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In March 1908, the BASF at Ludwigshafen provided financial support to Fritz Haber in his attempt to synthesize ammonia from the elements. The process that now famously bears his name was demonstrated to BASF in July 1909. However, its engineer was Haber’s private assistant, Robert Le Rossignol, a young British chemist from the Channel Islands with whom Haber made a generous financial arrangement regarding subsequent royalties. Le Rossignol left Haber in August 1909 as BASF began the industrialization of their process, taking a consultancy at the Osram works in Berlin. He was interned briefly during World War I before being released to resume his occupation. His position eventually led to His Majesty’s Government formulating a national policy regarding released British internees in Germany. After the war Le Rossignol spent his professional life at the GEC laboratories in the UK, first making fundamental contributions to the development of high-power radio transmitting valves, then later developing smaller valves used as mobile power sources in the airborne radars of World War II. Through his share of Haber’s royalties, Le Rossignol became wealthy. In retirement, he and his wife gave their money away to charitable causes.

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INTRODUCTION

On 29 March 1976, Dr Ralph Chirnside, a long-time friend and colleague of Robert Le Rossignol’s at GEC’s Wembley laboratories, visited the 91-year-old at his home near Beaconsfield. Chirnside was a member of the Committee of the Royal Institute of Chemistry and his visit was connected with their centenary celebrations the following year. The Committee felt that it would be an appropriate occasion to refer to the contributions that had been made by some of its most distinguished members. Chirnside informed the Committee that he would invite Le Rossignol’s co-operation with this endeavour in an attempt to put on record the important part he had played alongside Fritz Haber in creating a technology for nitrogen ‘fixation’ via the high-pressure synthesis of

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ammonia from its elements. Chirnside had been given an ‘impressive list’ of members who were several years older than Le Rossignol, but none he could recognize whose achievements were a match. Even so, he commented that ‘very few British chemists today seem to know this’. Chirnside’s subsequent conversation with Le Rossignol was tape-recorded and a transcript remains with the family. A few weeks later Le Rossignol passed away. Some of what they discussed appeared in Chirnside’s sincere obituary of Le Rossignol, but, despite his best intentions, little of what the two men put on record that day has ever entered the history of chemistry.

But Chirnside’s interview was not the only attempt to recognize Le Rossignol’s achievement. Haber never tired of praising him: at the Scientific Union meeting at Karlsruhe in 1910, the Hurter Memorial Lecture in 1913, and again in his Nobel Prize acceptance speech in 1920. In 1928, the German scientific elite invited Le Rossignol to contribute to a Festschrift in Naturwissenschaften to celebrate Haber’s sixtieth birthday, and when Johannes Jaenicke began researching Haber’s life in the late 1950s with a view to a biography, it was to Beaconsfield he came. Jaenicke described Le Rossignol as one of Haber’s ‘oldest and most trusted employees’, whose ‘opinions stood well above others as a competent referee for Haber’s life’.

In conversation with Jaenicke on 16 September 1959, Le Rossignol gave an account of his role in the discovery of ‘fixation’. Acerbic, sometimes sarcastic, perceptive, frank and comical, yet always respectful of Haber, this unique account redefines our understanding of the discovery of the technology. For, in Le Rossignol’s words that day: ‘Haber did the theoretical side, and I did the engineering side . . . I did the practical work . . . I had nothing to do with the business side . . . [and] . . . Haber did the whole of the patent matter.’ Like Chirnside, Jaenicke ‘recorded’ the conversation in a detailed transcript, and Le Rossignol may well have looked forward to seeing his recollections published in Jaenicke’s biography. But in the late 1980s – long after Le Rossignol’s death and overwhelmed by his task – Jaenicke deposited his research at the Max Planck Society in Berlin – and then walked away. Based on this ‘treasure trove’, the late 1990s and early 2000s saw several biographies of Haber appear. But Jaenicke’s transcript has remained biographically dormant. None of the biographies – not even the monumental effort by Szüllössy-Janze – has ever tempered Haber’s singularly dominant position in the history of ‘fixation’ by evaluating the importance of his contribution(s) with respect to Le Rossignol’s experimentation and engineering. The story is therefore unbalanced, and although Chirnside’s transcript has only recently been made biographically available, it concurs with other evidence which shows that Haber’s position in the history of ‘fixation’ may be less assured than his award of an individual Nobel Prize would otherwise have us believe.

UCL AND THE TECHNICAL HOCHSCHULE, KARLSRUHE

Robert Le Rossignol was born at 17 David Place, St Helier, on 27 April 1884, the fourth child of Augustin and Edith. His father was in medical practice. Educated first at Victoria College Jersey, Le Rossignol graduated in chemistry (Second Class) in 1905 from UCL under William Ramsay (figure 1). He won the department’s gold medal for experimental excellence in his first year (1901), and even as an undergraduate he was published: in physical chemistry and radio-chemistry; and then as a postgraduate in organic chemistry. In 1906 he was elected a Fellow of the Chemical Society, and in the same
year he became an Associate Member of the Institute of Chemistry of Great Britain and Ireland.\textsuperscript{13} Crucially too, he was ‘always interested in mechanics’ and at UCL he had taken a course in engineering alongside chemistry and had access to the practical skills that would be necessary for him to provide a solution to the problem of ‘fixation’.\textsuperscript{14} One

Figure 1. A fragment of a photograph from the UCL archive, taken in 1904. William Ramsay is seated, second from the left, in the second row. Robert Le Rossignol appears seated at the end of the same row. This is the earliest available photograph of Le Rossignol. (Courtesy of Professor Alwyn G. Davies, FRS.)
must also be aware that Ramsay was an outstanding experimental scientist and his laboratory was a foundry of innovative experimentation. Much of this demanded a high degree of practical aptitude and technical knowledge. Such an environment ideally suited Le Rossignol and the skills he developed there are admirably reflected in his early undergraduate and graduate publications.

Le Rossignol began working with Haber at Karlsruhe in September 1906, but it was not Haber’s fame that attracted him. That summer, Le Rossignol, his father, Augustin, and his sister, Elsie Edith, took a holiday in Switzerland. Here he met a friend who described Haber as ‘a very nice man’, and as Karlsruhe was close to the Black Forest Le Rossignol found that ‘a great attraction too!’ And so he travelled to Germany to spend ‘three glorious years’ with Haber. Le Rossignol described the early months as a ‘happy time for everybody’, and Haber as just a charming ‘big boy’. He ‘could not have been nicer’; he was never the ‘Herr Professor’, he was down-to-earth and he could enjoy things thoroughly. He was also extremely kind and he would find time to help everybody, Le Rossignol often being invited to Haber’s home to improve his German. Le Rossignol also came to Karlsruhe at probably the happiest time in Haber’s life; J. E. Coates – a contemporary – later recalled his own time there:

‘One remembers summer evenings around a punch bowl in the Stadtgarten, or walks through the woods to some favourite Gasthaus, when [Haber’s] lively spirit, his stories and charming ways were a great delight.’

Le Rossignol and Haber got on well together. Both men were from ‘old families’, comfortable with the values such a provenance provides. Neither showed any ‘spectacular’ early academic promise but both became professional physical chemists via organic chemistry, each eventually developing an interest in chemical technology. Both men also felt that they came to Karlsruhe purely by chance. At Karlsruhe, these two formed one of the most important partnerships in the history of chemistry, a partnership of two quite different personalities. Determined, but ‘kindly’, and with a ‘simple uncomplicated philosophy of life’, Le Rossignol was a calm character, able to accommodate both triumph and disaster alike. Haber, in contrast, was precocious and characterized by restlessness, creativity, an enthusiasm for all things new and a burning ambition to do well. His attitude to his chosen vocation was very much the ‘gentleman scientist’, where considerations of ‘reward’ were measured in terms of honour, service, patriotism, respect and fame. But financial reward was important too, and this dichotomy introduced tension and complexity into his later life. Le Rossignol was an example of a more modern genre, the scientist as employee, the ‘professional chemist’, more the ‘tradesman’ – a tendentious yet accurate description – where reward was measured simply in terms of money to make a living. These two philosophies were complementary and over the years many indicators of Le Rossignol’s importance to Haber can be found. But even at this early stage, Haber realized that he had acquired a particularly able student. Through Coates’s lecture we see why he came to regard him so highly:

[Haber’s] scientific work was never lacking in thoroughness and attention to detail. It is true however that he found no deep interest in the minutiae of experimentation as such. He liked his men to be clever experimenters and greatly appreciated good work by them, but he expected them to work out the finer details.

Coates’s view was echoed by Le Rossignol, who once commented of Haber in the laboratory: ‘we used to laugh ... he was just doing something and it went off ... bang!’
And Le Rossignol recalled that Haber had ‘little knowledge’ of engineering. Here then was the basis of Haber’s appreciation of his new student. A few semesters after arriving at Karlsruhe, Haber appointed Le Rossignol as his personal assistant, and in October 1907, when Arthur B. Lamb’s English translation of Haber’s internationally acclaimed book on gaseous thermodynamics was published, it was Le Rossignol who provided the translation for the Appendix to Chapter Five. Finally, of all the capable students Haber had gathered at Karlsruhe, when confronted with Walther Nernst’s private criticism of his work for the Margulies brothers, it was to Le Rossignol that Haber turned to repeat the experimentation upon which his reputation depended.

**THE MARGULIES BROTHERS, WALther NERNST AND NITROGEN FIXATION**

It had long been known that the simplest way to ‘fix’ nitrogen was via the elemental synthesis of ammonia (NH₃). Ammonia could then be converted into valuable nitrogenous fertilizer or to nitric acid, a precursor to many important industrial chemicals. Around 1903–4, Haber received an unexpected request from the Margulies brothers of Vienna. They had detected traces of ammonia in their chemical plant and wondered if they had stumbled upon a viable method of making this valuable chemical. There had been many attempts to promote a reaction between nitrogen and hydrogen, none of which had succeeded. Haber, therefore, was noticeably uninterested in this opportunity. However, persuaded by their generous financial offer, he and his student Gabriel van Oordt spent the summer of 1904 investigating a process that the two brothers had suggested. Preliminary experiments indicated little hope for their method. Haber then decided to examine the thermal synthesis of ammonia from its elements at 1020°C using an iron catalyst. His understanding was that, whatever the pathway to ammonia, the yield was governed by the position of the ammonia equilibrium in what was suspected to be a reversible process:

\[
\frac{1}{2} \text{N}_2(g) + \frac{3}{2} \text{H}_2(g) \rightleftharpoons \text{NH}_3(g) \quad \Delta H_{298}^\circ = -46.2 \text{kJ mol}^{-1} \quad (1)
\]

Haber looked at this reaction from both sides, formation and decomposition, sequentially in the same apparatus. He conducted the experiment at atmospheric pressure, placing two reaction tubes in series in an oven, each followed by an ammonia absorption bottle (figure 2). Passing ammonia into the first tube, the decomposition equilibrium was established:

\[
\text{NH}_3(g) \rightleftharpoons \frac{1}{2} \text{N}_2(g) + \frac{3}{2} \text{H}_2(g)
\]

Residual ammonia was absorbed and the remaining nitrogen and hydrogen entered the second tube, establishing the formation equilibrium:

\[
\frac{1}{2} \text{N}_2(g) + \frac{3}{2} \text{H}_2(g) \rightleftharpoons \text{NH}_3(g)
\]
The yield of ammonia, however, was predictably low, 0.005–0.012% – although Haber favoured the higher value as representative. He published his results in 1905, then dismissed the whole episode. But his choice to publish at the higher yield set in motion a series of events that began his collaboration with Le Rossignol, defined his career as a physical chemist and led to the ‘most important technical invention of the twentieth century’. Had he chosen the lower figure, these events might never have occurred and the ‘Great War’ might well have been ‘over by Christmas’ because of Germany’s inability to ‘fix’ sufficient nitrogen for her munitions.

Soon after Le Rossignol arrived at Karlsruhe, Haber received a letter from Walther Nernst challenging these results. Using his new ‘approximation formula’, Nernst examined all the published data for gaseous equilibria. Encouraged over a range of reactions where his formula correctly predicted yields, he found that there was disagreement in the single case of Haber’s figures for ammonia. Haber’s yield was larger than Nernst’s formula predicted. The two men were to resolve their differences at the Bunsen Society meeting in Hamburg in May 1907. In the meantime, Haber asked Le Rossignol to repeat van Oordt’s work using the same apparatus but with greater care. Much was at stake. This work was to be publicly examined by Germany’s pre-eminent physical chemist and, sound as Le Rossignol’s efforts later proved to be, he recalled that ‘Haber was afraid’. The men met on 12 May 1907. Nernst’s presentation – a repeat of Haber’s work – was clinical. His paper contained just two pages and seven results – between 685°C and 1040°C. Nernst studied the equilibrium using a platinum catalyst at 50–70 atmospheres (atm) to maximize the percentage ammonia formed. Having adjusted his figures to Haber’s atmospheric pressure, he moved to the theoretical calculations using his ‘approximation’ formula. Here, ad hoc ‘corrections’ to some of the constants were made, justified with arbitrary comments such as ‘which proved more useful in practice’ or ‘was too low’. Finally, he reduced his complex equation to one of imperious mathematical austerity, and compelling agreement was achieved between his theory and his practice. But Nernst was beguiled by the ‘large’ amount of ammonia he produced and failed to recognize that his was a poor equilibrium.

In a discussion that followed Nernst’s presentation, Haber rose to describe Le Rossignol’s experimentation and his own calculations. These two men had laboured for months on the revised investigation and had submitted a substantial paper to the Society. Forty-nine separate experiments were reported at six different temperatures using four different catalysts. But the transcript of Haber’s ‘presentation’ shows that it was curiously defensive and not at all representative of their work. He immediately withdrew his earlier value of 0.012% ammonia because Le Rossignol’s new figures could not justify it. He presented a single table summarizing Le Rossignol’s experimental results and then...

Figure 2. The Haber–van Oordt apparatus. (From Haber, op. cit. (note 10), p. 260.)
proceeded to describe his own calculations. Le Rossignol’s results responded well to
treatment by both the conventional approach and Nernst’s ‘approximation formula’
without modification of the various constants. The agreement between theory and practice
was almost perfect, but Le Rossignol’s figures were still significantly higher than
Nernst’s. In the exchange that followed, Nernst was brutal. He described Haber’s previous
figures as ‘severely inaccurate’ and the new figures, with yields of only a fraction of a milligram, as equally suspect, ‘suggesting’ that the two men should now operate at higher
pressures to improve their accuracy. Nernst’s authority carried the day and a consensus
soon emerged that the Haber–Le Rossignol figures were inaccurate.

Convinced of their procedures, Haber and Le Rossignol began another investigation at a
modest elevated pressure of 30 atm. Their results were published in April 1908, and
here, in what Coates later described as a ‘beautiful piece of work’, they comprehensively
responded to Nernst’s criticisms. Le Rossignol first showed that Nernst’s equilibrium
was ‘very bad’. His re-examination of Nernst’s ‘simple’ experimental arrangement (Nernst’s
own description of his apparatus) identified problems with the oven, diffusion from the
reaction tube, difficulties with impurities, formation of a film on the surface of the catalyst,
and residual carbon dioxide in the commercial gases used by Nernst – but unaccounted for
in his calculations. As none of this had been addressed, Nernst’s figures would always lie
on the side of reduced yields of ammonia. Le Rossignol’s experiments also probably
introduced what was to become an essential component of high-pressure chemistry, his
special ‘conical valve’. With this device, Le Rossignol achieved precise control of the gas
flow, performing 56 pressurized experiments of ammonia formation/decomposition using
manganese and iron as catalysts, reporting a series of these in temperature groups of 700°C,
800°C, 900°C and 974°C – the most detailed examination thus far. Haber then wedded Le
Rossignol’s experimental results to contemporary theory. And, even though the ammonia
synthesis had a fearsome reputation, he showed that there was nothing unusual about the
reaction, being described perfectly well by both the standard thermodynamic equations of
the day and the ‘approximation formula’. The implication was obvious. Furthermore, after
Hamburg, the two men permitted themselves a little indulgence that, in view of their new
results ‘Herr Nernst was not entitled to his previous objections’.

But this paper provided something else really quite surprising – for Haber at least. It was
not the fact that he was right about the position of the equilibrium, nor the ease with which
he achieved agreement between theory and practice, but rather the ‘comfort’ with which
pressurized gases could be controlled and moved through an apparatus with an innovative
but otherwise entirely conventional level of technical engineering. In this regard, Haber
was overwhelmed by Le Rossignol’s ability, calling him ‘a true engineer!’ and
although Haber had gathered considerable scientific talent at Karlsruhe, many of whom
were to go on to achieve careers of distinction, in all ‘things ammonia’ he came to rely
on and respect Le Rossignol above all others.

With regard to the origin of Le Rossignol’s interest in engineering, the transcripts shed
little light. But what is almost certain is that he must have known that the transport of
gas(es) at high pressure was easily achieved. Engineering of the required type already
existed at UCL. Morris Travers’s hydrogen liquefier was initially a primitive device
constructed using a beer barrel to generate hydrogen from zinc and sulfuric acid, a 100 ft³
steel gasometer, copper tubing and blanks from Clerkenwell in London, an exhaust pump
borrowed from a student, a compressor used for charging torpedoes, and valves made
within the department. Yet this arrangement easily circulated hydrogen gas at 180 atm
through the liquefier during Le Rossignol’s time there. And as the liquefier was operated by ‘senior students’ in the department – and Le Rossignol was certainly one of these – he must have been familiar with its construction, operation and maintenance.51

By April 1908 the ingredients for something spectacular were coming together at Karlsruhe. Although not the original intention, Le Rossignol’s experimentation suggested an industrial application which, because of low yields, operated on a continuous circulation – not a batch – basis.52 But it demanded high temperatures, extraordinary pressures and an efficient – as yet undiscovered – catalyst. Nothing like it existed in the world of technical gas reactions at the time, but Le Rossignol’s uncommon ability to blend theoretical understanding with accurate experimentation and innovative engineering convinced Haber to move from the purely academic study of the ammonia equilibrium and consider the possible creation of an industrial ‘fixation’ technology.

The development of high-pressure ‘fixation’

The creation of a pilot technology based on Le Rossignol’s model would represent ‘perhaps the most demanding technical chemical project ever undertaken in an academic setting’,53 but Haber began to favour this route even though he had been investigating a more popular route at the time, the ‘burning of air’ in the electric arc.54 The latter attracted the support of the BASF at Ludwigshafen, and on 6 March 1908 Haber concluded two contracts with them. In the first, BASF offered him a share in their profits from any patentable, productive, arc development. But Haber also insisted that BASF support his efforts to synthesize ammonia. Through a second contract, he again secured a share in profits and a larger salary for Le Rossignol, describing him as ‘indispensable’; in return, BASF imposed commercial secrecy regarding collaboration and publication.55 But subsequently, on 1 May 1908, Haber made an additional private financial arrangement with Le Rossignol, one which promised him 40% of his ‘royalties’ if he helped him achieve a technically feasible, patentable ammonia synthesis.56 Other indicators aside, there could be no greater recognition of Le Rossignol’s importance to Haber, for the potential profit from ‘fixation’ in Germany alone – and worldwide by licence – was of ‘stellar’ proportions. Quite simply, with this ‘generous arrangement’, as Chirnside later called it,57 Haber was offering to pay Le Rossignol to solve the engineering problems for him. And his confidence was well placed because within a year, beginning with the purchase of a compressor,58 Le Rossignol’s engineering created a process of elegance and efficiency, while simultaneously delivering commercially appealing yields of synthetic ammonia.

Haber was a reluctant experimentalist.59 At Karlsruhe, he had long been moving from the ‘lab to the log’, beginning with the arrival of Hans Luggin there in 1896. Luggin’s interests were in thermodynamics and electrochemistry and in 1898 Haber published a well-regarded textbook on electrochemistry,60 followed later by his acclaimed work on gaseous thermodynamics.61 The working relationship that Haber subsequently developed with Le Rossignol mirrored that which previously existed at UCL between Le Rossignol and George Donnan, who in 1903 published a joint paper,62 in which Le Rossignol performed the experimentation and Donnan the theoretical calculations.63 Such became the division of work at Karlsruhe.64 But as far as engineering was concerned, Haber was really just a facilitator. He provided funding and the environment; he procured samples of ‘exotic’ materials as candidate catalysts;65 he orchestrated developments with BASF; he
continually suggested, enthused and kept spirits high when problems arose; and in their private arrangement he provided the greatest incentive for Le Rossignol to succeed. But his lack of engineering skill meant that Haber’s suggestions were not always practical. For example, he suggested ammonia be removed by absorption, then released by lowering the pressure. But this represented an interruption to a continuous process, Le Rossignol pointing out that it was better to ‘trap’ (liquid) ammonia by cooling, returning the ‘remainder’ gases to the catalyst. This kind of insight, coupled with the skills to make it happen, allowed him to provide a solution.

But in the history of the discovery of ‘fixation’, biographers demand that we should consider another: Haber’s technician, Friedrich Kirchenbauer. So what of his involvement? We know that Haber never entered into any kind of financial arrangement with Kirchenbauer, and neither did he submit any patents nor publish any papers with him. Indeed, communication between the two must have been difficult, because Haber could not understand Kirchenbauer’s Pfälzer dialect, and, according to Le Rossignol, Kirchenbauer – although a skilful engineer with whom he ‘got on well’ – had to be ‘advised … what things should be done’. So, facilitated by Haber, but supported by Kirchenbauer, Le Rossignol engineered a machine around a process that continuously circulated a 3:1 mixture of hydrogen and nitrogen at 180–200 atm and 500–600°C over a catalyst, removing the ammonia as a liquid, and returning the ‘remainder’ gases – replenished with a fresh charge of the mixture – to the catalyst. To minimize thermal work he used the exothermic nature of the synthesis (Equation 1) to pre-heat the incoming gases, and used the warm gases entering the liquefier to heat the cold gas returning to the catalyst. So ‘appropriate’ was his solution that it was replicated by Carl Bosch in his industrialization of the process; and of all the components necessary to achieve success, three are of particular historical importance, viz. Le Rossignol’s conical valve (figure 3), his circulation pump and the catalyst(s).

‘Conical valves’ had been around for almost a century. However, Le Rossignol’s valve had a new and innovative aspect to qualify it for a Gebrauchsmuster (basic copyright protection). Described contemporaneously as a ‘needle’ valve, it used a conically tapered pin – the needle – inserted into the valve inlet to open gradually an annular space for finer control of flow. The design of this valve was recorded in Germany in March 1908, before the construction of the fixation apparatus began, because it had nothing to do with that engineering, being developed earlier for a friend. The valve became a critical component in high-pressure chemistry and Le Rossignol’s name became famous in Germany, but not for ‘fixation’. Today, his ‘needle’ valves are ubiquitous.

The circulation pump, too, has historical significance. On 26 March 1909, a group from BASF – including Carl Bosch – was invited to Haber’s laboratory to examine the machine, by then producing liquid ammonia at ~1 cm³ min⁻¹. Bosch was never involved with the discovery of ‘fixation’ in any ‘hands-on’ sense, but there were nevertheless many technical questions. One in particular which Le Rossignol recalled was Bosch’s inquiry of the pump: ‘what about the dead space?’ To circulate the gas, Le Rossignol designed and built a ‘double-acting’ reciprocating pump, capable of moving gas smoothly at approximately 72 m³ hr⁻¹. Le Rossignol was surprised by Bosch’s ignorance and he had to explain that the dead space played no role in the ‘trap’ because liquid ammonia behaved like water, thinking to himself: ‘You don’t know that much, great Bosch!’ For such a young man as Le Rossignol was then, to have to explain this to Bosch indicated just how innovative his engineering was.
But engineering was not the impediment; rather it was the difficulty of discovering an efficient catalyst. The transcripts make clear that neither Haber nor Le Rossignol were experts in catalysis, candidates being examined on a trial-and-error basis, but yields were always disappointing. The breakthrough came when Haber procured ‘exotic’ samples of osmium and uranium. These increased yields to a point where the BASF were again invited to Karlsruhe to convince them to adopt the technology. On 2 July 1909 the final version of Le Rossignol’s machine was demonstrated using osmium. After an initial period when repairs had to be made, it began forming liquid ammonia at about 6 or 7 p.m. That night it made 500–600 g of ammonia, and BASF were utterly convinced. What was to happen next would be out of Le Rossignol’s hands, but he realized that he was part of an historic occasion and he obtained a memento of the day: two 6-inch sealed...
glass capillary tubes about two-thirds full of the first synthetic ammonia. He kept them for almost 44 years. On 3 January 1953 he donated both tubes to the Science Museum in London.85

THE ANTEBELLUM

Haber and Le Rossignol were to play no part in the subsequent industrialization of their process, and in August 1909 Le Rossignol left Karlsruhe for the Osram lamp works in Friedrichshain, Berlin, where both Haber, 86 and Max Meyer, 87 had secured a consultancy for him. Today, the electric lamp is ubiquitous, mundane and noticed only when it fails. But in the early part of the last century the technology attracted the best brains and intense research effort. Le Rossignol’s brief concerned tungsten, ideally suited as filaments, but brittle. Work on tungsten had been conducted by Coolidge and Langmuir in the USA and Le Rossignol went there in 1910 and 1912 to study their techniques.88 In 1910 he stayed with Coolidge at Schenectady, the trip doubling up as a honeymoon with his wife, Emily.89 Agnes Emily Hedwig Walter (b. 21 January 1885) was the youngest daughter of Carl Walter of Karlsruhe, and the couple were married there on Tuesday 11 October 1910, the announcement of their marriage appearing in The Times of London the following Friday. Le Rossignol later described this combination of business and honeymoon as ‘not a good mixture!’90 Subsequently, he had some success regarding ductility, but Osram were not enthusiastic and it fell to Coolidge to revolutionize the whole business with his ‘swaging’ technique.

In Berlin the Le Rossignols lived comfortably at Prinzregentenstrasse,91 their commitment to Germany strengthened with the birth there of their first son, John Augustin, in September 1911. Haber remained at Karlsruhe as BASF began the industrial uptake of their process. The starting point was the search for a catalyst, osmium and uranium being soon discounted.92 As early as January 1910 a replacement was found and they moved to find an economic supply of hydrogen and nitrogen, and to construct the high-pressure converters at a pilot plant at Ludwigshafen.93 Haber however became impatient regarding publication, BASF eventually agreeing to a meeting in Karlsruhe on 18 March 1910.94 Here Haber exhibited the high-pressure apparatus and described the circulation process. His lecture was reported widely. On 18 May 1910, The Times carried an article on ‘The synthetical production of ammonia’ and – for the first time – dubbed it the ‘Haber’ process, even though they reported that Haber had conducted ‘a series of experiments with the assistance of Mr R. Rossignol’.

By 1911 BASF had perfected the production of the feedstock gases. The same year saw the resolution of the problems with the high-pressure converters, annual production of ammonia reached approximately 11 tonnes, and plans were in place to construct a ‘nitrogen’ (fertilizer) plant at Oppau near Ludwigshafen.95 In September 1912, at the International Congress of Applied Chemistry in New York, BASF ‘loosely’ described their new patented process and announced that the Oppau works were then under construction. The patents, however, had been challenged in the German national courts in March 1912. But the challenge was dismissed – ironically by the intervention of Nernst.96 Later, Nernst met Le Rossignol in Berlin, confiding in him that even he could not have done the ammonia work better, to which Le Rossignol replied that ‘he had been [their] best friend’,97 adding, ‘Herr Geheimrat, es war auch mit Ihre Hilfe’;98 Nernst, he
said, ‘swallowed it like butter’, inviting him to meet Einstein at a dinner at the Berlin Automobile Club. With success at the courts, dining with the European scientific elite and the prospect of significant wealth, life was good for Le Rossignol. A second son, Peter Walter, was born at Prinzenregentenstrasse in August 1913.

The Haber–Le Rossignol relationship sprang to life again some years before that, when Haber became the director of the new Kaiser Wilhelm Institute in Berlin in 1911, a position which finally allowed him to escape the ‘finer details’ of the laboratory and to concentrate on the development of research groups in the established areas of physical chemistry, physics and colloid chemistry, and eventually in areas as diverse as textile chemistry and insect pest control. From Berlin the two men published together once more in February 1913, having at last been granted permission by BASF to disclose their original work. On 28 May 1913 The Times ran a detailed article clearly identifying ‘the Englishman’ Le Rossignol as Haber’s partner. However, by September 1913, Oppau was fully functional so their paper was technically obsolete and the two men were soon to receive royalties. Later, on 26 November 1913, Haber gave the Hurter Memorial Lecture at Liverpool University, where he addressed the ‘fixation’ of nitrogen via the ammonia synthesis, sincerely acknowledging the role of Robert Le Rossignol. He also revealed that the industrialization of their process had now been completed, to the great benefit of all ‘agriculturalists’.

The first full year of production at Oppau was 1914, the year the Great War began. For Haber, his role in gas warfare was to eclipse his contribution(s) to chemistry. Even today, blood-red graffiti spelling the word ‘Mörder’ (Murderer) is sometimes found daubed at the University in Karlsruhe as young students recall Haber’s role. For the Le Rossignols, their commitment to one another through marriage had already isolated them in the eyes of the German state. Under the German citizenship law of 1870, women lost their status by marrying someone without German nationality. At the time Le Rossignol regarded himself as ‘not quite a real German’, neither therefore were Emily nor the children. The Le Rossignols may well have considered leaving Germany prior to the war. But their position in terms of citizenship had to be balanced against their prospect of significant, legitimate financial gain. Europe, of course, had been simmering for years, but the events at Sarajevo caught everyone by surprise. When Great Britain unexpectedly declared war, the Le Rossignols were still in Berlin. They were to remain there until December 1918, not from choice but owing to Germany’s decision to intern British male citizens.

**BERLIN, 1914–18**

Internment began on 6 November 1914. The process was completed within three weeks and was to proceed ‘firmly’ but ‘without brutality’. A ‘short-term’ camp existed in Berlin at the disused Ruhleben racecourse, and this, because of ‘circumstance’, became the main camp for British internees throughout the war. Le Rossignol’s address at Prinzenregentenstrasse placed him in close proximity to the Ruhleben camp so he was easily arrested on the very first day of internment. Over the next three weeks, internees streamed into Berlin, but Ruhleben was hardly prepared. It had eleven stable blocks which served as barracks for the prisoners, housed both in the horse-boxes themselves and in the lofts above (figure 4). The boxes were about 12 feet square and into each
one six men were packed. Those in the lofts fared no better, and in these spaces over 300 men had to live, eat, sleep, wash and dry their linen.

As for those articles necessary for some semblance of civilized life, provision was equally mean. Each man was given a coarse towel, a tin bowl to hold his food and nothing else. There were no knives, spoons, forks, plates, cups, nor cakes of soap. These could be purchased but many had no money and had to wash without soap, eat with their fingers and drink from the tap. Exercise, too, was a problem. Men had to exercise in the stable yards. The soil was sandy and loose and as there was no provision for drainage it quickly transformed into mud when it rained – and there was much rain in the autumn of 1914. Puddle merged into puddle and through this cold quagmire men had to wade up to three times a day to fetch food from the kitchens and to reach the latrines that the American ambassador described as ‘a danger not only to the camp but to Berlin’ for no disinfectant was ever provided by the authorities. To this was added the pitiless, piercing winds from Poland and the Pinsk marshes that cut the camp each winter.

Although Le Rossignol left no record of his internment, the evidence suggests that it was a deeply humiliating experience, and such as he would not have taken easily to it. These were members of the comfortable middle classes, used to the finer aspects of life, thoroughly integrated into elite German society and with no tendency towards any form of social disruption or national subversion. Ruhleben turned Le Rossignol’s life ‘upside-down’. His internment coincided with the time when the camp was at its worst, when it was overcrowded and volatile, and during a cold, wet winter – the coldest ever recorded in western Europe. But unexpectedly, on 22 March 1915, he was released to Berlin ‘for the purpose of resuming his former occupation’. Charlotte Haber’s memoirs explain the reason why: that it was ‘as a result of the direct intervention by Haber in exchange for
the release of a German interned in England’. Haber’s intervention reflected the high regard he had developed for Le Rossignol over the previous eight years. It is quite remarkable that he found time to lobby on Le Rossignol’s behalf when otherwise fully engaged with matters of national importance, such as the preparation for the gas attack at Ypres/Langemarck. Nevertheless, Le Rossignol was now ‘free’, but on his release ‘his trace was lost’, as he stepped ‘into the shadows’ and returned to Osram to do ‘what he liked’, which meant investigating new ways of exhausting lamps. His work here led to patents being filed across Europe and in the United States in October 1916. The distribution of these applications shows that the improvements were internationally significant in terms of the manufacturing of the lamps, leading to improved lifetimes and economies in effort and raw material, and facilitating automated mass production. They also made considerable progress towards the way in which lamp exhaustion was later to become standardized. Soon, this work assumed an unexpected importance.

**HIS MAJESTY’S GOVERNMENT, 1916–17**

On 31 October 1916 the American embassy in Berlin sent a dispatch to its sister embassy in London. It referred to

> an enquiry made by Mr Robert Le Rossignol, released to Berlin for the purpose of resuming his former occupation, whether any disapproval on the part of the British Government exists, and whether, in case of his eventual return to England, he would subject himself to censure or loss of standing.

This note generated a flurry of communications at the highest levels in the British Government, communications which included those of figures such as Lord Newton, Assistant Under-Secretary of State for Foreign Affairs, in charge of two departments at the Foreign Office and Controller of the newly established Prisoner of War Department, and Arthur Balfour, the former Prime Minister, then Foreign Secretary from 1916 to 1919. However, the Government’s initial reaction was hesitant, for there seemed to be no policy in place to deal with such requests and no indication of what Le Rossignol’s ‘former occupation’ was. Considerations were passed to the various departments and, as a consequence, the Foreign Office suggested placing any responsibility for his position firmly on Le Rossignol’s shoulders. But the Ministry of Munitions soon discovered that Le Rossignol had worked closely with Haber on synthetic ammonia – a vital German war resource – and that he was a Fellow of the Chemical Society, married to a German lady, and they considered it ‘probable’ that the production of ammonia may well be the ‘former occupation’ to which he was returning.

As deliberations progressed, Le Rossignol’s case was raised personally by the American ambassador in Berlin who expressed frustration that his enquiry was one of many received by the embassy but that there was no guidance as to what should be done. In such cases, Ambassador Gerard made a practice of advising men that, where the work was not concerned with the manufacture of the materials of war, it would probably not be unpatriotic to accept the employment. The embassy therefore acted unilaterally, but Le Rossignol’s case eventually led to the Home Office formulating a national policy much in line with the American approach. However, before Le Rossignol could be informed of this, and without establishing what his ‘former occupation’ was, the Foreign Office...
independently replied to his request in terms favoured by the Ministry of Munitions. This letter, dated 12 February 1917, explained:

As it is understood that Mr. Le Rossignol’s former occupation is connected with the operations of war, his Majesty’s Government would view with strong disapproval his resumption of that occupation, and in such an event he would have to be prepared to face all the consequences of such disapproval in the event of his return to this country.\(^{116}\)

Le Rossignol’s reply was ‘immediate’.\(^{117}\) He was clearly distressed that the nature of his work had not been properly conveyed to the British Government and his patriotism questioned. Le Rossignol explained:

I am employed in a glow-lamp factory, my sole work being to improve the methods of manufacture of glow-lamps such as are used in every household, I have nothing to do with the construction or manufacture of lamps which may be used for the purposes of war. If the British Foreign Office objects to my present occupation I will give up the same and take the consequences such as having to leave my family and be re-interned in Ruhleben.\(^{118}\)

Eventually, this explanation was accepted, the opinion of the British Government being that it would be ‘unjust to condemn a British subject for having worked at “the study of explosives” in peace-time in a country where much important work was being formed’. But a postscript added to a note requesting the views of the Government on the proposed employment of British civilians in Germany during World War I was the most perceptive comment: ‘P.S. If Le Rossignol is really of much value, the Germans would have let him out long ago.’\(^{119}\)

The family were to remain in Berlin throughout the war. But, as Le Rossignol was leaving Germany with Haber’s financial legacy, another legacy – the work he did at Karlsruhe – was helping the Royal Swedish Academy of Sciences decide the award of the Nobel Prize for Chemistry for 1918.\(^{120}\) Even before 1918, the Chemistry Committee had experienced disagreement. As early as 1916 the ageing Peter Klason had proposed Haber for the prize. However, Chairman Hammarsten was concerned that Sweden’s neutrality might be compromised by awarding a prize for a process that prolonged the war. But Haber returned to the nominations list in 1918, receiving just a single endorsement, and now with ‘blood on his hands’. A preliminary vote backed Haber’s nomination but, at a full committee meeting on 12 November 1918, Hammarsten deemed that the time was still not yet politically right to reward Haber. However, there was a growing movement towards Haber among committee members and the whole episode resurfaced a year later when they abandoned impartiality and their responsibility to evaluate all the evidence, and, without dissent, but with clear political intent, proposed that the Academy award the prize to Haber alone. Meanwhile, on 6 December 1918,\(^{121}\) ignorant of events in Sweden but with far more pressing things on his mind, Robert Le Rossignol and his family fled Germany for a new life in the UK.

**THE GEC LABORATORIES, 1919–49**

The United Kingdom was not economically crippled by the burden of the Great War,\(^{122}\) but it was psychologically damaged by German naval bombardments, aerial bombing and
chemical warfare, the country having previously regarded itself as ‘impregnable’. After the war, many industrialists decided never again to permit themselves to be dependent on German science. This applied to the GEC, who from 1906 had collaborated with Osram in Berlin, importing filaments to include in their own lamps made at Hammersmith in London. By 1909 GEC had made a substantial investment in bulbs and completed the Osram Lamp Works at Hammersmith to manufacture high-quality Osram bulbs, offering one-third shares to the German and Austrian patent holders as enticement. However, by 1915 with the war in its second year, the large German shareholding in the Lamp Works had provoked a very negative press. Hugo Hirst, the German-born co-founder, chairman and managing director of GEC, and the chairman of Osram, told a company meeting of GEC that, because of the increasing vulnerability that many felt at being dependent on German science, a way had been found that would keep future control of the works in British hands, namely the creation of their own industrial research laboratory to serve all of the Lamp Works’ needs.

In 1918 the laboratories were formed in a wooden building at Hammersmith, later moving to customized premises at Wembley. They began with just four members, including Clifford Patterson as founding director, but in March and May 1919 there was an ‘influx’ of staff who, over time, were to become senior members. Le Rossignol joined GEC as such, being invited to do so by Paterson because of his understanding of Osram lamp production in Berlin, initially at Hammersmith, then later at Wembley. Here, one group continued with lamp technology, but as radio communication was becoming a new and exciting field another group, including Le Rossignol, developed the ‘valve team’, charged with improving both the manufacture and performance of these devices, especially for radio transmitting purposes. In terms of radio communication, lamp technology was still of considerable value, especially for small receiving valves, but the development of large high-powered transmitting valves presented major new interdisciplinary problems which crossed the boundaries of mathematics, chemistry, physics and electrical engineering, at the same time generating new disciplines such as statistical testing and materials science, and embracing the new ‘quantum theory’. Understanding Le Rossignol’s efforts here demands some appreciation of ‘thermionic’ technology, but undoubtedly the eclectic nature of the discipline was what motivated Le Rossignol to move from lamps to valves. In this sense, he was developing as a thoroughly modern scientist, which distinguished him not only from Haber, whom quantum theory had largely left behind, but from many of his contemporaries.

At the end of the war, the largest commercially available transmitting valves – the ‘glass’ valves – could deal with an input of just 1 kW, so it was necessary to parallel a great number of them to achieve high-power radio frequency amplification. With regard to improvements in amplification, glass valves suffered from a number of deficiencies, especially heat dissipation at the anode, and a major problem confronting the development of more powerful valves was the requirement that the temperature of the glass should not exceed approximately 200°C. For high-power radio frequency transmission (i.e. hundreds of kW) an entirely different type of valve had to be developed, one in which the internal anode would have to be part of the glass envelope of the valve so that the whole could be immersed in water, or in oil, or blown by air. Thus, in 1923, the ‘cooled anode transmitter’ or ‘CAT’ valve was conceived, but only after a way of making reliable joints between glass and nickel-iron anodes had been discovered. Much work had already been done in America by the Western Electric Company regarding metal-to-glass bonding. But
for many the process remained a mystery, achievable only by the most talented of glass blowers. Progress could only be made with cooled anode valves if this technique could be mastered and devolved to the laboratory craftsmen who had to build the valves.

It was here that Le Rossignol made a fundamental contribution by using a variation on an already known process. Alloys of nickel and iron could be made which had approximately the same coefficients of expansion as the glass envelope and which could be joined directly to the glass if the alloy was thinly copper plated. Between 1922 and 1923 Le Rossignol, together with C. A. Morton, was the first to ‘glass’ successfully pieces of nickel-iron (anode) tube to the envelope, the first specimen of which, according to Clayton and Algar’s history of the GEC laboratories, was christened by them ‘the Great Seal of England’! The method was adopted by GEC and so, early in the development of cooled anode technology, the engineering of probably the most critical component had been mastered. For the craftsmen in the workshops, however, this process must have been magical when seen for the first time, for in his 1936 paper Le Rossignol tells us, in typically modest fashion: ‘the making of a large glass-to-metal joint usually inspires awe in the uninitiated, but as a matter of fact, once the technique has been grasped there is no great difficulty in making such joints’.

Le Rossignol made a fundamental contribution to the development CAT valves used all over the world, not only by developing a practical way to ‘glass’ the anode to the valve envelope, but also by addressing their cooling systems and finally by inventing a modulation system which provided unparalleled reception quality from broadcasting stations using these valves. An early GEC valve (the CAT1) was installed at the new BBC long-wave station at Daventry in Northamptonshire in 1925. With an output of 25 kW, Daventry was the most powerful transmitter in the world at the time. A later valve (the CAT12) operated the transatlantic telephone line, and in 1934 the new BBC Droitwich super-transmitter (a 500 kW CAT14) became operational, an event recorded by the eminent documentary maker John Grierson. Although Droitwich made Daventry obsolete, the latter was retained, first as a reserve for Droitwich, and then for transmitting coded messages across Europe during World War II. In 1937 the transmitter also hosted an important pre-war experiment, one which laid the foundations of a technology that contributed to the successful outcome of the war, namely the terrestrial radar stations and the airborne radars. In terms of the perfection of the CAT valve, Robert Le Rossignol was a member of a team at GEC, but it is undeniable that once again – as with ‘fixation’ – his ‘fingerprints were all over the technology’. The techniques he developed, particularly glass-to-metal seals, were equally applicable to smaller valves. These became increasingly important to the laboratories as the decade progressed because they were ideally suited as ‘power’ sources in airborne radars and navigation systems during the war.

On the outbreak of war, Hirst (now Lord Hirst) told Paterson to place the laboratories at the disposal of the Government and not to permit commercial considerations or industrial rivalry to stand in the way of the war effort; according to Paterson’s diary, neither did he wish the laboratories to make any profit on research done for the Services. To all those working at the laboratories this was how they conducted themselves over the war years. Work was undertaken because staff had the best expertise to achieve a solution and not because it would place GEC in an advantageous position after the war. Sometimes, solutions provided by the laboratories were taken to production by other companies and so GEC ‘lost out’; even so Paterson had no time or respect for anyone in any position
whom he believed to be furthering his or her personal agenda or playing corporate politics. For almost every member of staff the years 1939 to 1945 were devoted, without exception, to projects aimed at winning the war. There was a tremendous expansion of facilities for the ‘pre-production’ and testing of a variety of valves developed specifically for wartime. Over 1000 newcomers joined the laboratories which relied heavily on its senior staff and Robert Le Rossignol’s intimate knowledge of the construction, manufacture, operation and characteristics of thermionic devices naturally made him a key player in ‘Wembley at war’. From September 1939, all the research groups turned their attention to devices for radar, navigation and communications, either in research and development or (as in Le Rossignol’s case) taking charge of valve ‘pre-production’. Throughout the war Robert Le Rossignol was the senior man on the laboratories’ staff concerned with the design of valves, and there was hardly a new valve developed during this time that did not escape his attention. But it is equally true that he was a very close colleague of Paterson’s, involved at the highest levels of decision-making, ‘privy’ to the most sensitive information and liaising with many of the principal scientific, military and government characters involved in the British war effort. On the first day of the war, Le Rossignol was placed in charge of the pre-production of probably the most important valve at the time, the ‘micropup’ (figure 6). During the war he was to take charge of the production of other valves, including the ‘magnetron’ – an example of the embodiment of earlier skills – and a device which became a ‘game changer’ as it generated revolutionary levels of microwave energy for radar.

As an indication of Le Rossignol’s importance to GEC during the war, Paterson’s wartime diary records that on 20 October 1943 Le Rossignol left for North America by sea, at a time when German U-boats had been largely withdrawn from the north...
Atlantic and the *Bismarck*’s sister ship, the *Tirpitz*, put out of action by British ‘midget’ submarines. He was to examine the American and Canadian expertise with magnetrons, their manpower per valve and issues of general wastage. He returned on 10 December 1943 and reported that he had had the warmest reception everywhere – particularly from the Schenectady (New York) folk under Coolidge, whom he had first met on his honeymoon in 1910. Paterson noted on 8 December that: ‘He showed the flag well and did credit to his Lab. and country. His reception there showing clearly what friends we have in the USA.’ According to Paterson’s diary, during the war years the laboratories produced 303,848 valves of 40 different types.

As the laboratories moved into the post-war era there could be little accommodation for Le Rossignol. He may have been increasingly concerned with plans for retirement, but there were some final duties to attend to, particularly following the unexpected death of Clifford Paterson in 1948. His position as director was taken by Oliver Humphries, ‘supported’ by a Scientific Panel – known as the ‘Seven Pillars of Wisdom’. Le Rossignol served on the Panel for the remainder of his time at Wembley, but retirement inevitably came and it was as a senior ‘management’ man, author of 24 patents on behalf of the GEC, that he finally stepped down from Wembley on his 65th birthday in April 1949, into what was to be a long retirement with Emily at Beaconsfield.

### The Haber–Le Rossignol Financial Arrangements

Because of the Great War, production of synthetic ammonia in Germany ran into hundreds of thousands of metric tonnes per year. Through his royalties, Haber became fabulously wealthy, especially between 1914 and 1917. His finances for 1918 were affected by the allied invasion of Germany and by being named as a war criminal. Thereafter, German hyper-inflation from 1921 to 1924 reduced his income to almost nothing. Throughout this period, however, Haber ‘played fair’ with Le Rossignol, who received his share of Haber’s payments. The first substantial payment to him was made in 1914 and the last in 1924, the latter about 2 million marks, nominally £20,000 but worthless because of hyper-inflation. But for 1915–17 alone, this author calculates Le Rossignol’s entitlement as somewhere between £22,000 and £30,000, a figure in ‘order-of-magnitude’ agreement with his 1924 payment, although it is uncertain how many years the latter payment covered.
These financial dealings were private and we cannot be sure how much Le Rossignol received overall because Haber’s financial arrangements have remained utterly impenetrable. Even so, over the duration of their contract, his entitlement ran into many tens of thousands of pounds. Because of ‘circumstance’, however, what he actually received was only about 10% of what was due. Even so, the amounts concerned were ‘astronomical’ for the time and Le Rossignol later told Chirnside that what he had received was ‘enough for one man’.  

Le Rossignol returned to Germany frequently during the 1920s, often meeting with Haber and taking care of the investments which remained there. The two men remained friends until Haber died in 1934. On their return to the UK the family lived modestly for many years at 7 St John’s Road, Harrow, eventually purchasing a substantial retirement home for themselves near Beaconsfield. We know, too, that Le Rossignol was careful with his money and, in this respect, the historical question that remains regarding his financial legacy from Haber is not really how much he received, but what became of what he received?

**Retirement at Beaconsfield**

On 11 September 1951, the *London Gazette* announced a number of new land registrations, including ‘St Helier’, the Le Rossignols’ new name for their retirement home at 67 Penn Road, Beaconsfield. When Chirnside came here in 1976 he found Le Rossignol as optimistic and as ‘full of life’ as ever – even though ‘life’ had not been kind to the couple. As early as 1934 young Peter Walter took his own life in Cambridge while studying Natural Sciences at Sidney Sussex, after (as he thought) failing his chemistry examination. 

And in September 1943, John Augustin, then an elite RAF pilot, was killed in the Italian campaign. Clearly a wealthy couple, the Le Rossignols’ financial bedrock was undoubtedly Robert’s share of Haber’s royalties. But at Beaconsfield, they were to give all of their money away to charitable causes, each gift quite enormous by the standards of the day.

The first gift was to the University of London, *viz.* £50 000 to establish the ‘Robert Le Rossignol Endowment Fund’ for ‘the advancement of education generally ... and in particular ... for the students and graduates of University College ... in the fields of Chemistry, Biochemistry, Chemical Engineering, Physics and Biophysics’. With this gift Le Rossignol used ‘some of his rewards’ to repay what he always saw as his ‘debt to UCL’. Further philanthropy followed.

The report of the Chairman of the Council of the Distressed Gentlefolks Aid Association (DGAA) for the year ending 31 March 1961 records: ‘a magnificent gift of £50 000 donated by a generous supporter and his wife who live in Buckinghamshire’. The Council planned to use the gift to extend or replace ‘Merlewood’, their nursing home in Virginia Water. The decision was ultimately made to extend the home and increase its capacity from 21 residents to 36. The foundation stone was laid by the couple on 10 July 1963. By November 1964, their extension was opened and all 36 beds were occupied (figure 7).

Another substantial donation followed, orchestrated by the Rev. Oscar Muspratt, the flamboyant vicar of Penn. On 6 May 1963, he established a charitable trust deed known as the Penn–Pennsylvania Fellowship to emphasize the ancient connection between Penn and Pennsylvania, regarded as bogus by most parishioners. He described this trust as ‘of
and he established its purpose: to provide a group of buildings opposite the church comprising affordable accommodation for the elderly, a community hall and car parking facilities. It was always an intention of the trust to raise money in Pennsylvania. A public appeal was another option. There were also many wealthy parishioners in Penn, and Muspratt was a persuasive character. But who would be prepared to back this ‘maverick priest’? In August 1964, the Le Rossignols provided the trust with a ‘magnificent gift’ of £40,000. Eventually, a smaller development of eight retirement apartments known as ‘Penn Mead’ flatlets were built. The flatlets, designed by the eminent architect Sir Hugh Casson – Muspratt’s cousin – were opened.
on 14 October 1967, and dedicated to the memory of the couple’s sons who ‘both died in the war’ (figures 8 and 9).

The couple were to live long enough to derive pleasure from these gifts, Emily passing away at ‘St Helier’ on 26 October 1975, followed eight months later by Robert at Wycombe General Hospital on the morning of 26 June 1976. In a final act, Emily left the residue of her estate to five British charities, while Robert’s last wish was that his estate be given to University College London Hospital Medical School to establish a research fund known as the Emily Le Rossignol Fellowship Fund to encourage research at postdoctoral level into some aspect of the ‘arthritic condition’, from which Emily had suffered for more than 40 years. These final gifts amounted to over £320 000,152 and inevitably bring us back to Chirnside’s transcript, which contains one illuminating sentence.153 Near the end of his life, Robert Le Rossignol said, ‘I hope I have been able to make proper and prudent use of my rewards, and I have tried to help some others less fortunate’, suggesting that he felt that he was just a custodian of this wealth, and that it should be ‘consumed’, not selfishly, but for the good of others, thereby mitigating the brutal circumstances by which much of it had undoubtedly been obtained.

CONCLUSION

Fritz Haber has dominated the history of the discovery of ‘fixation’. The circumstances of his life, his powerful personality, Jaenicke’s ‘critical mass’ of biographical evidence and the
romantic notion of the ‘gentleman scientist’ bound by honour and patriotism have all proved attractive to historians. In terms of honour, Haber fulfilled the expectation made of him. His sincere recognition of Le Rossignol for the work he did, the fact that he ‘played fair’ by him in their financial arrangement and intervened to get him released from Ruhleben testify to this side of his character. It is reflected too in the support Haber provided for his children and his second wife, Charlotte, after their divorce, and in his resignation from the Kaiser Wilhelm Institute when ordered by the Nazis to remove his Jewish scientists. In 1933, when leaving for a position at Cambridge, he sought an ‘honourable separation’ from Germany to avoid the Reichsfluchtsteuer for ‘unpatriotic desertion’, which would not only have decimated his finances but branded him a tax evader. Such was his emotional attachment to Germany, it was a legacy he could not countenance, and this illustrates the ‘tension’ he felt at being torn between his obligations on the one hand and his pursuit of money as reward on the other.

Haber’s patriotism, too, was unquestionable. He later said of World War I: ‘Science is for the world . . . but for your country in time of war’ But we should not suppose that he enjoyed war per se. He hated the suffering, the waste of life, the pointlessness of it all, for in his emotional ‘ground state’ he was kindly, helpful and benevolent. But it is equally true that the excitation of war transformed him into a ruthless autocrat, a side of him which in peacetime he either suppressed or made manifest as his ‘strength of purpose’. He gave his whole being over to the struggle for victory and nothing was allowed to deflect him: neither family, nor human suffering, nor considerations of international law. He brought a vitality to all the positions he held and he always placed Germany first. For three or four generations past, his family had fought for, or served,
Germany and he was proud to have become a Prussian officer and such an influential military man. So when defeat finally came, it weighed heavily upon him, as did the personal repercussions of his role in chemical warfare.

In the wider terms of his science, Haber was characterized by versatility. There was hardly an important branch of contemporary physical chemistry to which he did not make a fundamental contribution. But, despite all his talents, his eclectic and fundamental contributions to chemistry, his energy and his devotion to duty, he is remembered by many today not by the epitaph he composed for himself – ‘He served his country in war and peace, as long as it was granted him’ – but in a way he would have never have wanted: ‘As a Jew ... the father of chemical warfare’.

But for those who knew him as a man and a teacher, Haber generated great affection, and their memories are naturally more forgiving. In his 1928 paper, Le Rossignol wrote:

> At the end of these lines I should like to take the opportunity to express my deep gratitude for the friendship granted by Haber. It is rare for a young person as I was at the time to be given the luck to come into contact with such an excellent teacher, a teacher who by his own enthusiasm and devotion to work [was] a model for his pupils and in whom they could always be sure to find a sincere friend and advisor. Even today, many of his pupils think of him with admiration and gratitude and remember the time they were allowed to walk alongside him.

In contrast to the effort expended on Haber, Le Rossignol has been remembered – if at all – only loosely, as Haber’s ‘co-inventor’, as his ‘young English assistant’ or as just another ‘fallen hero’ in a pantheon of canonical scientists. In reality, however, as Chirnside recalled in 1976, for most chemists today he has not even achieved that humble standing. Today the echoes of Le Rossignol’s life and his achievements are faint. ‘He lies in the dark corners of our past’, one at UCL told me. The reasons for this are manifold. Le Rossignol undoubtedly had a tendency towards ‘Victorian modesty’. This author can find no example of him championing his work in public, and on the rare occasions he wrote or spoke of ‘fixation’, he often deferred to Haber. Neither can one find any evidence of him seeking praise for his work in any ‘laudatory’ sense, and he never seemed to harbour any resentment regarding his lack of recognition.

But there were reasons beside his modesty. In peacetime, the BASF’s ruthless prosecution of commercial secrecy prevented the two men publishing quickly and widely to gain the recognition they wished. Le Rossignol’s move to Berlin disrupted their working relationship, and Haber’s authority dominated the dissemination of their work. Haber’s public praise fell silent because of the war, and, by moving ‘into the shadows’ to avoid any association with a man so closely connected with the German war machine, Le Rossignol became isolated and anonymous. But another powerful reason lies with the Royal Swedish Academy of Sciences, who on 13 November 1919 awarded the 1918 Nobel Prize in Chemistry to Fritz Haber alone. Through Haber’s Nobel Prize acceptance speech, Le Rossignol’s contribution to nitrogen ‘fixation’ was finally recognized at the highest level. However, it came at a price, for it was to be acknowledged by a man whose status as a named war criminal had only just been revoked and by way of an Academy whose decision was to fall into disrepute. For the same committee that had considered the Chemistry award the previous year now reversed its decision and, without dissent, awarded the prize to Haber with scant regard for any of its earlier concerns.
According to Friedman, this remarkable behaviour by the Academy appears to have been driven by a belief that in the confusion that embraced Germany at the time, no political party there offered any hope for culture and learning and Swedish scientists therefore turned to comfort their German colleagues. In this sense, the Academy adopted the view that, although the Imperial Government of Germany had fallen, the country’s elite culture remained and it was this culture that was honoured by their awards in 1919. This view, however, proved both naïve and optimistic, because international reaction was swift and damning, and in the ‘feeding frenzy’ that soon consumed all things ‘Haber’ among the Allies after the war, the fragile memory of Le Rossignol was overwhelmed. The accolade ‘Haber–Le Rossignol process’ never gained currency, and history abandoned his story. For others who have suffered the same fate as Le Rossignol, their peers have sometimes demanded a wider recognition of their achievements. The names Lise Meitner, Oswald Avery, Jocelyn Bell-Burnell, Andrew Benson and James Bassham come to mind immediately. But for Le Rossignol there has been no such retrospective.

‘As a young man’, Le Rossignol told Chirnside, ‘I wanted to be a professional chemist.’ It was the reason he sat the examinations of the Institute of Chemistry in 1906. But in conversation with Jaenicke in 1959 – and long before any biographies of Haber had appeared – he had accepted that ‘my name will not be remembered for big things’, which, if one adopts the notion of the scientist as ‘tradesman’, becomes an understandable consequence of that standing. Indeed, Le Rossignol’s death certificate describes him as simply ‘Scientist, (retired)’. There is little doubt, that in terms of the historical recognition of his work, ‘circumstance’ dealt Le Rossignol a poor hand, and when recalling his life, as this paper does, it is difficult to avoid the accusation of ‘fallen hero’. But in the light of the new evidence, such descriptions are not a just and fair historical judgement of the scientific importance of this man, because an appreciation of his life goes beyond the ammonia synthesis, and this above all is the principal purpose of the paper.

However, with regard to ammonia, there are aspects of Le Rossignol’s work that distinguish him from others who have failed to gain wider recognition. At Karlsruhe, he solved a problem that had bedevilled chemistry for over 100 years and in doing so he ‘trumped’ the efforts of three giants of physical chemistry, contributed to four Nobel Prizes and created a technology that ‘detonated’ a world population explosion – the latter an unparalleled contribution to humanity. There are also other uncommon – if not unique – aspects to the work he performed there: for example, the private financial arrangement with Haber, the fact that his work has been regarded as probably ‘the most demanding technical chemical project ever undertaken in an academic setting’ at the time, and Coates’s opinion that ‘the “Haber” process had been brought to such an advanced stage in Karlsruhe before its translation to the industrial scale’. Hardly any of the fundamental engineering and chemistry involved has changed since Bosch and Mittasch developed the huge plants at Oppau and Leuna – adding just one new component, the first heterogeneous industrial catalyst.

In his obituary of Le Rossignol in 1977, Chirnside describes him thus:

He was essentially a practical man, basically a chemist with strong engineering skills and understanding. He had an amazing grasp of the inter-relation of chemical, physical and electrical concepts and could work out on paper complex problems from a few basic relationships. Throughout his life, and in retirement, he retained his practical mechanical aptitude.
This mix of scientific understanding and practicality characterized his life and work, and Haber’s fame – or infamy – should not now deflect historians from a more complete understanding of Le Rossignol’s role in the discovery of ‘fixation’.

Finally, however, neither should one understate the legacy of Le Rossignol’s original discovery. Today, industrial nitrogen fixation – a ‘sledgehammer’ mimic of one of the most gentle and fundamental reactions of nature – makes roughly the same amount of ammonia as the sum total of all the world’s biological nitrogen fixation. The industry now consumes 1–2% of the world’s energy output; 2% of the world’s natural gas is used to make hydrogen for the process; worldwide approximately 140 million tonnes of synthetic ammonia are produced each year and ‘Haber–Bosch’ is still the only chemical process that uses nitrogen as a feedstock. But there was once a more optimistic hope, because even the best optimized ammonia plants consume vast amounts of energy. Just a few weeks before he died, Le Rossignol discussed the television film The chemical dream with Chirnside, which demonstrated contemporary advances in enzyme chemistry, the implication being that a catalyst might one day be found that emulates nitrogenase, the enzyme found in nitrogen-fixing microbes such as rhizobia. But the natural process has proved difficult to emulate and neither is biological fixation a paragon of efficiency. So researchers today agree that the biggest challenge to ‘Haber–Bosch’ will come from plant biology – i.e. genetic modification – which will ‘engineer’ cereal crops to associate with nitrogen-fixing bacteria in the soil in the same way as the legumes, dramatically reducing the need for artificial fertilizer. Until that happens, and well over 100 years after Le Rossignol’s discovery, ‘Haber–Bosch’ will remain supreme.

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To Professor Alwyn G. Davies FRS, at UCL Chemistry Department, for suggesting I write this paper, for materials he has supplied and for his continued interest in the Le Rossignol story. To Professor Margit Szöllözi-Janze, University of Munich, for answering my many questions regarding her biography of Haber. To the Le Rossignol family for fully engaging with this work, to Frau Hede Hauser for her expert translations of various texts, and to Mr Christopher White, former Chairman of the Penn–Pennsylvania Trust for materials supplied, his help and his enthusiasm. Finally, to Mr T. B. Powell for many hours of discussion regarding Le Rossignol, and to Dr Ben Marsden and the Royal Society editorial team for their expert guidance to the author during the submission of the paper.

The work presented here was abstracted from the author’s biography of Le Rossignol and his life alongside Haber.

NOTES

1 The term ‘nitrogen fixation’ was introduced in the late nineteenth century. Although the world has no shortage of elemental (atmospheric) nitrogen, nitrogen bound to, or fixed chemically to, other atoms in organic or inorganic compounds is far more useful. The process of achieving the chemical binding of atmospheric nitrogen was therefore termed ‘fixation’.

2 R. C. Chirnside. The transcript – twelve pages of annotated typescript – is available via this author by prior permission of the Le Rossignol family.

4 Haber’s talk was later published as F. Haber, ‘Über die Nutzbarmachung des Stickstoffs’ (‘Making nitrogen useable’), *Verhandlungen des Naturwissenschaftlichen Vereins in Karlsruhe* 23, 20–23 (1909/1910), and F. Haber, ‘Über die Darstellung des Ammoniaks aus Stickstoff und Wasserstoff’ (‘The synthesis of ammonia from nitrogen and hydrogen’), *Z. Elektrochemie* 16, 244–246 (1910).


8 Jaenicke’s and Le Rossignol’s letters from this period and the transcript of their conversation are held at the Max Planck Gesellschaft. Archiv der MPG, Va. Abt, Rep. 0005, Fritz Haber, Haber Sammlung von Joh. Jaenicke, Nr 253 (Jaenicke’s letters) and Nr 1496 (conversation transcript). Personal communication, March–April 2013.


10 Haber’s technical contribution was (largely) confined to the theoretical calculations based on his book *Thermodynamik technischer Gasreaktionen. Sieben Vorlesungen (The thermodynamics of technical gas reactions: seven lectures)* (R. Oldenburg, Munich, 1905.) An English version by Arthur B. Lamb was published in 1907.

11 Chirnside, *op. cit.* (note 2).


14 From the Archives at UCL Chemistry Department, a three-page handwritten account of his career by Le Rossignol, supplied to me by Professor Alwyn Davies, FRS. It is anonymously annotated, ‘written in 1961’, and probably accompanied Le Rossignol’s gift to UCL at that time (see note 146). Also Jaenicke, *op. cit.* (note 8), Nr 1496.

15 Jaenicke, *op. cit.* (note 8), Nr 1496.

16 Ibid.

17 Ibid.

18 Ibid.


21 Chirnside, *op. cit.* (note 2) and Chirnside, *op. cit.* (note 3).


23 Jaenicke, *op. cit.* (note 8), Nr 1496.


26 Haber, *op. cit.* (note 10).

27 The fractional notation for chemical equations was first introduced by Haber in his book on gas thermodynamics. Haber, *op. cit.* (note 10).

The formation (desired) reaction proceeds with a decrease in volume. This direction is favoured by increasing the pressure according to the Le Chatelier Principle. The higher the pressure, the higher the yield of ammonia at equilibrium. Haber favoured atmospheric pressure because of the simpler apparatus required.


With the onset of ‘trench warfare’ (September 1914), German fixed nitrogen supplies were estimated to last six months. Supplies of Chile saltpetre were denied the country by the British naval blockade. Fixed nitrogen via coke by-product recovery and the ‘cyanamide’ process hardly kept pace. Smil, op. cit. (note 31), chapter 3. If it had not been for the (potential) oxidation of ammonia from the nitrogen plant at Oppau to produce nitric acid for munitions, Germany might well have had to concede.

Nernst published his ‘Heat Theorem’ in 1906. It applied to pure crystalline solids at absolute zero, but he found a way to apply its principles to calculate the equilibrium constants of gaseous systems. This became known as his ‘approximation formula’.

Jaenicke, op. cit. (note 8), Nr 1496.


Jaenicke, op. cit. (note 8), Nr 1496.

Nernst and Jost, op. cit. (note 35), pp. 523–525. Haber’s ‘presentation’ was appended to the Nernst paper as part of the ‘Discussion’.

F. Haber and R. Le Rossignol, ‘Über das Ammoniakgleichgewicht’ (‘The ammonia equilibrium’), Ber. Bunsengesellschaft. Phys. Chem. 40, 2144–2154 (1907). Received on 29 April 1907, but published shortly after the meeting.

Nernst and Jost, op. cit. (note 37).

Le Rossignol later observed that gas cylinders at the time were supplied with simple ‘shut off’ valves that ‘in no way allows an easy regulation of the out-flowing gas stream’. For this purpose complicated or reducing valves are necessary’. This observation led eventually to his special conical valve. Feinregulierventil’ (‘A simple precision regulating valve’), Z. Anal. Chem. 48, 9, 568 (1909). This paper made his name famous in Germany: Jaenicke, op. cit. (note 8), Nr 1496.


Coates, op. cit. (note 19).

Jaenicke, op. cit. (note 8), Nr 1496.


Seeing the valve, Haber suggested that Le Rossignol take a Deutsches Reichsgebrauchsmuster, a basic copyright protection lasting initially for three years, extendable to six. The process was eased by Haber’s brother-in-law, Meffert, a patent attorney. After the expiry of the Gebrauchsmuster, Le Rossignol received £500 – a ‘lot of money then for an impecunious student!’, according to Chirnside, op. cit. (note 3), p. 269.

Haber and Le Rossignol, op. cit. (note 41), p. 181.

Ibid.


Robert le Rossignol, engineer of the ‘Haber’ process

50 Travers, op. cit. (note 49).

51 Travers, op. cit. (note 49).

52 Le Rossignol, op. cit. (note 7) and Le Rossignol, op. cit. (note 14).


56 Ibid., p. 174, citing Vgl. HS 2067 (BASF, W I Haber, Verträge ab 1920), Aktennotiz Holdermann betr. Zahlung der BASF an Haber, 25 February 1953. This private contract was later renegotiated for the year 1918 (see note 139). The two men also agreed to share a proportion of their royalties with the Technical Hochschule to provide a foundation endowment for the benefit of the progression of physical chemistry at the Institute. The ‘Haber Foundation’ was realized in 1916 and only disappeared when it merged with other foundations at Karlsruhe in 1985. Personal communication, 1 August 2014, and M. Szöllössi-Janze, op. cit. (note 9), p. 225.


59 Jaenicke, op. cit. (note 8), Nr 1496.

60 Grundriss der technischen Elektrochimie auf theoritischer Grundlage (Outline of technical electrochemistry based on theoretical foundations) (R. Oldenburg, Munich, 1898).

61 Haber, op. cit. (note 10).

62 Donnan and Le Rossignol, op. cit. (note 12).

63 Chirnside, op. cit. (note 2).

64 Le Rossignol described this arrangement as an ‘ideal partnership’. Le Rossignol, op. cit. (note 14), p. 2.

65 In 1908 the Auergesellschaft in Berlin offered Haber a position as consultant through which he had access to ‘exotic’ materials that he could select as potential catalysts. One such material was osmium and another was uranium. Osmium was rare. The Auergesellschaft, however, had much more uranium, a ‘waste’ product left over from their process for extracting radium from uranite.

66 Chirnside, op. cit. (note 2).

67 Ibid., p. 5. However, the vapour pressure of the liquid ammonia was slightly higher than the tables indicated.

68 Haber ‘inherited’ Kirchenbauer from Julius Le Blanc when he took his chair at Karlsruhe on 10 August 1906. Haber described him as ‘an unusual employee of special value’. Stoltzenberg, op. cit. (note 48), p. 61. It is also relevant here to refer to the Preface of Anthony S. Travis’s book, The synthetic nitrogen industry in World War I (Springer, Cham, 2015), where he correctly identifies Le Rossignol alone as ‘co-inventor’ of the ‘Haber’ process.


70 Jaenicke, op. cit. (note 8), Nr 1496.

71 Ibid.


73 See note 45.

74 ‘Conical screw down valve with an angle of inclination between 85° and 90°’, submitted in Germany on 16 March 1908 and in the UK on 16 July 1908, accepted 1 April 1909, UK Patent No. 15,065. See also Le Rossignol, op. cit. (note 41).

75 Jaenicke, op. cit. (note 8), Nr 1496.
Readers are encouraged to look at informative animations of such devices on YouTube. For example: https://www.youtube.com/watch?v=4UnzUPqTD5E (accessed December 2016). The ‘dead space’ refers to the volume behind the piston in a single-acting pump, which tends not to be moved. The animations show that this is not the case in a double-acting pump and the movement is much more efficient and smoother.


As Le Rossignol would have wished, the tubes remain at the Museum, inventory number 1952-391. Letters and documents regarding Le Rossignol’s donation were kindly supplied by John Herrick, Rory Cook and Shani Davis of the National Science Museum. Personal communication, April 2011. The first tube, 1952-391/1, was displayed/stored inside a spherical, pressure-tested, glass container between 1986 and 2002. The second tube has remained largely in storage. At the time the author contacted the Museum (March 2011), the first tube was at the Museum’s Smith Centre Exhibition. The second was in the Science Museum’s Small to Medium Object Store at Blythe House. Both tubes are available to view today.

As far as Haber was concerned, the development of the Haber–Le Rossignol process was BASF’s problem; little – if any – of it would be done at Karlsruhe. For Le Rossignol, there was no prospect of employment with BASF, and Haber’s report to BASF on 3 July 1909 had already indicated that his ammonia account was 4400 Marks in the red. Szöllössi-Janze, op. cit. (note 9), p. 180. Le Rossignol’s position was therefore in doubt. Unsurprisingly, in August 1909 he left Haber and travelled to the Auergesellschaft, Berlin, where Max Meyer, a great friend and former colleague at Karlsruhe, had already secured a lucrative position for him as an advisor to work on the manufacture of ‘glow’ lamps. Ibid., pp. 185–186.

The ‘circulation patent’, BASF 1908, D.R.P., Patentschrift Nr 235421, and the ‘high pressure patent’, BASF 1909, D.R.P., Patentschrift Nr 238450. Patent applications were signed by both Haber and Le Rossignol – although Le Rossignol’s involvement was confined to simply signing before the Consuls. Jaenicke, op. cit. (note 8), Nr 1496. Nernst’s previous criticisms of Haber–Le Rossignol were tempered by an ‘honorarium’ from the BASF. Smil, op. cit. (note 31), p. 100. At the patent hearing, Nernst declared his work as of ‘scientific interest only’ and of ‘no technical relevance’. Only Haber–Le Rossignol had ‘created the prerequisites for technical success’. Stoltzenberg, op. cit. (note 48), p. 95.
Robert le Rossignol, engineer of the ‘Haber’ process

97 Chirnside, op. cit. (note 2).
98 Jaenicke, op. cit. (note 8), Nr 1496.
99 Ibid.
101 Haber and Le Rossignol, op. cit. (note 80).
102 Haber, op. cit. (note 5), p. 54.
103 Ibid, p. 52.
104 Described by Klaus Nippert, Archivist at Karlsruhe University, in the BBC Radio 4 production *The chemist of life and death*, broadcast on 13 April 2011. Nippert went further, describing how students often cover over Haber’s name on ‘Fritz Haber-Way’, replacing it with ‘Clara Immerwahr’, his first wife, herself a chemist and deeply opposed to chemical warfare (see note 143).

105 Leeds University Library, Special Collections MS 705, Papers of Henry James Hodsman (1886–1951), from a letter to Hodsman on behalf of Haber written by Le Rossignol in February 1913. The letter also establishes that Haber and Le Rossignol were working together in Berlin at the time.

106 My understanding of the treatment of British nationals in Germany at this time is primarily due to the following texts: Mathew Stibbe, British civilian internees in Germany: the Ruhleben camp, 1914–1918 (Manchester University Press, 2008); J. Powell and F. Gribble, The history of Ruhleben: a record of British organisation in a prison camp in Germany (W. Collins Sons and Co. Ltd., London, 1919).

107 Ruhleben lay between the boroughs of Charlottenburg and Spandau.

108 Stibbe, op. cit. (note 106), p. 64.


112 A comment attributed to Charlotte Haber, in Szöllözi-Janze op. cit. (note 9), p. 176.

113 Chirnside, op. cit. (note 2).

114 All the correspondence referred to in this section is held in The National Archives, Kew (hereafter TNA), Foreign Office files, FO 383-211, FO 383-279 and FO 383-312.

115 Foreign Office files, op cit. (note 114), FO 383-279.

116 TNA, FO file FO 383-211.

117 His letter was dated 23 March 1917. TNA, FO 383-312.

118 Ibid.

119 TNA, FO 383-279, postscript, 22 January 1917.


transmitter’, https://www.youtube.com/watch?v=7hr4xwpZYJ0 (accessed 28 November 2016), which shows the CAT14 valves being moved to the transmitter hall and explains their cooling requirements.


Chirnside, op. cit. (note 2).


Chirnside, op. cit. (note 2).

Le Rossignol, op. cit. (note 122).

Grierson, op. cit. (note 122).


The terrestrial radar stations used high-power (750 kW–1 MW), water-cooled ‘de-mountable’ valves. The GEC concentrated on compact air-cooled ‘sealed off’ valves for airborne interception, air-to-surface vessel radars, and the revolutionary new ground scanning radar, H2S. See Clayton and Algar, GEC, op. cit. (note 122), chapter 2. See also E. G. Bowen, Radar days (Taylor and Francis, Philadelphia, 1998).

Clayton and Algar, Scientist’s war, op. cit. (note 122), p. ix.

For many programmes there was no time to transfer a design to a valve factory. ‘Pre-production’ units were therefore set up in the laboratories and transferred to factories away from German bombing raids later. Clayton and Algar, GEC, op. cit. (note 122), p. 124.

Chirnside, op. cit. (note 2).

Clayton and Algar, Scientist’s war, op. cit. (note 122), p. 414.

Chirnside, op. cit. (note 2).

Clayton and Algar, Scientist’s war, op. cit. (note 122), p. 431.

Ibid.

However, Le Rossignol was retained for a further ten years by GEC as a consultant. Le Rossignol, op. cit. (note 14), p. 3.

A phrase used by Le Rossignol: Chirnside, op. cit. (note 2), p. 7. It may not have been the case.

In late 1918, the impending occupation of Ludwigshafen meant uncertainty regarding Haber’s future royalties. He therefore made a generous new private contract with Le Rossignol to make a direct payment to him for 1918 from his own funds: Szőllözi-Janze, op. cit. (note 9), p. 812, and personal communication, op. cit. (note 56). Max Mayer, who handled Haber’s finances during the war, had reduced Haber’s royalties to draw the Allies’ attention away from him, the balance to be recovered from BASF after the war: Szőllözi-Janze, op. cit. (note 9), p. 481, and personal communication, op. cit. (note 56). Meyer was also responsible for paying Le Rossignol, payment from Haber being considered ‘inappropriate’: Chirnside, op. cit. (note 2), p. 6. Le Rossignol never received his 1918 payment. In 1924 he placed a complaint before the German English Arbitration Court: M. Szőllözi-Janze, op. cit. (note 9), p. 812, and personal communication, op. cit. (note 56). It was later withdrawn. After hyper-inflation, there are traces of a financial settlement between Haber and the BASF to compensate him: Szőllözi-Janze, op. cit. (note 9), p. 486, and personal communication, op. cit. (note 56), but it is not clear if Le Rossignol ever received his share of this settlement. In 1920 Haber received approximately 140,000 Swedish Krona from his Nobel Prize, which he kept in a Swedish bank. There is no evidence that Le Rossignol received any of this. Finally, a change in German Patent Law on 9 July 1923 extended the life of a patent from 15 to 18 years, meaning that the high-pressure and circulation patents (see note 96) – which would have expired in 1923/24 – now continued to 1926/27. BASF never informed Haber of this, and both he and Le Rossignol failed to receive royalties for this period. Haber was ‘conned’. Szőllözi-Janze, op. cit. (note 9), p. 486, and personal communication, op. cit. (note 56).
Robert le Rossignol, engineer of the 'Haber' process

140 Chirnside, op. cit. (note 2).
141 From BASF production figures at the time, Haber’s royalty payments in Pfennigs per kg of ammonia (Szöllőzí-Janze, op. cit. (note 9), p. 482), and from historical taxation bands in Germany and the UK – both from Gerd Hardach, The First World War, 1914–1918 (University of California Press, Berkeley, 1977).
142 Chirnside, op. cit. (note 2).
143 Peter died on 26 May 1934, ironically from (coal) gas poisoning. His suicide was not the only one in the story of ‘fixation’. Clara Haber shot herself in May 1915 on learning of Haber’s involvement with chemical warfare. However, some have also identified a tendency to depression, a ‘family trait’: Stoltzenberg, op. cit. (note 48), p. 175. Hermann, Haber’s son by Clara, committed suicide in New York in November 1946. In 1949, his eldest daughter, Claire, Haber’s granddaughter, took her life in Chicago, where she had been working on counter-agents to poison gases. See ‘The secret story of the poison gas family suicides’, The Times, 30 July 2014.
145 This author does not pretend to know the detail of all the benefaction of the Le Rossignols over the years. The benevolence described here is that which is available in the public domain.
146 Le Rossignol signed a deed of charitable trust with the University of London on 16 March 1961. The details of the Endowment Fund were kindly supplied to me by Professor Andrea Sella at UCL Chemistry Department (personal communication, May 2009).
148 A national British charity begun in 1897 by Elizabeth Finn and her daughter to provide help to relieve the problems of old age, illness, social isolation and disability. Today it is known as Elizabeth Finn Care. I am grateful to Petra Gomersall and Geoffrey Roper, Legacy Officer and Compliance Project Analyst respectively, for the details of the Le Rossignol gift (personal communication, March 2015). http://www.elizabethfinncare.org.uk (accessed 28 November 2016).
149 From a letter in the Archives of the Trust written by Muspratt to the Charity Commission on 1 September 1965, and the Agreement between the Trustees and the Le Rossignols dated 15 August 1964. Both kindly supplied to the author by Mr Christopher White, former Chairman of the Trustees, February 2012.
150 A description of Muspratt used by one of the parishioners on a visit the author made to Penn in February 2012.
151 Muspratt, op. cit. (note 149).
152 The recipients of the gifts, and the sums involved, are taken from the couple’s wills and the values of their residual estates on probate. UK Documents, 29 Bunning Way, Islington, London, N7 9UP. http://www.probaterecords.co.uk (accessed 28 November 2016). Emily’s condition led to her becoming immobile and reclusive – according to some whom the author met at Penn. The author has therefore been able to reveal little of Emily’s life, but we can gain some measure of this lady through her will, which shows that she dispersed her estate widely among friends, family (in the UK and Germany), domestic employees and, of course, her charities. Indeed, a much more vibrant picture of Emily emerges than we could ever have otherwise imagined, a lady with a wide circle of friends and a sound humanitarian foundation to her life.
153 Chirnside, op. cit. (note 2).
154 Ibid. and see note 139.
155 The Reichsfluchtsteuer (Reich flight tax) was applied to prevent the flight of capital from the Weimar Republic.
156 The recollections of Eva (née Haber) Lewis, the 94-year-old daughter of Fritz Haber, describing the philosophy of her father in the BBC radio programme ‘Nitrogen’, on 1 April 2013, part of the Why Factor series. He actually said ‘In peace for mankind, in war for my

158 Le Rossignol, *op. cit.* (note 7).
159 Chirnside, *op. cit.* (note 2).
161 Haber, *op. cit.* (note 6).
162 Friedman, *op. cit.* (note 120), pp. 115–139.
165 Jaenicke, *op. cit.* (note 8).
166 Le Chatelier, Ostwald and Nernst all abandoned their attempts to synthesize ammonia. Le Rossignol’s work not only led to a prize for Haber but was generally regarded as robust verification of Nernst’s ‘Heat Theorem’ and contributed to Nernst’s recognition in 1920. The Bosch–Bergius joint award in 1931 was also founded on Le Rossignol’s work. Largely because of the ‘Haber’ process and the production of ‘cheap’ nitrogenous fertilizer, the world’s population expanded from roughly one billion at the turn of the last century to approximately seven billion today. Le Rossignol was especially proud of his contribution to living standards in the ‘Third World’. Chirnside, *op. cit.* (note 3), p. 271.

167 Coffey, *op. cit.* (note 53), p. 89.

171 Little remains of Robert Le Rossignol’s life. According to the family, no photographs remain and there are just a few reminders of his time at GEC, viz. a copy of his 1936 paper, Le Rossignol and Hall, *op. cit.* (note 122), some notes regarding refrigeration, and a small notebook with handwritten references to papers from the 1930s and 1940s. St Johns Road, ‘St Helier’ and Merlewood have all been redeveloped. But there is one tangible reminder of his relationship with Fritz Haber, the Penn Mead flatlets, still serving the community after almost 50 years. Unlike the Merlewood extension, they were built in an enduring style, and the author was fortunate to visit in February 2012. However, all that remains of the Le Rossignols is a small stone plaque in the entrance hall recording their gift. The hall is otherwise dominated by a powerful portrait of Rev. Muspratt donated to the Trust by his wife after his death in 2000. As with Haber, even here it seems that Le Rossignol is overshadowed.

173 Peplow, *op. cit.* (note 170).