarization of academic research, important contributions by civilian science to the development of new weapons and defences of war, and an intensification of the organization of industrial production, of which planned research was part. Range-finding of artillery by sound detection employed physicists such as Max Born as well as psychologists such as Kurt Koffka and Max Wertheimer, whom we will meet in the next chapter as instigators of the new Gestalt theory, from 1915.<sup>35</sup> The most notorious example of academic-military-industrial science, however, was the systematic waging of chemical warfare. Chemical warfare was no aberration. Instead, as tracing the life and career of Fritz Haber will show, chemical warfare was the expression of organized science and managed innovation.

'No nation can withdraw from economic competition, the pursuit of technology and advancement of industry, without putting its very

existence at risk', Carl Engler, the rector of the Technical University in Karlsruhe, had argued in a speech in 1899, continuing: the 'struggle for existence - the fate of the nation - is decided not just on bloody battlefields, but also in the field of industrial production and economic expansion.'<sup>36</sup> Such social Darwinian rhetoric - war as an inevitable component of the struggle for existence between nations - was not uncommon in the 1910s.<sup>37</sup> Engler went on to echo the warning cry and call to arms made by the English scientist William Crookes, who had told the British Association for the Advancement of Science in 1898 that, unless chemistry could turn the nitrogen of the air into fertilizing nitrates, the world would starve and Western civilization would end; in Engler's audience was the chemist Fritz Haber, whose life and achievements illustrate the linkages between the working worlds of science, industry and the military.<sup>38</sup>

Haber was born in 1868 to a Jewish family in the Prussian city of Breslau. Set on an academic career, opposed by his father, who knew the extent of anti-Semitism in German universities, he nevertheless studied chemistry in Berlin, a patriotic choice, since the growth of chemical industries was driving Germany's industrial economy at breakneck speed.<sup>39</sup> Specializing in physical chemistry, Haber was rebuffed when he applied to join the field's leader, Wilhelm Ostwald, in Leipzig. Instead, he began a series of industrial placements and low-status academic work. He also renounced his Jewishness, accepting the arguments of the historian Theodor Mommsen that patriotic duty demanded it.<sup>40</sup>

In 1894, Haber was employed as an assistant at the chemistry institute of the Technical University of Karlsruhe, which had close working links both with the state government of Baden and with the great chemicals firm BASF, 40 miles north on the Rhine. He married another Breslau chemist, Clara Immerwahr, and cracked on with research. Around 1903, the Margulies brothers of Vienna, owners of chemical works, contacted Haber and offered him consultancy money to investigate an intriguing indication of ammonia production in their factories. Haber attempted to replicate the conditions, heating nitrogen and hydrogen to 1,000 degrees Celsius, while introducing iron filings to act as a catalyst. Barely any ammonia was produced, and he informed the Margulies brothers of the disappointing result. Here the intensely competitive and hierarchical nature of German academia is relevant. The ambitious Haber already felt himself in competition with his superiors, Wilhelm Ostwald and Walther Nernst. In 1907, Nernst publicly trashed Haber's account of the ammonia equilibrium point.

Haber redoubled his efforts in the laboratory. He marshalled all his resources – setting his best chemical engineer, an Englishman named Robert de Rossignol, to work, acquiring the best in gas compressors to drive the pressure as high as could be achieved, and drawing on his industrial allies, with BASF funding a research programme to the hilt. Finally, in what seems at first glance to be an extraordinary moment of contingency, but in fact illustrates just how important the working world of electro-technical and chemical industry was to science, in 1908 a Berlin gas and electric light company, Auergesellschaft, had passed to Haber rare earth elements to test as materials for light-bulb filaments.<sup>41</sup> Haber tried one of these rare earths, osmium, as a catalyst. The combination worked. ‘Come on down! There’s ammonia’, shouted Haber. ‘I can still see it’, his assistant later recalled. ‘There was about a cubic centimetre of ammonia. Then Engler joined us. It was fantastic.’<sup>42</sup>

Haber swiftly contacted BASF. Buy the world’s osmium, he advised. But BASF were not convinced that this laboratory demonstration, with its immense pressures – two hundred atmospheres – and rare elements, could be scaled up. Here the BASF chemical engineer Carl Bosch’s judgement of what was possible was decisive. The scaling up of the Haber–Bosch process, a product of the German working world of the 1900s, was arguably the most influential contribution of science to the twentieth century.<sup>43</sup> Cheap ammonia can be used to make cheap nitrates. The so-called Green Revolution in the second half of the twentieth century, in which new high-yielding crop varieties combined with the widespread application of pesticides and fertilizers, including nitrates and ammonium sulphate, would by some counts feed 2 billion people in China and India who would otherwise starve.<sup>44</sup> This was the substance behind Max von Laue’s elegy for Haber: that he had ‘won bread from air’. The Green Revolution will be discussed in chapter 14.

Nevertheless, the mass production of ammonia was of more immediate consequence for sustaining the fighting power of Germany in the First World War. Nitrate, a powerful oxidizer, was a component of gunpowder, while nitric acid was essential to the production of modern explosives. While Chilean mines dominated the world’s pre-war supply of nitrates, the supply lines linking Chile to Germany were cut early in the conflict. If the war had been short and swift, like the Franco-Prussian War of 1870–1, then the German command would have had nothing to worry about: existing stockpiles would have sufficed. But as the mobile war stalled, and as massive bombardment became the main battering ram of advance, so supplies of ammunition were rapidly running out for lack of nitrates. Walther

Rathenau, Germany’s foremost organizer of technological systems, mobilized industry, including BASF, to the patriotic cause. Bosch, chivvied on by Haber, transformed BASF’s ammonia factories into nitrate factories. By May 1915, BASF was producing 150 tons of nitrate per day and sustaining Germany’s industrialized warfare.

The strong ties between German industry, government and academia had been tightened in the years prior to 1914. Specifically, in 1910, the theologian Adolf von Harnack, one of the most eminent scholars in Germany, had pitched an idea to Kaiser Wilhelm: the imperial nations were locked in competition and the quality of scholarship, which in turn could only be secured by generous funding, would determine the outcome.<sup>45</sup> In the United States, the immense wealth of the second industrial revolution – oil, steel, and so on – was being recycled by philanthropists such as Rockefeller and Carnegie into research institutes against which Germany’s academic institutes could not compete. ‘This cannot, this dare not remain the case’, Harnack concluded, ‘if German science and with it the fatherland – its inward strength and its outward image – are to avoid grave damage.’<sup>46</sup> Swayed, but unwilling to commit scarce imperial funds, Wilhelm summoned Germany’s industrialists to Berlin on 14 May 1910. For the Fatherland, the captains of German industry would fund the Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften (Kaiser Wilhelm Society for the Advancement of Science), which in turn would manage the channelling of German industrial wealth into new, large research Kaiser Wilhelm Institutes. They became power-houses of twentieth-century German science.

Institutes founded before the First World War, mostly in the southwestern suburb of Berlin of Dahlem, included the Kaiser Wilhelm Institute (KWI) for Biology (1912), the KWI for Biochemistry (1912), the KWI for Brain Research (1914, not in Dahlem but the other side of the city, in Buch), the KWI for Chemistry (1911), a KWI for Coal Research (1912, in Mülheim in the Ruhr) and the KWI für Arbeitsphysiologie (1912, work or occupational physiology). Further Kaiser Wilhelm institutes were opened during the war, including a KWI for Experimental Therapy (1915), a KWI for German History (1917, Berlin), a KWI for Iron Research (1917, Aachen, near the border with Belgium) and a KWI for Physics, which was founded, with Albert Einstein installed as director, in 1917.

Nevertheless, the institute of direct interest to us now was the KWI for Physical Chemistry and Electrochemistry, founded in 1911 and built in Dahlem, Berlin. The funds were supplied by Leopold Koppel, financier and controller of assets that included the Auergesellschaft

gas and electric light manufacturer, which in turn had forged consulting links with Fritz Haber. It was Koppel's support that swung Haber the directorship of the prestigious KWI for Physical Chemistry and Electrochemistry away from his more established rival, Walther Nernst.<sup>47</sup> Haber, with family, moved from Karlsruhe to Berlin in July 1911. He found the city at a peak of imperial anxiety and patriotic excitement: Germany and France were squabbling over Morocco, and the appearance of a gunship, the *Panther*, off the port of Agadir seemed, for a moment, to be the opening shot of a new European conflict.

In fact, by the time war did break out, Haber, from his base at the KWI, had become the central node of a network of contacts that spread across imperial Berlin. As we have seen, he was able to help Walter Rathenau and Carl Bosch turn the BASF ammonia factories into producers of nitric acid for explosives. This network would enable Fritz Haber, an academic chemist with a successful consultancy, to become a military organizer of chemical warfare, a powerful scientist-soldier, a man of high status in the imperial hierarchy.

Germany was not the first country to use chemical weapons in the First World War. Britain, France and Germany were each researching tear gas weapons in 1914: the French tried tear gas in August 1914, the Germans used a chemical that induced sneezing in October 1914, near Neuve-Chapelle, and the British prepared to launch a few so-called stink bombs.<sup>48</sup> None of these attacks was effective – or even, at the time, recognized by the enemy. The shift in attitudes to chemical warfare occurred in late 1914 and early 1915 as the war stalled. In December 1914, desperate for a new tactic, the chief of staff, Erich von Falkenhayn, consulted Emil Fischer, professor of chemistry at the University of Berlin, about the possibility of chemicals that might put soldiers 'permanently out of action'; Fischer seems to have been reluctant, but Fritz Haber was keen.<sup>49</sup> He suggested chlorine, a gas that was heavier than air and would drift and fill trenches, a gas that attacked the lungs, asphyxiating a victim.

In January 1915, Fritz Haber was authorized to start a substantial programme to develop chlorine as a chemical weapon. His scientific group included three future Nobel laureates: James Franck and Gustav Hertz (who together won the physics prize in 1925) and Otto Hahn, the future discoverer of nuclear fission.<sup>50</sup> Haber also collected and trained hundreds of specialized gas troops, who would learn how to handle the chlorine containers and how to deploy the gas on the battlefield. In March 1915 the development and training was over, and the troops were sent to the Ypres salient, a bulge in the lines

of trenches of the Western front. The German commander at Ypres was initially reluctant to use this new, unfamiliar and unpredictable weapon, which he knew would raise charges of atrocity. However, an accidental release, caused by an enemy bombardment, which killed three German soldiers, convinced him of chlorine's potency. On 22 April 1915, the gas valves were loosened, and clouds of chlorine, like yellow smoke, drifted over Canadian, French and Algerian troops. Soldiers, completely unprotected, suffocated or ran.

Both sides were surprised when the first use of chlorine punched a 4-mile gap in Allied defences. If the German army had been prepared, then it could have poured through and made advances of hundreds of miles, perhaps turning the war. But General Erich von Falkenhayn had seen the Ypres salient as 'merely a diversionary move; it would help "to cloak the transportation of the troops to Galicia"', assisting the eastern front.<sup>51</sup> In fact, 1 mile was gained. In London, newspaper editors at first played down the attacks, but as soon as the physiologist John Scott Haldane submitted an official report, published on 29 April, confirming the lethality of the gas, the editorials and letters pages filled with accusations of atrocity; *The Times* called it 'an atrocious method of warfare', the use of which would 'fill all races with a new horror of the German name'.<sup>52</sup>

In fact the other nations responded in kind as soon as research, development and production permitted. The British deployed chlorine at Loos in September of the same year. Chlorine dispersed quickly and had other disadvantages. The chemists therefore quickly developed new compounds. Phosgene, isolated by the French chemist Victor Grignard, was highly toxic, colourless and smelled only faintly (of hay).<sup>53</sup> Defensive technologies, such as gas masks, partly countered chlorine and phosgene. Germany responded in 1917 with mustard gas, a liquid, which lay on the ground for weeks, blistered the skin on contact and, if it got into the lungs, caused deadly bleeding. 124,500 tons of poison gas was used in battle in the First World War, roughly in equal quantities by Allied and Axis powers, mostly chlorine and phosgene. If anything, chemical weapons favoured the Allies, at least on the western front, where the prevailing wind was at their backs.

Each side built a considerable alliance between chemical producers, scientists and the military in order to develop and produce these new weapons. The British, French and Americans each expanded their chemical warfare branches, mobilizing chemistry. Remarkably, in the United States, more than 10 per cent of the country's chemists eventually would aid the work of the army's Chemical Warfare Service.<sup>54</sup> A contemporary American journal found only one chemist who had

refused to assist the gas project.<sup>55</sup> Haber's Kaiser Wilhelm Institute, under military command from 1916, was at the centre of an empire of 1,500 staff, including 150 scientists.<sup>56</sup> The gas produced was used both for killing soldiers and for killing vermin, the lice and insects that infested the front. As the historian Edmund Russell argues, this connection between chemical warfare and insecticides continued through the twentieth century.<sup>57</sup> Haber enjoyed the military life. More specifically, he had no regrets about developing chemical weapons: it was his patriotic duty as a German, and he felt, in a sentiment that he shared with other commentators, such as J. B. S. Haldane in Britain, that the weapons, when their psychological effects were compared to the alternative of being ripped apart by an explosive shell, were, if anything, cleaner and more modern forms of killing. His wife, Clara, disagreed, and shot herself with Haber's military pistol in May 1915.

Aircraft and tanks were two other technologies that drew heavily on organized scientific expertise and promised breakthroughs in the stalled, trench warfare. Aircraft, which could fly over the lines, started the war barely different from the Wright brothers' designs and ended the war as a sophisticated and powerful technology. Despite exaggerated claims for impact on battle, both before and after the Great War, aircraft were actually used for niche functions: reconnaissance, artillery sighting, aerial photography, and combating the enemy's planes. Aeroplanes often crashed, were unreliable and, like gas, could be countered with defensive techniques, such as improved listening. Nevertheless, flying aces, such as the American Eddie Rickenbacker and Manfred von Richthofen, better known as the Red Baron, became celebrated, not least because their individuality and bravery stood out in contrast to the reality of industrialized warfare and the unknown soldier.

Nevertheless, the increased stability, reliability and speed of aircraft were the outcome of rounds of intensive improvement and invention. In Britain an Air Inventions Committee was set up, complementing the Royal Aircraft Establishment, Farnborough, one of the most important sites of British science in the twentieth century. Sciences such as metallurgy were shaped by this military inquiry – the investigation of cracks, for example, prompted broader speculations about the mechanical properties of solids in the post-war years; in particular, research at Farnborough during the First World War on the propagation of cracks as a mode of plastic deformation of metals 'in turn became an immediate predecessor to modern dislocation theory'.<sup>58</sup> X-rays were one application of the new physics of direct relevance: they were used to probe the structure and frailties of materials.

As the length of the war encouraged the institutionalization of continuous invention, so strategists disputed the best use of aircraft, tanks, trucks with internal combustion engines, and other novelties. In 1918, a junior British staff officer, J. F. C. Fuller, urged replacing the war of attrition with a new strategy, a direct attack on the headquarters and supply lines of the German command with tanks, supported by aircraft. This scheme, the basis for 'Plan 1919', relied on the metaphor of the army as body: rather than bleed the enemy to death slowly with a million cuts, Plan 1919 aimed at the 'brain'. Fuller later called his plan 'brain warfare', and Plan 1919 a 'shot through the brain'. Plan 1919 was neuropathology as military strategy. McNeill, locating a different emphasis, argues that the 'remarkable feature of the "Plan 1919" was that its feasibility depended on a weapon', the fast, manoeuvrable tank, 'that did not exist when the plan was drawn up'.<sup>59</sup> Here was the epitome of 'deliberate, planned invention'.

### Mobilizing human science

Health was also managed. Preventative medicine on the front kept many infectious diseases at bay; indeed, 'inoculation and other systematic precautions against infectious diseases, which in all earlier wars killed far more soldiers than enemy action', argues McNeill, 'made the long stalemate of the trenches possible'.<sup>60</sup> Nevertheless, the influenza epidemic of 1918–19 killed more people throughout the world than fell on the fronts of the Great War. The mobilization of medical and scientific expertise to support the management of war society created opportunities for ambitious disciplines. Psychology in the United States provides a clear example.

We saw in an earlier chapter how psychologists, such as Alfred Binet, Théodore Simon and Lewis M. Terman, had developed and promoted tests of intelligence to various clients as a means of securing status and resources for a young discipline. Nevertheless, outside professional circles, before the First World War, 'mental tests usually met with skepticism, if not outright hostility'; but the entrance of the United States into the war gave a chance to the psychologists 'to prove themselves', and their techniques, to be respectable.<sup>61</sup> One such opportunist was Robert M. Yerkes, president of the American Psychological Association, who in 1917 appealed to his colleagues that 'Our knowledge and our methods are of importance to the military service of our country, and it is our duty to cooperate to the fullest extent and immediately toward the increased efficiency of

our Army and Navy'; in particular, psychologists should not restrict themselves merely to the identification of mental incompetents, but rather offer a comprehensive service, a 'classification of men in order that they be properly placed in the military service'.<sup>62</sup>

Yerkes chaired the Psychology Committee of Hale's National Research Council and won the support of another member, surgeon general of the army William C. Gorgas, who had witnessed the potential of science deployed in a military context as part of Walter Reed's campaign against yellow fever in Cuba. In the summer of 1917, Yerkes, with Terman, trialled a test, 'examination A', and analysed the results at Columbia University; he was soon urging its deployment as the basis of separating officer-class recruits from others. Yerkes soon had rivals. Walter Dill Scott and Walter V. Bingham, at the Carnegie Institute of Technology, who had developed tests of potential salesmen, viewed Yerkes as a dilettante, and offered a businesslike scheme of even greater generality. However, Yerkes and Scott found themselves collaborating for the greater good: 'we shall do much more for our science, as well as for national defense', wrote Yerkes, by doing so.<sup>63</sup> They soon had an 'Alpha' test, for literate recruits, and a 'Beta' test, for illiterates. Yerkes persuaded the army to open a school of military psychology, at Fort Oglethorpe, Georgia, to train examiners; by May 1918 the examiners were handling 200,000 intelligence tests a month.<sup>64</sup>

There was no doubt that the army was under strain: the US Army had ballooned from 6,000 officers and 200,000 soldiers in March 1917 to 200,000 officers and 3.5 million soldiers in November 1918; the secretary of war had conceded that 'Some system of selection of talents which is not affected by immaterial principles or virtues, no matter how splendid, something more scientific than the haphazard choice of men, something more systematic than preference or first impression, is necessary to be devised.'<sup>65</sup> Kevles stresses the opposition of the military to the psychological tests; to 'the critics', he summarizes, 'the intelligence testers were interfering with serious business, saddling the army with questionable personnel practices, and, above all, undermining traditional military prerogatives'.<sup>66</sup> The test results conflicted with the judgement of experienced officers. Furthermore, the military suspected the scientists of opportunistically gathering data, useful to their science, but wasting the valuable time of an army marching to war. John Carson, in a more recent historical study, detects a more nuanced situation, a 'story of negotiation and transformation', in which both sides, faced with an unprecedented moment of mass mobilization, made concessions.<sup>67</sup>

Despite the language of objectivity and the systematic application of science, it is clear that the tests, as they were devised, carried out and analysed, were freighted with assumptions. Kevles contrasts Yerkes's faith that he was measuring 'native intelligence' with the implicit knowledge that lay behind such Alpha questions as 'The Knight engine is used in the - Packard - Stearns - Lozier - Pierce Arrow'.<sup>68</sup> Other Alpha questions included:

4. Why is beef better food than cabbage?
  - Because
  - it tastes better
  - it is more nourishing
  - it is harder to obtain
6. If someone does you a favor, what should you do?
  - try to forget it
  - steal from him . . .
  - return the favour
10. Glass insulators are used to fasten telegraph wires because
  - the glass keeps the pole from being burned
  - the glass keeps the current from escaping
  - the glass is cheap and attractive
16. Why should we have Congressmen?
  - the people must be ruled
  - it insures truly representative government
  - the people are too many to meet and make their laws.<sup>69</sup>

Franz Samelson, a third historian of this episode, agrees that one of the 'root problems was the belief of the psychologists that they were scientifically measuring essentially "native ability rather than the results of school training", a belief for which they had no real grounds except their awareness that this was what they had set out to do, and, of course, their prior assumptions about the nature of intelligence.'<sup>70</sup> According to contemporary testimony, the examiners of the Beta tests for illiterates, 'for the sake of making results from the various camps comparable', had been 'ordered to follow a certain detailed and specific series of ballet antics, which had not only the merit of being perfectly incomprehensible and unrelated to mental testing, but also lent a highly confusing and distracting mystical atmosphere to the whole performance.'<sup>71</sup> Bored and mystified recruits 'dozed off en masse'. The measured intelligence of illiterates duly fell.

Yerkes's programme was abolished in 1919. But psychological testing remained as a feature of personnel management in the

army. Furthermore, Yerkes, and other psychologists, had assiduously trumpeted their discipline's patriotic contribution to the war, and celebrated its apparent successes. The Rockefeller Foundation stumped up \$25,000 to develop the tests for use in schools; the resulting National Intelligence Test was given to 7 million children in the 1920s.<sup>72</sup> Carl Brigham made the army Alpha test the basis of the Scholarly Aptitude Tests (SATs), a hoop through which university students in the United States, and increasingly elsewhere, would be made to jump in the twentieth century. Business, too, was interested. Psychology, declared Terman in his 1923 presidential address to the American Psychological Association, had been turned from 'the "science of trivialities" into "the science of human engineering"'. The psychologist of the [earlier] era was, to the average layman, just a harmless crank . . . no psychologist of today can complain that his science is not taken seriously enough.<sup>73</sup> What had made the difference was psychology's well-publicized mobilization in the working world context of the war.

Finally, intelligence testing in the First World War was encouraged by, and contributed to, broader trends. First, intelligence testing, as devised by the psychologists, was one more example of the methods to judge similarity in a world, forged in the processes of industrialization and urbanization, marked by the export of similar things. An early critic of tests, Justice John W. Goff of the New York Supreme Court, had ruled that 'Standardizing the mind is as futile as standardizing electricity'.<sup>74</sup> But Goff was wrong on both counts. Just as the spread of electrical networks rested on the agreements of negotiated electrical standards, so method of management in mass society could be seen to depend on negotiated standards of equivalent minds. Twentieth-century institutions – educational, military, workplace – would all be shaped by such arguments.

Second, feelings of difference were just as important as judgements of similarity; indeed, they were two sides of the same coin. In the United States, the progressive emphasis on efficiency went hand in hand with eugenic visions of a well-ordered society. Officers who imbibed this culture were more ready to accept the psychologists' claims. 'At the very least', concludes Carson, 'Progressivism's effects on the military were to predispose officers, when confronted with problems not amenable to traditional army solutions, to look toward techniques that could be deemed "scientific" as the answer to their needs.'<sup>75</sup> The results of intelligence testing fed directly into the eugenics debate. Well-publicized results included the average mental age of the American soldier (thirteen, when twelve was considered the

'upper limit of feeble-mindedness') and the relative performance of black and white soldiers. Both would be challenged in the 1920s and shown to rest on mistakes and hidden assumptions, but not before being accepted as scientific 'fact'.<sup>76</sup>

Psychology, then, rose in esteem as it contributed to the management of putting an army into the field. Other medical sciences were mobilized to keep soldiers at the front. Psychiatrists, for example, were called upon to make expert judgements in suspected cases of malingering. They were crucial to shaping the category of 'shell shock' in the First World War. The term was coined by Charles S. Myers, a psychologist who had built up experimental psycho-physics at Cambridge and travelled on the 1890s Torres Strait expedition, and later in the war would devise tests to help select the operators of acoustic submarine detectors.<sup>77</sup> Symptoms were extremely diverse, including uncontrollable shaking and the reliving of experiences, and some were sympathetic, such as stomach cramps inflicting soldiers who had been knifed in the gut and snipers who lost their sight. Nor was shell shock restricted to those who had experienced shelling by artillery, or even frontline experience. Interestingly, suffering varied according to relative agency: a man in an observation balloon, fixed, was much more likely to be a victim of shell shock than a pilot, who was mobile and self-directed. An intense debate raged between those who saw shell shock as a physical condition, a degradation of the nerves, and those who saw it as the result of damaged minds. Such a debate had clear and obvious relevance for old and new disciplines (psychology, physiology, psychoanalysis), as well as for military authorities, who wanted the men back in the field.

In Britain, one particular effect of the huge numbers of soldiers diagnosed as suffering shell shock was to break down pre-war attitudes, in particular the firm line drawn between the insane and the sane. If 'healthy young males' could so suddenly exhibit symptoms of neurasthenia, then fixed categories were called into question; 'shell shock' was the label for this 'no-man's-land'.<sup>78</sup> The trend was from physiological to psychological understanding. Physicians deploying psychoanalytic techniques, such as W. H. R. Rivers (another Torres Strait veteran) and William Brown at the Craiglockhart War Hospital in Scotland, treated shell shock with modified talking cures, replacing rest or electric shock therapies. Rivers, in *Science* in 1919, noted how the extraordinary conditions of war had both 'shown the importance of purely mental factors in the production of neurosis' and also led to a wider recognition of 'the importance of mental experience which is not directly accessible to consciousness'.<sup>79</sup> The psychoanalytic

argument ran that war enabled many unconscious desires and violent wishes to surface, which the repressing mind struggled to contain; indeed, 'all sorts of previously forbidden and hidden impulses, cruel and sadistic, murderous and so on', were being officially sanctioned in the soldier.<sup>80</sup> The result of this struggle was mental disintegration and shell shock. Collectively, the war was exposing civilization's repressed unconscious horrors. The First World War marked the entry of psychoanalysis into the working worlds of British medicine, where it was contested, while at the same time prompting an anguished national debate over morality, cowardice and war.

### The ratchet effect of war

Wars have a general tendency to sharpen debates between old and new ways of doing things. It is important to see science enrolled in both sides of the debate. It is entirely arguable that none of the horrific novelties of the First World War – the gas, the tanks, improved aircraft, the submarines and their defences – were as important as the contributions made by chemists and biologists to maintain traditional supplies. In a war where men and materials were brought to railheads but then were moved forward by horse, the feeding and supply of horsepower was critical. Max Delbrück, the elder, organized the industrial production of yeast as a means of producing well over half of Germany's animal feed during the war. The process used substrates nutrified by ammonia produced using Haber's methods. Indeed, it is in similar schemes that the historian spies early articulations of 'biotechnology'; specifically in Austria-Hungary the economist Karl Ereky copied and expanded Danish methods for huge pig farms, and reflected on the whole in a book titled *Biotechnologie*.<sup>81</sup> Another contribution to the production of bulk materials was made by Chaim Weizmann, who, drawing on methods developed at the Pasteur Institute, found a biotechnological way of turning starch into acetone and butanol, chemicals essential to the production of smokeless powder.<sup>82</sup> 'There is no truth in the story', writes historian Robert Bud, however, 'that the British Balfour Declaration, offering Palestine as a national home for the Jews, was made out of gratitude to Weizmann.'<sup>83</sup>

But perhaps there is truth in a generalization, of which the Balfour Declaration of 1917 is just one case, that the fluid, destabilizing, crisis conditions of war allow the articulation and introduction of policies that would be almost inconceivable in peacetime. Furthermore there

exists a recognized 'ratchet effect': measures introduced in wartime, often labelled temporary and justified by appeals to national security, have a habit of remaining in place after the conflict has ended.<sup>84</sup> Wars therefore also have the tendency to expand the state. When science and scientists were mobilized during the First World War, the result was not just a redirection of research programmes but also an increase in the interconnections between state and scientific institutions. (Indeed, institutions like the National Research Council in the United States were fashioned, by public scientists such Hale and Millikan, in a manner that preserved an apparent autonomy of science while nevertheless harmonizing science towards military agendas.) But did the ratchet effect apply to science policies? Were changes in science that were prompted by the conflict retained after the Armistice?

Generally, the civilian scientists mobilized during the First World War returned to civilian life afterwards. One interesting effect of this trend concerns women scientists. Less than 1 per cent of academic scientists in post in 1900 were women. However, in parallel with other sectors, a combination of the pressing demands for labour during a total war and the patchy social fluidity typical of wartime, plus the creation of new roles in a drawn-out, transformative conflict, formed the conditions encouraging scientific jobs for women. Thus it was that 'pressing manpower needs' created jobs for women in chemistry and engineering in countries such as Canada, Australia, England and Germany, while new applications, such as military X-ray medicine, were invented and staffed by women, including Marie Curie and Lise Meitner.<sup>85</sup>

At the war's end many scientists did indeed revert to pre-war occupations: Marie Curie to her radioactivity projects, William H. Bragg to University College London to continue X-ray crystallography, George Ellery Hale to California. Yet the return of civilian scientists to civilian posts should not be at all surprising, and should not be taken as evidence that the First World War had little lasting effect on science. Many civilian scientists retained linkages (such as Bragg consulting for the Admiralty) or, more importantly, fought to retain institutional gains. The fate of Hale's National Research Council is instructive. The council's success in coordinating research had increased government and industry's respect for academic science, physics in particular.<sup>86</sup> The Carnegie Foundation, previously reluctant, now raised the possibility of an endowment, placing the council on a secure, permanent financial base. Furthermore, scientists, such as Hale, who were deeply suspicious of government support for science, fearing government control of research agendas, enthusiastically embraced both the

notion of philanthropic funding and the institutional format in which the National Research Council was kept private and independent yet retained its unique status and constitutional responsibilities. Hale manoeuvred to persuade Woodrow Wilson to make the peacetime council permanent in this form. His wish, with a modification or two, was granted. 'We now have precisely the connection with the government that we need', crowed Hale.<sup>87</sup>

In Britain, war encouraged the making and retaining of an institutional landscape with some broad similarities to that in the United States. In 1913, to disburse the one penny per person collected under the introduction of national health insurance in 1911, a Medical Research Committee (MRC) had been set up. The committee decided to fund long-term medical research rather than target 'short-term specific problems', such as tuberculosis.<sup>88</sup> Before and during the war the government was subject to a constant tirade from public scientists who argued that their expertise was not being tapped sufficiently deeply or efficiently. These scientists formed a Committee for the Neglect of Science in May 1916 to press their case and to offer their services to government. However, the sting had been drawn from this would-be British NRC by the formation of a body closer to the centre of the state apparatus. First an advisory body, the Privy Council on Scientific and Industrial Research, was set up, in July 1915. This body mutated into the Department of Scientific and Industrial Research (DSIR), established on 1 December 1916. It was a complex, unusual body, half advisory council, half tiny government office. However, the DSIR could channel government funds to civil science while retaining, through its advisory council, a measure of autonomy.

But these civil bodies, created during the war, were dwarfed by institutions that channelled military expertise. Many military institutional innovations were retained, particularly in the technological fields opened up and expanded over the years of conflict. In Britain the Admiralty and War Office retained the expanded experimental establishments, such as the Admiralty Experimental Station at Parkeston Quay, Harwich, and the Royal Aircraft Establishment at Farnborough. In the United States, the National Advisory Committee on Aeronautics (NACA), which had been established in 1915 after the Smithsonian Institution, led by its secretary Charles D. Walcott, persuaded Congress, was retained. (NACA, much later, would transform into NASA.) While the budgets of many of these bodies were slashed in the difficult economic years of the aftermath, the more important point is that they were kept.

In general, historian William McNeill is right to see the industrialized, drawn-out conflict of the First World War as promoting a shift towards organization and, if not permanent mobilization, then towards further coordination and interconnection. Even if, as Alex Roland notes, following Carol Gruber, disharmony in government-military or science-industry relations 'arrested the enterprise [of cooperation and increased patronage] well short of its potential', we must also take such cries of dismay as evidence of the encouragement of unusual cooperation.<sup>89</sup> In the United States, and to some extent in Britain and France, the military had gained access to new techniques and expanded facilities; scientists had gained kudos from contributing to the war effort and prestige without sacrificing control. We will examine the situation in Russia later.

### Science and nationalism

However, Germany, imploding in 1918 and castigated as the aggressor, presented a profoundly different picture. The consequences for science in the new Weimar Republic will be explored in the next chapter. One of the conditions under which Weimar scientists worked was isolation caused by the breaking of international scientific links after 1918. In October 1914, in the first nationalistic spasms of the war, a manifesto carrying ninety-three signatures had appeared in German newspapers. It read, in part, as follows:

To Civilization!

As representatives of German sciences and arts, we hereby protest to the civilized world against the lies and slander with which our enemies are endeavouring to stain the honour of Germany in her hard struggle for existence – in a struggle that has been forced on her.

...

It is not true that Germany is guilty of having caused this war. Neither the people, the Government, nor the Kaiser wanted war . . .

And after denying the war atrocities in Belgium, including the destruction of the library at Louvain, these ninety-three 'heralds of truth' concluded:

It is not true that our warfare pays no respects to international laws. It knows no undisciplined cruelty. But in the east, the earth is saturated with the blood of women and children unmercifully butchered by the wild Russian troops, and in the west, dum-dum bullets mutilate the breasts of our soldiers . . .

It is not true that the combat against our so-called militarism is not a combat against our civilization, as our enemies hypocritically pretend it is. Were it not for German militarism, German civilization would long since have been extirpated . . . The German army and German people are one . . .

We cannot wrest the poisonous weapon – the lie – out of the hands of our enemies. All we can do is proclaim to all the world that our enemies are giving false witness against us . . .

Have faith in us! Believe that we shall carry on this war to the end as a civilized nation, to whom the legacy of a Goethe, a Beethoven, and a Kant, is just as sacred as its own hearths and homes.

Alongside the names of prominent scholars and artists, signatories included some of the most eminent names in German science, among them Fritz Haber, Max Planck, Wilhelm Wundt, Adolf von Baeyer, Paul Ehrlich, Emil von Behring, Emil Fischer, Ernst Haeckel, Philipp Lenard, Walter Nernst, Wilhem Ostwald and Wilhelm Röntgen. A counter-manifesto – a ‘Manifesto for Europe’ organized by the physiologist Georg Friedrich Nicolai – which drew the support of precisely four signatories, albeit including Albert Einstein, went unpublicized.

The scientific institutions of the Allied countries retaliated. Fellows of the Royal Society of London demanded that all Germans and Austrians be struck from the list of foreign members, while the French Académie des Sciences expelled those who had signed the manifesto.<sup>90</sup> George Ellery Hale, in communication with the French, vehemently agreed with the ostracization of German scientists, but also spotted an opportunity to reconstruct the institutions of international science in a manner against the interests of Germany. In early 1918, Hale proposed that each of Germany’s enemies should set up a body along the lines of his own National Research Council; these bodies would then federate as an Inter-Allied Research Council.<sup>91</sup> The result in 1919, after much politicking, was the creation of an International Research Council, a body composed of Allied and neutral countries, specifically designed to exclude the Axis powers. Japanese scientists were in an unusually delicate position since their institutional links were often to Germany, while in the war Japan had fought for the Allied cause.

True internationalists, such as the Dutch astronomer Jacobus C. Kapteyn, deplored this division of science, ‘for the first time and for an indefinite period, into hostile political camps’.<sup>92</sup> Internationalism, structured by technology and held to be the hallmark of science, had also been the theme of Nicolai and Einstein’s ‘Manifesto for Europe’:

Never before has any war so completely disrupted cultural co-operation. It has done so at the very time when progress in technology and communications clearly suggest that we recognize the need for international relations which will necessarily move in the direction of universal, worldwide civilization . . . Technology has shrunk the world . . . Travel is so widespread, international supply and demand are so interwoven, that Europe – one could almost say the whole world – is even now a single unit . . . The struggle raging today can scarcely yield a ‘victor’; all nations that participate in it will, in all likelihood, pay an exceedingly high price. Hence it appears not only wise but imperative for men of education in all countries to exert their influence for the kind of peace treaty that will not carry the seeds of future wars, whatever the outcome of the present conflict may be.<sup>93</sup>

One ‘man of education’ who set out to exert influence was the English astronomer Arthur S. Eddington, who organized an expedition to Brazil in 1919 to observe the light-bending effect on starlight, visible at the moment of solar eclipse, predicted by Einstein’s general theory of relativity. ‘The war had just ended, and the complacency of the Victorian and Edwardian times had been shattered. The people felt that all their values and all their ideals had lost their bearings’, recalled Ernest Rutherford. ‘Now, suddenly, they learnt that an astronomical prediction by a German scientist had been confirmed by expeditions . . . by British astronomers . . . [It] struck a responsive chord.’<sup>94</sup> Yet the expedition was no foregone conclusion: it faced intense anti-German opposition and only succeeded because of the driving belief of Eddington, a Quaker, in the pacifism exemplified, he thought, by international science. Furthermore the ‘collective memory of this test of Einstein’s theory as a straightforward and harmonious cooperation between scientists from nations embroiled in political conflict was not solidified until many years later’, notes historian of the expedition Matthew Stanley, and ‘it was only through Eddington’s deliberate presentation of the expedition as a milestone in international scientific relations that it came to have that valence.’<sup>95</sup> Nevertheless, the symbolism was perfect, and the results further heightened Einstein’s towering reputation: ‘A prophet who can give signs in the heavens’, wrote J. B. S. Haldane, ‘is always believed.’

In a controversial attempt to reassert the spirit of scientific internationalism, the Swedish Academy of Sciences pointedly awarded the first two post-war Nobel prizes to Germans. Furthermore, both – Max Planck (Physics, 1918, for energy quanta) and Fritz Haber (Chemistry, 1918, for the synthesis of ammonia) – had signed the ‘Manifesto of Ninety-Three’. Haber, in particular, was reviled as the

father of gas warfare. In contrast, German and Austrian scientists were banned from many international gatherings, such as the League of Nations' Commission internationale de coopération intellectuelle, which met in 1922, or the Solvay conferences, which restarted in the same year.<sup>96</sup> Likewise, the fifth international congress of mathematicians took place in Strasbourg, now of course a French city, and excluded German mathematicians.<sup>97</sup> However, in some fields, such as radioactivity research, professional and personal bonds were so strong that a truly international community survived the war; Rutherford, for example, organized the purchase of radium to support Meyer's Vienna institute.<sup>98</sup>

Science, wrote the American philosopher John Dewey in 1916, 'has not only rendered the enginery of war more deadly, but has also increased the powers of resistance and endurance when war comes'; yet, Dewey argued, the response to the catastrophe of war should be not to reject but to extend science:

The indispensable preliminary condition of progress has been supplied by the conversion of scientific discoveries into inventions which turn physical energy, the energy of sun, coal and iron to account . . . The problem which now confronts us . . . is the same in kind, differing in subject matter. It is a problem of discovering the needs and capacities of collective human nature as we find it . . . and of inventing the social machinery which will set available powers operating for the satisfaction of those needs.<sup>99</sup>

Dewey recommended that pupils be educated in the process of scientific inquiry, 'the only method of thinking that has proved fruitful in any subject', as he had emphasized in *How We Think* (1910). The method, once learned, applied to everything; teaching could start with 'varnishes or cleansers, or bleachers, or a gasoline engine'; 'without initiation into the scientific spirit one is not in possession of the best tools which humanity has so far devised for effectively directed reflection'.<sup>100</sup> Dewey's philosophy shaped interwar science education in the United States.

In general, however, the Great War was seen as a catastrophe for Western civilization, and some, citing gas and other technologies, blamed science for contributing to the horrific character of modern industrialized warfare. Herbert Kaufman, writing in the *Boston Sunday Herald*, to just pick one example, wrote:

For half a century we have liberally endowed, supported and encouraged the scientists. Community funds paid for the institutions in which they were educated and underwrote their experiments.

And all the while, we believed that these endeavors were promotions in the interest of civilization . . .

To-day we stand horror-stricken before the evidence of inhumanities only made possible through scientific advancement.

Chemistry, you stand indicted and shamed before the Bar of History! . . . You have prostituted your genius to fell and ogreish devices . . . You have turned killer and run with the wolf-pack.

But we will reckon with you in the end.

This particular diatribe was shrugged off in the August 1916 letter pages of *Science*: 'To blame chemistry for the horrors of war', one commentator noted, was 'a little like blaming astronomy for nocturnal crime';<sup>101</sup> yet the wider point was conceded: 'science has increased the amount of suffering war inflicts'. That science could be so implicated in the catastrophe of civilization of the First World War contributed to a general sense of crisis that marked the post-war years, no more so than in Germany.

## 5 SCIENCE AND THE FIRST WORLD WAR

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