The X-ray tubes case study is an intriguing one that leaves the reader somewhat bewildered. Could it really be true that Bouwers had succeeded in freeing himself from Holst's supervision, even though as the lab's manager Holst seemed to have been able to influence every other part of the research programme? And how was it possible that the clever entrepreneur, Anton Philips, approved of an activity that kept yielding substantial losses for so many years? That this activity was not profitable can be explained by the fact that sales were disappointing. But why then continue? Was it, as Blanken suggests, that he expected to get grips on the German radio patents by acquiring the Müller company with its X-ray expertise?[11] Or was it his humanistic concern about the availability of X-ray technology for Dutch hospitals? Having seen the data, we can only conclude that no final answers to those questions can be given. Whatever the best interpretation of the data may be, the X-ray technology story in the Philips company provides a good example of the role fulfilled by colourful individuals in a technological innovation process.

4.3 Ferrites

Ferrites are non-metallic magnetic materials that can be used for permanent magnets and for cores in electromagnets. Research in the field of ferrites is an example of materials research instigated by practical needs (magnetic material for Pupin coils in telephone cables and in loudspeakers).[12] Ferrites particularly suited the purpose because they have a high electrical resistance and therefore low Eddy currents. Eddy currents arise from high frequency signals in magnet cores; the overall result is energy loss. The need for those materials was not established through trial-and-error but by investigating the magnetic properties of a certain group of materials, the ferrites, that had $MeO.Fe_2O_3$ as their molecular formula (whereby Me is a bivalent metal oxide, like Cu or Pb). This is similar to the way in which gas discharges were dealt with. The expectation was that having a better understanding of the underlying phenomena would result in better designs.

In the case of gas discharges, Elenbaas was a key person. Here, too, we find such a key person, namely Snoek. In the gas discharge case we saw that individuals such as Elenbaas and Bol were very eager to have their name linked to an invention. This should make us cautious about too easily presuming that inventions were the domain of those individuals who claimed responsibility for them. Usually scientific research is teamwork, and it would be a distortion of the true facts to make it look as if one or two individuals could have done all the work. In the case of the ferrites, we should not only focus on Snoek but also take into account the contribution made by Verwey and De Boer.

Ferrite Research in the Nat.Lab. Prior to 1936

In 1909 Hilpert of the Technische Hochschule in Berlin published an article on the possibilities opened up by using ferrites for magnet cores. He also acquired a patent for this work on using ferrites for magnetic cores. Hilpert had found that ferrites were particularly useful where high frequencies were concerned. It is not clear whether his work was implemented at that time. In Japan in 1930, Kato and Takei embarked on their own ferrite research. Not only the properties, but also the structures of ferrites were investigated. It appeared that ferrites had a spinel structure. Spinel is the mineral $MgO.Al_2O_3$. The Japanese researchers were also able to acquire patents for their work. In 1940 Snoek got hold of a piece of the ferrite material that the Japanese had developed. He did some X-ray and chemical analyses, and after that ferrite research really started to take off in the Nat.Lab. During the 1940s the Nat.Lab. was the most prominent lab that worked on ferrites. Outside the Nat.Lab., only a few others, like Adelsköld and Hoffman, made contributions of any significance.

Before that, incidental studies into magnetic phenomena had been done for practical purposes. Philips' chromium foundry had been producing magnets of hardened steel since 1924. That material was used for magnets in loudspeakers. In 1931 the chromium-iron deliveries stopped, and a new product was sought to keep the factory active.[13] After 1932 magnet steel for permanent magnets was not only produced in Eindhoven, but also in Blackburn (UK). Sometimes practical problems had to be solved, such as problems relating to the production of magnet cores for transformers and loudspeakers. In particular, there was the problem of Eddy currents causing serious energy losses with high frequencies (such as radio frequencies).

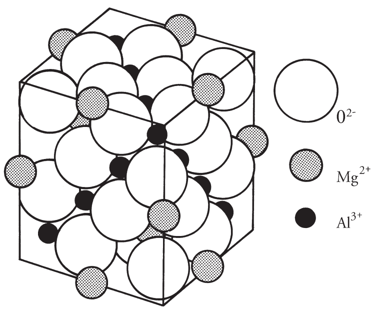

Figure 13. Unit cell of the spinel $MgAl_2O_4$. The oxygen ions are much larger than the metal ions. The Mg ions are surrounded by four oxygen ions, the Al ions by six (from Garratt 1976, Vol. 2, p. 217).

According to Verwey, who joined the lab in 1934, Holst had identified this as a key problem. Practical ways of preventing Eddy currents forming in metals involved splitting up the core into slices of metal. Eddy currents could not run between the slices. Another option was powder cores. Here, too, the fragmented structure of the core prevented Eddy current formation. What is evident though is that these solutions complicated the production process. The core should rather be a homogenous material. This was what made highly resistant non-metallic magnetic material so interesting, because with such material Eddy currents were small. Already before he had obtained the Japanese material, Snoek had studied the material mentioned in Hilpert's patents. He was not satisfied with it because there were still substantial energy losses even though the Eddy currents were low. Snoek experimented with combined ferrites, like magnesium manganese ferrite, but his findings were not patentable because they fell under Hilpert's patents. Gradually, more scientists became involved in the ferrite research project. In 1934 Verwey started a study into recrystallisation and molecule grids. Van Bruggen, an assistant, did the practical work, both for Snoek and Verwey. The spinel structure was found to be of importance to energy losses, but the work did not yield usable results. Snoek and Verwey had rather different approaches. This sometimes gave rise to tension between the two, not unlike the type of tension seen between Elenbaas and Bol. Verwey tended to focus on theoretical considerations. Snoek, however, had a more practical attitude. He worked primarily on Pupin coils and not on magnetic phenomena as such. Verwey was sometimes reproachful towards Snoek because Snoek would not show enough interest in Verwey's crystallographic discoveries. Besides that, Verwey doubted if Snoek's claim that energy losses had been measured by the radio research colleagues was true, because his impression was that Snoek irritated those colleagues because of his stubborn behaviour. The articles both men published in the *Philips Technical Review* reflected their two different approaches. In 1935 Van Arkel, Verwey and Van Bruggen published two articles on the phase system of ferrites; in the same year Snoek published an article on the magnetic and electrical properties of single ferrites, which mainly focused on the homogeneity of the material. In addition, in 1937 Snoek himself expressed his opinion that their subject could be 'approached from different angles: if one takes the concepts of crystal structure and (ferro) magnetism in their most principle sense, then one could investigate how the fundamental magnetic properties depend on the properties of single crystals. Such a consideration, important as it may be for our theoretical insight, would teach us nothing about the size and shape of the magnetisation curve in dependence of factors such as heat treatment, purity, grain size and crystal orientation. In particular, it is the latter sort of considerations that are of interest in practice.' This remark fits in well with the suggestion that Snoek had adopted a very practical approach.

The effort put into ferrite research diminished in the years 1934 and 1935, probably due to the lack of success and maybe also because of the tensions between Snoek and Verwey. In 1937 the research was resumed again. In 1940, the analyses of the Japanese material gave the ferrite research in the Nat.Lab. a new impetus.

The Road that Led to Ferroxcube

In November 1936 a meeting was held about the progress being made in ferrite research. Snoek presented his work on materials for coil cores. Rinia who was involved in radio research also took part in the discussions. His work done in 1933 on the properties of high-frequency powder core coils for radio probably had been one of the reasons for starting the ferrite research. He had concluded that the Ferrocart coils that had been used until then were suitable for frequencies of up to about 400 kHz, but not for higher frequencies. Ferrocart coil cores consisted of a mixture of iron powder and a thickening material, built up in thin layers separated by paper sheets. Six was involved in telephone cable research. Then there was Meerkamp van Embden, who during the 1930-1939 period worked at the chemical lab, at the Nat.Lab. and in the magnet factory. He presented information about production problems. The meeting, and notably the presence of Meerkamp van Embden, illustrates the close relationship between the lab and production work in the factories. Meerkamp van Embden had himself explicitly expressed the need for close co-operation between the factory and the lab.[14] From the minutes of this meeting Hoitzing concludes that from then on, ferrite research had become a separate entity within the total research programme.

In 1937 Snoek discovered that iron did not show magnetic after-effects when all the nitrogen and oxygen had been removed from the material. The after-effect was known to be responsible for a substantial part of the energy losses in Pupin coils, but a more important impetus came when Snoek got hold of Japanese ferrite material. Articles written by Takei in 1937 and in 1939 showed that Japanese ferrite research was quite advanced, but that up until then the Japanese industry had not expressed much interest in it. The fact that the Japanese had proved that it was possible to produce ferrite with modest losses gave Snoek added impetus to continue research into these sorts of materials. The analyses carried out on the Japanese ferrite material had made him aware of the relationship between the way in which the material was cooled and sintered and its oxygen absorption. Druyvesteijn later recalled a remark made by Snoek: 'I actually never noticed if we did the glowing by reduction or oxidation.'[15] Hoitzing shows that Snoek could have been aware of the relevance of this difference from Verwey's work, but as we have seen, Snoek did not seem generally to be very interested in Verwey's theoretical work. From then on, Snoek's work would focus on the preparation of the ferrites. In that respect, the research was of a different nature than the Japanese research that had been more concerned with the characterisation of the material. Snoek's aim was now to search for purity. The purity of the material before it was ground and sintered proved to be important for the magnetic properties of the ferrites in conjunction with the spinel structure of the material. In 1941 Snoek invented a procedure for preparing a ceramic ferrite material which involved baking a very finely divided mixture at a low temperature and then absorbing oxygen at low temperatures. The procedure (not the resulting material) was patented. The method was applied to copper zinc ferrite, and the trade name for the resulting ferrite became: Ferroxcube. The name consists of 'fer' for iron, 'ox' for oxide and 'cube' denoting the cubic crystal structure of the ceramic. The name was used for different types of ferrites: Ferroxcube I was copper zinc ferrite, Ferroxcube II was magnesium zinc ferrite, Ferroxcube III was manganese zinc ferrite, Ferroxcube IV was nickel zinc ferrite, and Ferroxcube V was the manganese ferrite for transformer cores. This list illustrates the versatility of the Ferroxcube: it could be adapted to suit the needs of the application. The outcome, however, remained a compromise: in spinel structure materials, high magnetic permeability ('magnetisability') is not compatible with low energy losses. The compromise, though, was good enough to result in very successful industrial Ferroxcube applications. Improvements in material properties were achieved by experimenting with other oxides. During WWII, Six co-operated with Snoek to use the outcomes of the Ferroxcube research for his work on telephone cables. Pilot Ferroxcube production was set up in 1941 in the ceramics department of the glass factory. Van Bruggen, Snoek's assistant, was transferred to that department. Snoek and Six would go to the factory to lecture on the properties of the ferrites from time to time. A third party involved in all of this was the Electro Technical Factory that carried out measurements for the factory.[16] In the apparatus factory the materials were used in products.

During the war, the practical relevance of the work had to be kept hidden from the Germans. In the reports written for the Verwalter, the scientists neutrally wrote that ferrite research was about 'materials for powder cores'. No mention was made of the importance of the material for achieving low energy losses. As we will see in the first Intermezzo, fake reports were common during the war, and we can see that the same thing was happening here, too. Yet, work continued as if there were no Germans around. The war also provided the opportunity to reflect more on certain fundamental theories, such as the solid-state physics theory, that had been developed since 1930 but which, up until the war, had not had much impact on ferrite research, apart from the case of Verwey's and De Boer's work (but as we saw, Snoek did not make much use of that). According to Hoitzing, by the end of the war ferrite research had changed in the sense that the material itself rather than its preparation had become the focus of study. According to Casimir, it was Holst who in particular began to emphasise the potential of solid-state physics for Nat.Lab. research (Casimir even assumed that Holst had invited him to join the lab because of his expertise in that area as a theoretical physicist).[17]

Further Research after WWII

After the end of the war, it was Went, Gorter and Wijn who pursued ferrite research. Meanwhile, Snoek concentrated on theoretical explanations for the losses. In 1950 he moved to the laboratory of a competing firm in the USA, known as Horizon Ltd. in Cleveland, Ohio. Snoek did not work there for long: he died within months in a car accident. In the same year a French scientist, Néel, published a theoretical explanation for the magnetism in ferrites that was based on the division of ions in spinel crystals. Snoek had been close to finding such an explanation, but his interests had never been very theory oriented, so he had not put a great deal of effort into elaborating his ideas on that. In 1970 Néel was awarded the Nobel Prize for his theory. If ever the Nat.Lab. was close to having a Nobel Prize winner in its ranks, it was probably here. We must not, however, forget that Verwey's theoretical work was just as important as Snoek's more practical work.

From 1948 onwards it was Went who led the ferrite research. Went had already worked with Snoek on manganese zinc ferrite. Until then, the main focus had been on ferrites for the cores of electromagnets. Now a shift was being made towards ferrites for permanent magnets. Before 1950 Ticonal was used for such magnets. Ticonal was an alloy of cobalt, titanium and copper, that had emerged from Nat.Lab. experiments. When, in 1950, cobalt and nickel became scarce because of the Korean crisis, a new material was developed that was given the name 'Ferroxdure'. Ferroxdure was a compound that consisted mainly of ferric oxide and barium oxide. When it came to the invention of Ferroxdure, serendipity had played quite a role. Since 1944 Jonker and Van Santen had been working on materials with the same crystal structure as Perovskiet ($CaTiO_3$). These materials had various interesting properties, like semiconductivity. One of these materials was hexagonal lanthanum ferrite. An assistant, Bannink, had made a mistake during the preparation of this material and had unexpectedly ended up with a magnetic material. Jonker guessed that hexagonal barium ferrite had formed in the process and this was confirmed by an X-ray analysis. The preparation was taken to the magnetic research group, and Gorter, who had already planned to work on hexagonal ferrites, found it to be very suitable for permanent magnets. It was even cheaper than the current compounds that were being used for permanent magnets.

For both Ferroxcube and Ferroxdure, a sound patent position was established. It was mainly after WWII that this patent position was exploited. The importance of establishing a good patent position can be illustrated by the case of ferrites. The deployment of these ceramic magnetic materials became widespread and they were used in a great variety of applications, not only for the original one, namely in loudspeaker coil cores and telephone cable Pupin coils. For example, ferrites were used in electromotor magnets, dynamos, focussing magnets, magnets for oil filters and cyclotron magnets. One more type of ferrite was developed in 1955: Ferroxplana. This material was the outcome of a study into a ferrite suitable for higher cut-off frequencies without a specific product need. It did not achieve the widespread application that the use of Ferroxcube and Ferroxdure achieved. By this time other laboratories, outside of Philips, started to make substantial contributions to ferrite research.

The American Bell AT&T company was one of the companies that became interested in the Philips Ferroxcube patents (in particular for use in cores for carrier wave telephony). Years later, the licence contract agreed to in 1947 enabled Philips to apply Bell's transistor knowledge at reduced cost. So even indirectly, the ferrite patents were a great asset to the company.

The case of the ferrites is an example of materials research conducted in the Nat.Lab. The basic reasons for it were practical: the need for magnetic material for loudspeakers and Pupin coils. Ultimately, the insight yielded by the research had a much wider impact. Several new ceramic materials were developed that were applied to a variety of products, and not only by Philips, but also by other companies. As in the case of gas discharges, this knowledge was the result of a combination of theoretical considerations and practical experimentation and problem solving. Sometimes two approaches followed by different scientists gave rise to certain tensions between people, but in the end both had a contribution to make.

The case study also illustrates the connection between factory and research activities that we see so often in this period of the Nat.Lab.'s history.

4.4 Holst's Rules Reconsidered

After having examined three examples of research practice in the Holst period we now return to the general characteristics of the Nat.Lab.'s significance to the Philips company during the first period of its history (1914-1946, and including the early years).

Casimir, one of Holst's successors, once summarised Holst's research management according to what he called the 'Ten rules of Holst'. A critical reflection on these rules will help us to round off Part I with a sum-