Physics as a Calling, Science for Society

Studies in Honour of A.J. Kox

Edited by

Ad Maas and Henriëtte Schatz

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Ten highlights from Museum Boerhaave

9 The magnet and the cold: Wander de Haas and the burden of being Kamerling Onnes' successor

Ad Maas

Wander de Haas has not received much attention from historians of physics. Yet, in his day, he was considered an important physicist. He was also well-known abroad: he attended two Solvay conferences, in 1921 and 1930, was awarded the Rumford Medal in 1934, and he was also a corresponding member of the *Académie des Sciences*. The clearest evidence for his reputation as a physicist, however, was the fact that he was chosen in 1924 to succeed Heike Kamerlingh Onnes (1853-1926) – together with Willem Hendrik Keesom (1876-1956) – as Director of the Leiden *Natuurkundig Laboratorium* (Physics Laboratory), the famous cryogenics laboratory: the 'coldest place on earth'.[1]

Wander Johannes de Haas (1878-1960) was born in Lisse, a town not far from Leiden, but he completed his secondary education in Middelburg, the capital of the province of Zeeland in the south-west of the Netherlands. In 1895, he started to study law to become a notary. After having worked for a short while in a notary's office, he decided to change course and study something completely different: physics. He began his studies in Leiden in 1900. From 1905 until 1911 he was the assistant of Kamerlingh Onnes and J.P. Kuenen (1866-1922). In the following thirteen years he took various positions as a professor, first in Delft, then Groningen and, finally, in Leiden. There, he became responsible for the investigation of electrical, magnetic and optical properties of matter, while his Codirector, Keesom, directed the research on helium and other gases, and the thermal properties of solids. Keesom was also responsible for the cryogenic installation.[2]

In the history of physics, De Haas is mainly known for his collaboration with Albert Einstein in 1915, which resulted in the Einstein-De Haas effect – research totally unrelated to cryogenic physics. He appears to have been a good networker: he succeeded Kamerlingh Onnes, did research with Einstein and, moreover, he married the daughter of Hendrik Lorentz.

De Haas became director of the *Kamerlingh Onnes Laboratorium* (as the *Natuurkundig Laboratorium* was then named) in a period when Leiden's position as leader in the cryogenic field was challenged. In 1924, for example, Leiden lost the monopoly for the production of liquid helium, which it had since 1908. Increasingly, other scientists and institutions made major discoveries. In 1932 however, the laboratory once more acquired a unique position when the world's second largest electromagnet was installed. At the cost of an estimated 33,000 guilders it was undoubtedly the most expensive tool ever purchased by Kamerlingh Onnes, who had still decided upon this acquisition. Together with the famous cryogenic apparatus it was an unequalled set of equipment to study magnetism at low temperatures. It was now up to De Haas to make a fresh start and reap the benefits of this investment. There were reasons for high expectations.

In this chapter, I will focus on De Haas' cryogenic research with the large magnet to see what ultimately has become of these investigations. In the first part, I will elaborate on the most eye-catching results: the spectacular cold-records achieved in the mid-1930s. With a new technique, called adiabatic demagnetization, temperatures as low as four millikelvin were achieved. Yet, this kind of research was, in fact, atypical given what the Leiden scientists really had in mind. In the second part, therefore, I will examine the main research programmes that De Haas carried out with the large electromagnet. I will discuss the most important results and take stock: did the magnet give a new impulse to the Leiden research? In the final part of the chapter, I will try to characterize De Haas as a physicist and elaborate on his role as a researcher. In doing so I will focus on a peculiar habit of De Haas: he sometimes locked himself in his laboratory, together with an assistant, to conduct experiments, preferably at unconventional hours.[3] Nobody has ever explained why he developed this habit, but at the end of this chapter, I will be able to hazard a guess.

Cold salt

The research that secured De Haas' place in the quest for absolute zero focused on a technique called adiabatic demagnetization. By using the traditional method – pumping away the helium vapour over a reservoir of boiling liquid helium with as much force as possible – the threshold of 1 Kelvin could be passed, albeit with some effort. In 1932, Keesom managed to achieve a world record of 0.71K, breaking the eleven year-old record set by Kamerlingh Onnes, who had reached 0.82K. Spectacular new records resulted from a new way of cooling that was devised – independently – by Peter Debye (1884-1966) in Zurich and by William Francis Giauque (1895-1982) in Berkeley, in 1926. This method uses paramagnetic substances, instead of helium. When a preparation of a paramagnetic substance is placed in a magnetic field, its atoms will align themselves in the direction of the field (and its entropy will decrease). This magnetically aligned preparation is cooled by traditional method, a bath of liquid helium, to a temperature of a little above 1K. Then, the contact between the preparation and the helium-bath is

Fig. 1 – Wander de Haas and his wife Gertruida Luberta de Haas-Lorentz.
Source: Museum Boerhaave

broken, in order to isolate it thermally. If the preparation is subsequently removed from the magnetic field, the magnetic moments of the atoms will lose their arrangement, which had originated under influence of the magnetic field. Because the entropy of the system must remain equal, this results in a decrease of temperature.[4]

Leiden was the perfect place to put magnetic cooling into practice. Not only did the Leiden scientists possess unparalleled capacities and decade-long experience in cryogenic research, from 1932 onwards they could use the world's second largest electromagnet to generate strong homogeneous magnetic fields over a relatively large volume. However, they were not the first to apply the new technique. Giauque, in Berkeley, managed to construct a helium liquefactor, out of the blue, using kerosene-cooled coils to generate magnetic fields. To Giauque's astonishment, the Leiden researchers appeared for quite a while to show no inclination to pursue adiabatic demagnetization experiments, even though they knew of his efforts. In April 1933 he succeeded in reaching 0.25K by putting a preparation of gadolinium sulphate in his magnetic cooling machine.[5] One month later, De Haas struck back by cooling a preparation of cerium fluoride to 0.19K. A month and a half later, he reached 0.08K with a preparation of cerium ethyl sulphate.

The adiabatic demagnetization programme was carried out by De Haas, Hans Kramers (1894-1952), and Eliza Cornelis Wiersma (1901-1944).[6] Kramers took care of the theoretical part, De Haas was the leader of the programme and Wiersma was responsible for the most important part of the construction. Wiersma was, according to his colleague Casimir, an all-round physicist, who could, unfortunately, slide hopelessly into irrelevant details, which may be one of the reasons why Berkeley initially beat Leiden. Nevertheless, Wiersma managed to construct a suitable apparatus to practice adiabatic demagnetization. The principal part was a cryostat, in which the preparation was pre-cooled with liquid helium, after having been magnetized between the poles of the electromagnet. Subsequently, the helium was pumped away, to isolate the preparation thermally. Finally, demagnetization was achieved by removing the cryostat, including the preparation, away from the poles of the magnet. This removal of the preparation was, incidentally, far from simple technically, because there were pumping pipes connected to the cryostat that could not be disconnected.

With the 0.08K that was achieved in 1933, the possibilities to reach lower temperatures with adiabatic demagnetization were by no means exhausted. The trick was to find paramagnetic substances with a large and constant sensitivity to a magnetic field at extremely low temperatures. Not all paramagnetic substances are equally sensitive in that respect. The measure of this sensitivity is a measure of the susceptibility of a substance. The larger the susceptibility, the more strongly a substance can be magnetized, and the greater the decrease of temperature that can be achieved by demagnetization.

Salts of some of the metals from the iron-group or from the rare earths best met these requirements. Reaching the lowest temperatures was a matter of testing a variety of these substances. In the end, though, the ultimate record of 0.0044K, which was set in early 1935, was achieved in a compound with elements from neither the iron-group, nor the rare earths. The substance that was used consisted of potassium chromium sulphate and potassium aluminium sulphate. It was not until the 1950s that a new leap forward into the extreme cold became possible, owing to another new technique: the magnetic cooling of the atomic nucleus.

Achieving low temperatures was one thing, but being able to measure the temperatures in these new areas of cold was quite another. Measuring temperatures accurately was a constant concern at the Kamerlingh Onnes Laboratory.[7] To determine the temperature of magnetically cooled salts, De Haas and his colleagues used Curie's Law, which states that the susceptibility of a substance is inversely proportional to its temperature. In other words, the greater the susceptibility, the lower the temperature. To measure its susceptibility the cooled salt was put inside a coil that generated a small magnetic field. The force exerted by this field on the substance, which was measured in a galvanic balance constructed by Wiersma, was used to derive the substance's susceptibility and to determine its temperature, by means of Curie's Law. The problem, however, was that Curie's Law is far from perfect, in particular at low temperatures. The record temperature of 0.0044K was, for example, a cautious estimate: later it was established that, in fact, the temperature must have been lower than 4 millikelvin.[8]

Considering the impressive records that were achieved, adiabatic demagnetization research was a huge success, at first glance. National as well as local papers – from Limburg in the South to Groningen in the North – reported faithfully about De Haas' latest records: 'Wonderful Success for Prof. dr W.J. De Haas', wrote the *Leidsch Dagblad* on 12 May 1933 after De Haas had reached 0.27K. In addition, De Haas was awarded a royal decoration.

However, from the point of view of the Leiden scientists themselves, perceptions may have been different. According to Leiden research ethics, merely establishing cold records was never a principal objective. No urgent need was felt to get into a rat-race with other laboratories to search for the lowest temperatures. Kamerlingh Onnes' maxim '*door meten tot weten*' (through measurement to knowledge) was still the leading motto. According to this motto, theories needed to be subjected to precision measurements in order to be corroborated, so adiabatic demagnetization was taken up, first and foremost, because it offered the possibility to study physical theories and the properties of matter in a new area of cold. De Haas focused especially on studying the properties of the magnetically cooled substances themselves. Their susceptibility was measured and also the behaviour of specific heats and entropy were investigated. As predicted by Nernst's Theorem, spins tend to align themselves in an orderly manner close to absolute zero, which should be accompanied by a sharp increase in their specific heat. This phenomenon was indeed observed. Even the 0.0044K record was, in fact, only a by-product of an experiment, whose main goal was to measure the temperature effect of different magnetic field strengths on some substances. Apart from the physical behaviour of substances, the determination of 'true' thermodynamic temperature from the values obtained by extrapolating Curie's Law remained a spearhead of the Leiden efforts.

After Wiersma had left Leiden to become professor in Delft, the 'coming man' was Hendrik Casimir (1909-2000), who later became Director of the Philips Nat.lab. (*Physics Laboratory*) and is well known among historians of science for his book *Haphazard reality*. He managed the Leiden research programme, without being able, however, to 'discover something essentially new'.[9] In fact, this could be concluded for all of the adiabatic demagnetization research until World War Two. From the point of view of De Haas and his colleagues, the adiabatic cooling programme may not have been as successful as it had seemed to outsiders.

Missed opportunities

Adiabatic demagnetization was just one of the research programmes for which the large electromagnet was deployed and it was certainly not the reason why it was installed. Kamerlingh Onnes had made the first drafts for the large magnet in 1917.[10] At that time, a series of magnetic investigations had just ended, which had already started around 1905. For this series, Onnes had been inspired by an idea of Paul Langevin that, at lower temperatures, the thermal motion that counteracts magnetic arrangements is largely absent. At lower temperatures, in other words, magnetism can be studied in its purest form, unhindered by thermal disturbances. This had been Onnes' basic argument for magnetic studies at low temperatures.

Onnes' magnetic research focused in particular on Curie's Law: the lower the temperature, the higher the susceptibility. Langevin's theory had in fact been an explanation for this law. It was a characteristic Onnes type of research programme. He expected that precision measurements might reveal deviations of Curie's Law at low temperatures. Such deviations, so Kamerlingh Onnes hoped, could be the result of effects connected to quantum theory. Although he still stood squarely in the world of classical physics, Onnes conjectured that magnetism could not be understood without quantum theory, and that the effects of quantum theory would reveal themself pre-eminently at low temperatures. What he was aiming for, then, was to investigate the foundations of magnetism that could provide insights into quantum theory.

For Onnes' research an electromagnet of the Weiss-type was ordered from the firm of Oerlikon in Switzerland. It was installed in 1913, weighed about 1000 kilos, had a capacity of 50,000 gauss, and was in fact the smaller brother of the large magnet that would be put into operation twenty years later. After 1914, however, the magnetic investigations were interrupted for a variety of reasons. When Onnes revived the research programme after the war – there were sufficient grounds to continue the research, as deviations from Curie's Law had indeed been found – the Oerlikon magnet was outdated.[11]

It is important to emphasize that Onnes' motivation for purchasing the large magnet had taken shape between 1905 and 1915. When the magnet became operational, in 1932, some twenty years of scientific developments had already passed. In 1932 there was no longer a central, fundamental, scientific objective to use it, such as studying the foundations of magnetism and quantum theory by testing Curie's Law. Thus, De Haas was obliged to completely reformulate the research programme.

This new programme was set out in a small article De Haas wrote on the occasion of the large magnet officially becoming operational:

> As for the programme for the large magnet, this is very versatile, since now already a series of studies are awaiting an extension to stronger fields. Examples are the magnetic research of weak magnetic substances, the change of resistance of metals other than bismuth, magneto-optical investigations at low temperatures, the continuation of the study of anhydrical chlorides, probably the research of supra-conducting alloys and, finally, the change of heat conductivity of crystals of Bismuth and other metals.[12]

Remarkably absent in this research programme was adiabatic demagnetization.

Until the outbreak of World War Two, this somewhat fragmented research programme was actually carried out, for the most part. Several studies were devoted to the 'halfmetal' bismuth. According to Wiersma, De Haas' interest in bismuth dated back to a study he had conducted as early as 1914. The study of the change in resistance of antimony in a magnetic field had led him to the conclusion that a strong change in resistance correlated with the strong diamagnetic character of the material. Apparently, he surmised that this relation between resistance and diamagnetism could reveal fundamental characteristics of magnetism, and he chose bismuth, a strong diamagnet, as the material to which he would extend this research. The bismuth series would not yield De Haas the fundamental insights he had hoped for, although two interesting achievements are worth mentioning.

The first one was the result of cooperation with the Russian scientist Lev Schubnikov (1901-1937), a guest at the laboratory who was an expert in making pure bismuth crystals. The two men discovered that, at low temperatures, the influence of the magnetic field on the resistance depends – in a volatile manner – on the direction of both the field and the electrical current in relation to the orientation of the bismuth crystals (the Schubnikov-De Haas Effect). Particularly remarkable was the spectacular increase of the electrical resistance of bismuth in a magnetic field at decreasing temperatures.[13] Schubnikov's investigation was the first one for which the large magnet was used, even before its official inauguration. De Haas apparently had high expectations of this type of research.

One of De Haas' students, Pieter van Alphen, came across another remarkable trait of bismuth. At low temperatures its susceptibility also appears to show periodic variations as a function of the strength and the direction of a magnetic field. This phenomenon is known as the De Haas-Van Alphen Effect. De Haas and Van Alphen did not realize that these fluctuations were, in fact, an empirical support for the recent, cutting-edge quantum-mechanical theory of magnetism of Lev Landau (1908-1968), which predicted a strong periodicity of the diamagnetic moment. Consequently they could not appreciate the true value of the discovery, even though they actually did cite Landau's work in their article. After the theoretical background had become clear, the De Haas-Van Alphen Effect – 'one of the first major examples of successful agreement between theory and contemporary experiment in solid-state quantum mechanics[14]' – was experimentally 'exploited' by, among others, David Shoenberg (1911-2004), in Moscow, to gain insight in the electron structure of metals, as the effect is not confined to bismuth. So much for the bismuth series.[15]

Jean Becquerel (1878-1953), a descendant of a famous scientific family and a frequent guest in Leiden, carried out the main part of the magneto-optical research. He observed the Faraday Effect (the rotation of the plane of polarization of a linearly polarized beam of light under the influence of a magnetic field) at low temperatures in paramagnetic crystals that he brought from the fine collection of minerals of the *Musée d'Histoire Naturelle* in Paris where he held tenure. This Faraday Effect was remarkably large at low temperatures in some crystals that contained rare earths (such as tysonite). According to Casimir, Becquerel's research was of superb quality and has been somewhat underrated. It offered insight in the interaction of forces within paramagnetic crystals. Becquerel's research proved to be instrumental for the search for the ideal composition for the application of adiabatic demagnetization. It was his research that showed that the elements from the iron-groups were suitable.[16]

Naturally, much of the research was devoted to the still poorly understood phenomenon of superconductivity. The Leiden physicists observed especially what happened when the threshold to superconductivity was passed – forwards and backwards – under the influence of changing temperatures and magnetic fields. Particularly interesting was the discontinuity of thermal conductivity found by De Haas and H. Bremmer by terminating superconductivity in a magnetic field. This was the first indication that the transition to superconductivity was also accompanied by changes in thermal properties, coming approximately at the same time that Keesom's group noticed a sudden jump in the specific heat at the transition point.[17]

Remarkably enough, this was in fact the only experimental breakthrough that was achieved after the large magnet became operational, even though Leiden had always held a leading position in the research of superconductivity. In the late 1920s, De Haas, together with J. Voogd and the Belgian metallurgist E. van Aubel, had still discovered that binary metallic mixtures of which neither component was a superconductor, such as the eutectic mixture of gold and bismuth, could become superconductive. A mixture of bismuth and thallium even appeared to remain superconductive in the highest magnetic fields that De Haas could generate. The remarkable superconductive behaviour of bismuth may have been an additional reason for De Haas' particular interest in this element, and also an old dream of Kamerlingh Onnes': creating powerful electromagnets by using superconducting coils.[18] For a while, this seemed to give new impetus to research in that direction but in practice Onnes' dream would not be realized.

Leiden just missed by a hair the most revolutionary breakthrough in superconductivity research during the 1930s – and arguably even since its discovery – the Meissner Effect. A conductor that has been brought in a superconductive state appears to 'drive out' the internal magnetic field. This driving out of the magnetic field meant that a superconductor could be regarded as a perfect diamagnet, giving rise to the famous 'levitation effect' that could be considered a characteristic property of superconductors. The Meissner Effect stood in complete contrast to the view, current at the time, that a conductor fixes, or 'freezes in', its magnetic field. This latter hypothesis, incidentally, had been forcefully supported by an experiment in 1924 by Kamerlingh Onnes and Willem Tuyn, who thought they had observed this 'freezing in' in a tin sphere.[19]

The freezing-in hypothesis had implied that first applying a magnetic field to the conductor and then bringing it in the superconductive state yields a different result than doing the experiment the other way around and applying a magnetic field to a superconductor. The Meissner Effect revealed that the sequence did not make any difference at all, which opened the possibility for treating superconductivity as a thermodynamic change of state. The so-called 'two fluid model' of the young Leiden physicists Gorter and Casimir would be the first attempt to do so. Yet, it would be the brothers Fritz and Heinz London who would give the first satisfactory phenomenological description of superconductivity, which, by the way, was not understood at the atomic level until the 1950s.

The Leiden physicists had been close to debunking the 'frozen field' hypothesis. Some experiments showed contradictory results, especially the measurements conducted by De Haas, J. Voogt and J. Jonker with a monocrystalline tin wire. These showed that either sequence, first cooling below the transition point and then applying a magnetic field, or the other way around, did not influence the result. Also, Casimir had started to doubt the hypothesis' validity on theoretical grounds. De Haas and two of his students, Gorter and Jonker, began planning an experiment to study the question once more, but during their preparations the message about Walther Meissner's and Robert Ochsenfeld's observations arrived from Berlin.[20]

The most groundbreaking achievements of the De Haas 'school' of magnetism and cold did not originate from the research programme that was formulated initially, but from two new types of research. The first of these was adiabatic demagnetization, as we have seen. The second was initiated by Cornelis Jacobus Gorter (1907-1980), a gifted and dynamic young physicist who actually worked with De Haas in Leiden only as a student. By the time he graduated, Gorter had secured a tenured position at the Teylers Museum in Haarlem (1931-1936), after which he moved to the University of Groningen (1936-1940) and later to the University of Amsterdam (1940-1948), before eventually returning to Leiden. In his doctoral research he already laid the foundations for ideas he developed in subsequent years regarding paramagnetic relaxation. With this technique important information about the constitution of matter can be derived from the fact that the magnetization of the atoms in an alternating magnetic field[21] is sometimes unable to keep up and begins to lag behind in phase. Unfortunately, Gorter's own experimental attempts, between 1932 and 1936, to observe this effect remained fruitless. Felix Bloch (1905-1983) and Edward Mills Purcell (1912-1997), who succeeded where Gorter failed, received the 1952 Nobel Prize for their work. Gorter also was unable to reap the benefits from his suggestion how to use nuclear spin resonance for the determination of nuclear magnetic moments. In this case it was the Austrian-American physicist Isidor Isaac Rabi (1898-1988), who would win a

Nobel Prize – in 1944 – supported by Gorter's ideas. According to his friend Casimir, Gorter did not capitalize on his ideas because he lacked the technical means and simply did not have the skills to develop new experimental techniques. Gorter himself contended, in retrospect, that perhaps he had been too versatile in his interests.[22]

This latter example, though only partly concerned with the Leiden physicists and relating to research in which the large magnet was not involved, tellingly illustrates the nature of the experimental magnetic research of De Haas and his colleagues during the 1930s. They operated in the frontline of the latest developments, achieved important results that often inspired other scientists to do pioneering research, but missed major breakthroughs. The Kamerlingh Onnes Laboratory disposed of advanced research equipment with unequalled capacities to conduct magnetic research at low temperatures, but it did not manage to capitalize on it.

It is clear, in conclusion, that the installation of the large magnet did not really give a new impulse to De Haas' research. He continued old research programmes with better equipment, but apparently without new inspiration. Ironically, the only successful new programme started by De Haas – adiabatic demagnetization – was, in a sense, successful in the 'wrong' way, according to the Leiden physicists, who did not consider chasing after new temperature records serious science. De Haas had little involvement in the cutting-edge research by Gorter and Casimir. Was he the wrong man in the wrong place? What kind of investigator was he?

De Haas as an investigator

In an obituary, Gorter characterizes the scientist De Haas as follows:

> In his investigations he showed no affinity with mathematical methods, in which his father-in-law H.A. Lorentz excelled, but he combined the skill to devise accurate experiments with a peculiar, but often very effective intuitive approach of important issues. He has been called a romantic researcher of nature and he felt indeed closer to the explorer than to the systematic formalist.[23]

His interests were to find 'new connections and unknown phenomena'.[24]

In fact, De Haas was an adventurous and impulsive experimentalist, who could tackle fundamental scientific issues with a single experiment that he devised with a simple set-up. The best example of his experimental aptitude are the measurements leading to the Einstein-De Haas effect, in which a fundamental question – evidence that electrons orbiting around atomic nuclei cause magnetism – was tackled with a simple, table-top set-up.[25] Even though the quantitative results

Fig. 2 – De Haas and the large magnet. Source: Museum Boerhaave

have not remained undisputed, it was an important experiment and it shows the nature of the experimentalist De Haas all over.

Two years before his work with Einstein, De Haas had finished his PhD in Leiden with work of a completely different nature. In order to test Van der Waals' equation of state, De Haas had measured the compressibility of hydrogen between the boiling and melting point.[26] This was not an adventurous endeavour to reveal the secrets of nature, but a typical, business-as-usual investigation of the Leiden cryogenics laboratory, using tried and proven methods. The research did not consist of one single experiment devised to decide upon a fundamental scientific question and did not involve a heroic attempt to discover new phenomena. It was just a small piece of a large research programme designed to provide insight into the laws of nature by virtue of accuracy and repetition. De Haas' dissertation fitted perfectly in the straitjacket of Kamerlingh Onnes' research factory and did not lead to earth-shaking results. In this way, De Haas, the adventurous, intuitive researcher looking for fundamental problems to solve with one experiment, was forced into the ethical mould of systematically pursued measuring programmes.[27] The point of departure in these programmes was the unequalled capacity to conduct research at the lowest temperatures, creating the conditions to test as many natural phenomena and laws of physics as possible with great precision. De Haas, in other words, worked in Leiden against his nature.

The successful Cavendish Laboratory is an example of a laboratory where research during the interbellum was instead driven by real scientific problems and pursued with relatively simple 'string and sealing wax' experimental set-ups.[28] This is the kind of environment that would have been more in line with the skills and inclinations of De Haas and one can only wonder what he would have accomplished in this type of research tradition.

Incidentally, there is one characteristic that De Haas, as an experimentalist, shared with the Kamerlingh Onnes ethic: his patience and perseverance to continue an experiment until all interfering factors that might possibly influence the results were removed. He was very disciplined in this respect and, according to Wiersma, he even had 'a special instinct for finding systematic errors in experimental results.'[29]

As Director of the laboratory he appeared to have the freedom to choose his own direction and style. However, the laboratory had a strong tradition that was not easy to change, not even for an all-powerful Director – if he would have wanted to do so. Obviously, it was unthinkable not to give the research equipment of the Kamerlingh Onnes Laboratory prime of place in the research conducted there. This applied to the large magnet that had been ordered by Kamerlingh Onnes himself, as well as to the unique cryogenic apparatus constructed with blood, sweat and tears by Kamerlingh Onnes and his associates. The only way to reap full profit from the unequalled capacities of the laboratory was to take the presence of the equipment as the point of departure and use it to test a great number of natural phenomena and laws of nature.

So De Haas was less inclined to be guided by spontaneously invented fundamental questions, than by the presence of the great magnet and the cold machine, which inevitably determined the course of his research. De Haas had to change from being a scientist driven by scientific questions to an instrument-driven investigator. It was, for instance, natural for Leiden, with its combination of extreme cold and strong electromagnet, to focus on adiabatic demagnetization research, and inevitably the laboratory engaged in it. This was a typical case of equipment-driven research.

Of course, the magnet and the cold-apparatus still defined a broad field of research in which De Haas could devise ingenious research topics and experimental set-ups, and he did so regularly. As Wiersma has noted, for example, De Haas not only supplied research topics to his students, he also devised the experimental methods. This seems to have been his particular strength. However, as the Director of a complete organization, he also needed to formulate long-term research programmes. He proved to be no programmatic innovator, nor did he manage to formulate one single, long-term research objective, and one can only wonder whether strategic, visionary thinking was part of his skills. In the end, the only new research programme he initiated himself was that of adiabatic demagnetization.

The problem for De Haas was, in other words, that a laboratory is more than just a 'neutral' facility for doing research. Not only the experimental equipment, but also the expertise of the investigators and the technical staff, as well as the research ethos, together form a tradition that tends to maintain itself, and be strongly ingrained in the laboratory's current and future research. It should not be forgotten that investigators and other staff were all trained to do low-temperature science, guided by Onnes' famous '*door meten tot weten*' motto. The people in the laboratory were all steeped in this experimental tradition.

Equipment, expertise and research ethos are all examples of durable, routine-like behaviour patterns and organizational structures that constrain the behaviour of individuals, such as De Haas. In the economic and social sciences, such factors are termed 'institutions'. Institutional explanations are used in these sciences to characterize the often sub-optimal economic performance of companies or countries that cannot be explained by 'objective' market-factors alone (about institutions, see Goodin 1996). Institutional theory can also be a useful tool for studying the history of scientific organizations. In another study I have argued that the stature of Amsterdam experimental physics between the World Wars also suffered from limiting institutional factors that were created in the past. As in Leiden, the research in the three Amsterdam physics laboratories tended towards being equipment-driven, even after the field of research appeared to have become outdated.[30]

In a sense, the large magnet is exemplary, and also symbolic for the Leiden research tradition that burdened De Haas and prevented him from making a fresh start with a new programme of research. De Haas never complained about his situation. As was mentioned in the introduction of this chapter, once De Haas had become Director of the Kamerlingh Onnes Laboratory, he developed a remarkable habit. Sometimes he locked himself in his office, together with a laboratory assistant, to conduct experiments. There he tried to tackle fundamental questions of physics in an inventive manner he devised himself. According to a description of these sessions by Wiersma, '[...] there is no end to his patience. What time it is, how long dinnertime has passed – al this does not matter. Series after series are tried and the more difficult, the greater his interest.'[31]

We do not know what kind of investigations De Haas pursued: according to Wiersma 'he seldom published them'. I believe, though, that there, in a place without large magnets and cold-machines, we can see a glimpse of the 'real' De Haas, released for a brief moment from Onnes' straitjacket and from the weight of the large magnet.

Notes

1. Casimir (1983), pp. 67-175; Van Delft (2007), pp. 571-586.
2. Casimir (1983); Gorter (1958); Gorter (1960); Van den Handel (1979); Wiersma (1937); Prins (1972).
3. Wiersma (1937), pp. 161-163.
4. Giauque (1964), pp. 236-250; Mendelssohn (1966), pp. 161-190.
5. Giauque (1964), pp. 236-250; Mendelssohn (1966), pp. 166 and 171; Stranges (1990). Incidentally, a main source of inspiration for Giauque (and also for Debye) had been an investigation by Kamerlingh Onnes and Woltjer, in 1924, on the magnetic susceptibility of gadolinium sulphate octahydrate.
6. For the Leiden research on adiabatic demagnetization until 1940 as related here, see Maas (2006).
7. See Van Delft in this volume.
8. De Klerk (1948), pp. 1-5.
9. Casimir (1992), p. 659.
10. Van Delft (2007) p. 537; Kamerlingh Onnes Archives, Museum Boerhaave, inv. no. 72.
11. Van Delft (2007), pp. 484-493.
12. De Haas (1932).
13. Wiersma (1937), pp. 164-165; Gerritsen (1943), pp. 161-162; Casimir (1983), pp. 335-336.
14. Hoddeson, Bayin & Eckert (1992), p. 129.
15. Ibidem, pp. 125-129; Gerritsen (1943), pp. 163-164; Shoenberg (1965); Casimir (1983), p. 336; Hoch (1992), pp. 211-213; Wiersma (1937), pp. 164-165.
16. Casimir (1983), p. 332; Wiersma (1937), pp. 166-167.
17. Wiersma (1937), pp. 170-171; Casimir (1983), p. 339; Gavroglu & Goudaroulis (1989), pp. 77-78; Dahl (1992), pp. 149-153; Matricon & Waysand (1994), p. 57.
18. Wiersma (1937), p. 168; Dahl (1992), pp. 136-142.
19. Gavroglu & Goudaroulis (1989), pp. 74-82; Dahl (1992), pp. 109-110; Van Delft (2007), pp. 564-570.
20. Casimir (1983), pp. 176 and 339-340; Dahl (1992), pp. 164-181; Matricon & Waysand (1994), pp. 57-65.
21. Paramagnetic relaxation can concern both the electron spin and the nuclear magnetic moment.
22. Gorter (1967); Chang (1975); Casimir (1983), pp. 175-177; Snelders (1985); Van der Waals (1996).
23. Gorter (1960), p. 167.
24. Gorter (1958).
25. Galison (1987), pp. 21-74.
26. De Haas (1912).
27. Besides reasons of principle there was also an important practical reason for the planned way of doing research in Leiden. In those days, liquid helium was scarce, so the experimentalists had to know very well what they were going to do with it. There was no question of wasting the precious liquid with sudden, adventurous brainwaves (Van Delft [2007]).

28. Hendry (1984); Crowther (1974), pp. 183-257.
29. Wiersma (1937), p. 162.
30. Maas (2005).
31. Wiersma (1937), p. 163.

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