Dr.philos. thesis

Roland Wittje

Acoustics, Atom Smashing and Amateur Radio

Physics and Instrumentation at the Norwegian Institute of Technology in the Interwar Period

NTNU Trondheim
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List of abbreviations used

AEG	Allgemeine Elektrizitäts-Gesellschaft
AT&T	American Telephone and Telegraph Company
DKNVS	Det Kgl. Norske Videnskabers Selskab (Royal Norwegian Society of Science and Letters)
DTM	Department of Terrestrial Magnetism of the Carnegie Institution of Washington
KTH	Kungl. Tekniska Högskolan (Royal Institute of Technology in Stockholm)
NeFAS	Nevnden for akustiske spørsmål (Committee for Acoustics Questions of NRK)
NRK	Norsk Rikskringkasting (Norwegian Broadcasting Corporation)
NTH	Norges Tekniske Høiskole (Norwegian Institute of Technology)

1. Introduction

Situated between two major catastrophes of the twentieth century, the interwar period was arguably one of the most interesting and most dynamic time periods in the history of physics. In the years between World War I and World War II, quantum mechanics was fully developed, leading to the Copenhagen interpretation and a fundamental change in the physicists' worldview. During the *Golden Thirties,* nuclear physics rose from the discovery of the neutron and the disintegration of nuclei by accelerators to the discovery of fission in 1938, at the dawn of WWII. The changes in physics during the interwar period were not only embodied in new findings and revolutionary changes in concepts but embedded in fundamental changes in research practices, research organisation and, last but not least, research technology. In the 1920s and 30s physics laboratories and scientific instruments changed significantly. Research installations became larger and more complex. Electrical installations became more elaborate and radio technology made its breakthrough. Together with the new technology, engineers, engineering practices and industrially made materials and components entered scientific instrument making, which was until then dominated by craftsmen and craft traditions. Contacts between research environments and industry grew stronger, with large corporate research institutions and industry supporting university laboratories with equipment and personnel.

These changes in physics, its practices and its instrumentation were situated within major changes in society at large. The 1920s and 30s were characterised by political and economic crises and the rise of the European dictatorships. Oswald Spengler's *Untergang des Abendlandes* (The decline of the West) was characteristic for at least parts of the intellectual climate of the time and had a major impact on the German academic environment. The influence of the Zeitgeist on the development of German theoretical physics has been subject of debate among historians of science.[1] The crises affected the scientific communities politically, economically and ideologically. The community of physicists was by no means homogeneous and was positioned between a rapid development of its knowledge, its practices and its fundamental concepts on one side, and an opposition against the abstractness of modern physics by parts of the academic environment on the other side. The hostility of a number of German experimental physicists against theoretical physics played a significant role in the Nazification of physics in Germany and the expulsion and persecution of Jewish and other unwelcome scientists. With intermediate stops in other European countries, most of the émigré physicists went to the USA. However, the emigration movement of European scientists over the Atlantic had started already before 1933, mainly due to the economic situation and better work opportunities in the USA. Whereas the European communities remained ahead in theoretical physics, America was taking a leading position in experimental physics and novel research instrumentation and research practices during the 1920s. The rapid growth of mass production and mass consumption in the American industry and other parts of its society emerged in close relationship to applied science and engineering and created large academic environments and industrially shaped research facilities. The domination of the American research community regarding large research installations appeared arguably most clearly with the development of particle accelerators in the 1930s, with Ernest Lawrence' cyclotron laboratory at Berkley as the most prominent example.

How were these global changes in science and society reflected in Norway, a small nation in the north of Europe with a very special geography and an industry and economy mainly based on raw products? How did the new physics with its new practices establish itself locally at the small physics department of the Norwegian Institute of Technology (NTH) in Trondheim? Within the local history of the small community of physicists at the northern periphery of Europe's scientific community, we can study the global changes in physics during the interwar period. The institute of technology has been the first place where many of the new technologies and practices have been introduced and developed in Norway. We can follow the transnational network of the Norwegian scientists and their orientation within the changing topology of physics. At the same time we can, and have to, account for the local peculiarities of doing physics at NTH in Trondheim and within the nation of Norway, as well as the personalities of the local actors. These peculiarities were not merely passively shaped by some abstract local and national constrains, but the research community was actively contributing to shape and alter these local conditions.

[1] See Forman, and von Meyenn, 1994.

The establishment of NTH in the first decade of the 20^{th} century, as an institution to support nation building and intellectual and economic independence, coincided with the break-up of the Swedish-Norwegian Dynastic Union in 1905. At the opening of NTH, in 1910, the role of the physics department was defined to teach basic physics to engineers. During the interwar period and with the appointment of Johan Holtsmark as NTH's second Professor of Physics, the department developed into a modern research institution with several advanced co-existing research agendas. Out of this variety of research agendas I have singled out three different research fields, technical acoustics, electron scattering and nuclear physics. An aspect that connected these three very different research fields at the small physics department at Trondheim was the appearance of a new kind of scientific instrumentation, novel electrical devices, largely based on radio technology.

Not without reason, acoustics was the first discipline to be transformed by the electrical instrumentation. With some justification the interwar period can be characterised as the age of electroacoustics. Radio broadcasting was established in the 1920s, and by the 1930s it made its breakthrough as a mass medium in most European countries. Like radio, sound motion picture, which came from Hollywood, set out to conquer the Western World in the late 1920s. Electroacoustic amplification, transmission and manipulation of speech and music became an omnipresent feature in both public and private spaces. During the 1920s and 30s, electroacoustic media technology contributed re-shaping the cultural and even political landscape of the Western World. With its features of industrial mass production, mass media and mass culture, the American telecommunication and media industry was the leading power of this electroacoustic invasion. But the intellectual and cultural climate of Germany's crisis-haunted Weimar Republic, as well as the strength of the German electrical industry also played an important role, especially in the Norwegian context. Electrical instrumentation, which formed the technological base for mass media and mass culture, was in America and Europe mainly developed by scientists and engineers at corporate laboratories or academic institutions with close contact to the industry.

The core narrative of Chapter 4 takes up the global features of interwar period science and technology, such as the rise of the media industry, the re-shaping of the field of acoustics into electroacoustics, the close relation between the corporate and the academic complex, the transfer of amateur radio practices to scientific instrument building and the transdisciplinary character of electrical instrumentation along with the thinking in terms of electrical analogies. We will see how all these features are interconnected and merged within the small and local environment of the physics department of NTH. In Trondheim we can draw a direct link between amateur radio technology and scientific instrument making through the story of how electrical engineering students from the Academic Radio Club in the 1930s got involved in scientific instrument building as well as in acoustics and nuclear physics research. The Academic Radio Club, founded mostly by electrical engineers in 1923, represented in many ways a technical face of the student social life in Trondheim, which was organised around the Student Society. With the construction of amplification and illumination systems and the wiring of the Student House, the radio club constituted a link between the social and cultural world of the Student Society and the engineering world of NTH's workbenches.

The radio club was allowed to organise its activities at the physics department and to invade the workshops with amateur radio instrumentation in its first years before the new Student House was built. Professor Johan Holtsmark not only tolerated the amateur radio activities but also actively participated in them. The transfer of knowledge and practices from amateur radio allowed Holtsmark to enter the field of technical acoustics research. The skills of Holtsmark's assistants, mostly telecommunication engineers with amateur radio background, in building electroacoustical measurement devices was of special importance. Holtsmark's transition towards the professionalisation of acoustics activities was also expressed in establishing technical acoustics as a course for telecommunication engineers. Holtsmark's entrance into the field of technical acoustics research and consulting coincided with increasing requirements for acoustical investigations and planning. In Norway, like everywhere else, there was a boom in investigations and consultancy assignments in applied acoustics triggered by the professionalisation of radio broadcasting as well as the appearance of sound motion pictures and acoustically engineered construction materials. Without much competition in a small country like Norway, Holtsmark established himself as the leading scientific authority in acoustical questions, particularly regarding architectural acoustics. Holtsmark's consulting for the Norwegian Broadcasting Corporation (*Norsk Rikskringkasting*) was important since it lead to major financial contributions to the NTH sound laboratories in the late 1930s. At the Trondheim physics department, however, scientific instrument design by electrical engineers did not stop with electroacoustics but spread to other fields of research. An example for the diffusion of electrical instrumentation and thinking into other research fields was the design and construction of an electrical analogue calculating machine to calculate electron scattering curves around 1935. Most of the electrical engineers involved in instrument building left the physics department after some years and took positions in Norway's growing electrical industry, such as Vebjørn Tandberg, who became the founder of the well known Tandberg Radio Factory. A few others stayed in academia, such as Roald Tangen who made the move from an instrument builder to an instrument user and became one of Norway's first nuclear physicists.

In 1933, Holtsmark started to organise the construction of a Van de Graaff proton accelerator, which was built between 1934 and 1937, again mainly by telecommunication engineers with amateur radio background. The availability of electrical engineers and contacts with American research groups made it possible for Holtsmark to build Scandinavia's first working particle accelerator. I follow up in detail the local establishment of this accelerator laboratory and its transnational network. The Trondheim Van de Graaff generator was a relatively small installation compared to the large machines and the race to higher and higher energies of the leading accelerator laboratories. But even though the Trondheim Van de Graaff generator could not compete with the internationally leading machines it found its research niche as a precision machine measuring low energy levels. The Trondheim Van de Graaff generator was an installation one could gain experience with and proved to be a very successful machine as regards establishing the research field of accelerator based nuclear physics, and it contributed in nurturing a new generation of physicists in Norway.

2. Historiography and methodology

This thesis is not about theory. But it is not against theory either. As for history writing in general, I approve of a *Methodenvielfalt*, a multiplicity of approaches, as well as multiperspectivity in history of science writing. In this chapter I want to clarify a number of concepts and ideas which underlay the history writing of this dissertation.

2.1. Eine Alltagsgeschichte der Physik?

Towards the micro-study of a small scientific community

> *"... Who, for example, dares write a book about an ordinary, only mildly successful, yet for that reason more typical, scientist? Such a book would tell us more about 20th century science than any number of biographies on Nobel laureates. ..."*
>
> [Svante Lindqvist, 1993][2]

The above quotation, taken from Svante Lindqvist's introduction to *20th century Swedish physics* can be taken as a guide to the methodology underlying this thesis. Historians of science have long focused on famous, or so-called *important,* scientists, suggesting that the large majority of scientists has little, or may be even no historical importance at all. In twentieth-century history of science the award of the Nobel Prize has served as a synonym for the

[2] Lindqvist, 1993, p. xxviii.

importance of a scientist. When I started my project of writing a history of physics at the Norwegian Institute of Technology (NTH) during the interwar period, one of the senior physics professors advised me against such a project: there was no Nobel Prize won for any of the research results achieved at the small physics department. There was basically not enough history to write about.

I hope to have managed in this thesis to convince the reader that this is not the case. But I would also like to challenge Lindqvist's portrait of the "*ordinary, only mildly successful ... more typical physicist*". The key lies according to my view in the notion of the "*successful scientist*". Success, also in science, can and has to be measured on a variety of factors. I claim, for example, that the small community of scientists and instrument makers at the NTH physics department under the leadership of Johan Holtsmark was very successful in introducing new research practices and in organising a variety of co-existing research agendas which stimulated each other. A Nobel Laureate, on the other hand, need not automatically be a successful scientist in all aspects, as for example lecturing or the organisation of research groups. The concentration on Nobel Laureates in history of science fails to explain the many facets of physics within a modern society like Norway. These facets are expressed in the role of physics departments within scientific and educational institutions (like NTH), the establishment of scientific practices and bodies of knowledge, the travelling of these entities across both regional and disciplinary borders, the interaction between research activities and higher education, or industrialisation, cultural aspects of physics, and so forth. Science has many different functions in society. To concentrate on a list of (predominantly male) big scientists and big events gives a narrowed image on what doing science is about and why society maintains scientific activities and institutions.

Alltagsgeschichte (the history of everyday life) is a concept of 1970s German social history.[3] *Alltagsgeschichte* is closely connected to approaches of micro-history and local history. Taking some of the justified criticism against aspects of the *Alltagsgeschichte* approach into account, I argue for a reflected micro-history that does not substitute but supplements macro-historical approaches.[4] I agree with historians like Jürgen Kocka that a limitation on the micro-historical small, without including the big picture, is dissatisfying.[5] I would, however argue that the micro- and the macro-historical approach in

[3] See, for example, Schulze, 1994, and Kaldal, 1994.

[4] Hans Medick in Schulze (1994), p. 40: "*Die Mikrohistorie ist eine Schwester der Alltagsgeschichte, geht aber in einigen Punkten ihren eigenen Weg, nämlich dort, wo sie ihre Methoden reflektiert ...*" I will continue to use the notion of micro-history, rather than the notion of *case study*, which has been a very common one in science and technology studies.

[5] Kocka in Schulze, 1994, p. 34.

history of science writing can complement each other in the way that micro-history is embedded in macro-history. The micro-history reflects the macro historical picture a way that allows us to learn about the large structures from the small. In this sense micro-history is not merely about analysing small structures, but analysing within small structures.[6] I think it is from this perspective how we have to understand Lindqvist's quote that we can learn more about twentieth-century science from a history about a "*typical scientist*" than from a biography of a Nobel Laureate. I do not want to deny the importance of local micro-history in its own rights. It is important for local environments to learn about their own history.[7] But the way I understand micro-history is that it reaches far beyond the local community. Writing micro-history of the small physics department at NTH during the interwar period tells us about the changes of the large structures of physics within this period of the 20[th] century.

Is doing science an activity of everyday life? For scientists the answer is easy: it certainly is. For most of society it is not. But does this make science different from other parts of society that also have their segregated everyday lives? Historians of science have long supported the view of science as an extraordinary activity.[8] The popular image as well as the self-image of scientists partly challenges the *Alltagsgeschichte* approach. The personal cult around famous scientists has dominated the popular image of science and has advanced to popular culture. Most prominent among these popular scientists is certainly Albert Einstein.[9] Scandinavia's most prominent 20[th] century physicist was Niels Bohr. His prominent place within modern Danish culture has been

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[6] Medick, citing G. Levi, in Schulze (1994), p. 44: "*Historiker untersuchen keine Dörfer, sie untersuchen in Dörfern.*"

[7] It has been a very interesting experience for me to give lectures about the local history physics at the physics department of the Norwegian University of Science and Technology (the successor of the Norwegian Institute of Technology) and to observe how my activities contribute to the local environment. Whether it is possible to learn from its own history is another issue, which I will not dare to touch.

[8] The rejection of the view of science as fundamentally different from other social activities by the New History of Science and Sociology of Scientific Knowledge does not need to be discussed here. Sociologists and social and cultural anthropologists have conducted a large number of studies on everyday life in the laboratory. From the vast amount of publications I can mention Latour and Woolgar (1979): *Laboratory life*, Traweek (1988): *Beamtimes and lifetimes : the world of high energy physicists* and Knorr Cetina (1999): *Epistemic cultures.*

[9] Einstein has been voted as *Person of the Century* by the *Time* magazine in 2000. The name and image of Einstein has been taken over by a coiffeur salon in downtown Trondheim. *Einstein* as a synonym for an intelligent person has also long been well established in Norwegian comic-book language.

subject to historical discourse.[10] The importance of Niels Bohr as a personalised institution and authority of science over the whole world, and especially within Denmark and the whole of Scandinavia is impossible to deny. Niels Bohr and the Institute of Theoretical Physics at the University of Copenhagen played an important role in putting the whole of Scandinavia on the focus of modern physics and to trigger and channel, for example, Norwegian research activities in the field. But, with one eye on Lindqvist's quote, it should be questioned whether we really need more biographies of Niels Bohr of the classical type. Interestingly enough there are many important stories about Bohr and the Institute of Theoretical Physics that are not told in the master narratives. The maybe-astonishing conclusion is that also Niels Bohr and the Institute of Theoretical Physics had its *Alltagsgeschichte.* Finn Aaserud's history about Bohr as a fundraiser for a re-direction of the institute towards nuclear physics and accelerator technology in the 1930s is an example for such new histories which are usually omitted in the biographical approaches, maybe because Bohr as a fundraiser does not fit our picture of the genius scientist who is not concerned with matters of money.[11]

2.2. Scientific practices and cultures

Origin, import and transformation

The micro-historical approach and the history of every day life in science are related to the model of science as sociocultural practice.[12] In the last decade there has been a move away from writing history of science as the history of scientific ideas and towards history of scientific practice and scientific culture.[13] Especially two book editions have marked this trend in history of science: *From Science as Knowledge to Science as Practice and Culture,* edited by Andrew Pickering (1992), and *Scientific Practice*, edited by Jed Buchwald (1995). As Andrew Pickering's book title suggests, the concepts of science as culture and

[10] See for example Lindqvist, 1993, p. xliv.

[11] See Aaserud, 1990, especially p. 16. For the importance of Bohr and the Institute of Theoretical Physics for Norwegian physics, see Vaagen, 1985, and Chapter 3, Section 5.

[12] Michel Callon has divided the various approaches in science studies into four models for the dynamics of science, where "*science as sociocultural practice*" is Model 3. See Callon, 1995.

[13] The history of scientific ideas is usually identified as history of science as knowledge. This notion, however, collides with the understanding of practice as a form of knowledge. Understanding practice as a form of knowledge makes "science as practice" and "science as knowledge" no opposites.

science as practice are closely related. But they are not synonymous. Whereas science as culture is an utterly broad and blurry concept which can (but does not have to) include most, if not everything, the idea of scientific practice becomes much more handy and precise. The focus on practice nevertheless suggests the understanding of science as a cultural activity. Science as practice is related to the concept of science as process, whereas traditional history of scientific ideas has presented science merely as products.[14]

Within epistemology, it has longer been recognised that knowledge does not only exist in ideas, but also in practice. In the *Concept of the Mind* of 1949, Gilbert Ryle called these two different aspects of knowledge, one pointing towards practice, and one towards theory, *knowing how* and *knowing that*. In modern science the scientific end product, which we may identify as theory, is usually a text and is thereby communicated through language.[15] In the natural sciences, theory is not only represented in language in the usual sense, but also in mathematical formalism and in other visual forms of representation, such as graphs, technical drawings, wiring diagrams or photography. It is generally agreed on that practical knowledge cannot be communicated through language like theory can. Practical knowledge is linked to personal experience and is usually communicated by doing rather than telling about. Michael Polanyi introduced the notions of skill and tacit knowledge into science studies. Polanyi compared science explicitly to craftsmanship and emphasised the importance of tradition within the submission of personal knowledge.[16] Typical examples of learning in practice within natural sciences are laboratory courses, where students carry out practical tasks under instruction. Already Ryle pointed out that there is no priority between theory and practice, and that they always come in a pair. It has become a commonplace to state that every practice has its theory and every theory its practice. Ryle made the case explicit for theorising as a practice.[17] More recently Andrew Warwick has analysed the influence of local practices in the reception and advancement of Einstein's theory of relativity by Cambridge mathematicians and Cavendish physicists.[18]

Knowledge in action cannot be divided in bits of theory and bits of practice. The practice of an activity is not the client of its theory.[19] As Ryle has noticed, "*we learn how by practice, schooled indeed by criticism and example,*

[14] For the notion of science as product or as process, see Ken Arnold, in Pearce, 1996.

[15] Molander, 1996, p. 14.

[16] Polanyi, 1958.

[17] Ryle, 1949, p. 27.

[18] Warwick, 1992.

[19] Ryle, 1949, p. 30.

but often quite unaided by any lesson in the theory."[20] To exemplify Ryle's argument, we might look at the way that most people, including scientists, learn how to use computers. Most people do not learn how to use computers by reading manuals or taking lectures, but by trial and error, by practice. As the reading of Ryle suggests, the division of theory and practice into two separated forms of knowledge seems to be an unfruitful project. Bengt Molander has described the distinction between theory and practice as a product of modern science rather than a guiding line that should be used in epistemology.[21] The division between theory and practice is, in other words, part of the scientific method and the scientific enterprise. The scientific concept of the division between theory and practice "allows" science to separate its knowledge from the process of production and to declare it as universal and superior to other systems of knowledge, such as craftsmanship, for example, where the knowledge is inextricably connected to its practice. The acknowledgement that the distinction between theory and practice is a construct of the scientific method itself does not make the categories of theory and practice less valid in the historical understanding of science. It especially reflects the structures of power, or we might say with Bourdieu, the distribution of symbolic capital within the sciences, as well as in the relation between science and society.

In my histories of physics at the Norwegian Institute of Technology I use the concept of different practices (instead of talking about one uniform practice) to understand the research dynamics of this small scientific environment, rather than advocating a strong distinction between theory and practice. There is a complexity of interconnected practices within science: research practices, teaching practices, practices of communication, practices of scientific instrument making, practices of observation, practices of representation, practices of writing, practices of organisation, practices of financing, and so forth. Pickering has pointed out three different aspects of scientific practice, which can serve as a guiding line: its topology, its temporality and its materiality.[22]

The topology of practice can be understood as a regional topology, or topography, as well as a disciplinary topology. Both are important for my micro-studies on the dynamics of scientific practices. How and where do these practices emerge, and how do they travel across disciplinary and regional borders? Different scientific disciplines and sub-disciplines use different practices. But practices are also imported from outside science, or from science into other realms of society. In my history on electroacoustics research at NTH

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[20] Ryle, 1949, p. 41.

[21] Molander, 2000.

[22] Pickering, in Buchwald, 1995, p. 55.

(Chapter 4) I have shown how practices from amateur radio have entered scientific instrument making and research in technical acoustics. The appearance of telecommunication engineers in acoustics research and of practices from electrical engineering aided in changing the character of acoustics from being a purely mechanical discipline towards becoming an electrotechnical discipline. Finally, practices from scientific instrument making in electroacoustics were exported to other sub-disciplines, such as nuclear physics and electron scattering, as well as to the manufacturing of commercial radios.

Scientific practices can be different. Scientific results, in contrast, are required to be universal. A controversy about the applicability of certain practices for the generation of scientific knowledge usually starts when different scientific practices lead to contradicting scientific results. Jeff Hughes' history on the Cambridge-Vienna controversy about practices in the counting of scintillations and consequently about radioactive processes is an example for such a controversy.[23] Hughes' history on the Cambridge-Vienna controversy about scintillation counting reveals even more: the Cambridge physicists did not win recognition in the controversy simply because of their "better" practice of counting, but largely because of their prestige and authority within the scientific community. There is a certain gradient in the exchange dynamics of scientific practices between the centres of science, like the Cavendish Laboratory at Cambridge, and the periphery, like the Norwegian Institute of Technology in Trondheim. Leading scientific practices are more likely to be produced in the centres of science and exported to the periphery than the other way around. In scientific disciplines and sub-disciplines, like radioactivity research, we can account for different collectives of practice, in a pair with Ludvik Fleck's *Denkkollektiven* (thought collectives).[24] Together with the thought collectives, the collectives of practice constitute the structure of a scientific community. To become a member of the community does not only require acquiring the style of thought (*Denkstil*) of the community, but also its scientific practices. In order to enter the research fields of nuclear physics or electroacoustics, for example, the NTH physicists had to adopt and control the practices of these research communities. This can imply very different things, from how to build scientific instrumentation and how to observe, to where to publish your papers and how to write them. Since the practices of research are learned most effectively by observation and practising under instruction, scientists travel to and work in other laboratories, preferably at the centres of research, in order to acquire these practices. The Berkley cyclotron laboratory,

[23] Jeff Hughes, 1993.

[24] See Fleck, 1935 (1980).

the Cavendish Laboratory, the University of Göttingen and the Institute of Theoretical Physics at Copenhagen were such international centres of physics during the interwar period, which were visited by large numbers of foreign scientists, often over longer periods.[25]

The gradient in the hierarchy in the scientific community between centre and periphery and the control of scientific practice as a means of power within the scientific community brings us to a notion of practice related to Pierre Bourdieu's elaborated concept of the *habitus* within social theory. As in science studies, Bourdieu's habitus is positioned within a vision of culture. The concept of the habitus is an interesting tool to grasp power structures within science. This does not only account for hierarchies between different scientific institutions but also for the structures and hierarchies within a scientific institution like NTH itself. With its separated communities of scientists (with the professors as the ruling group), non-scientific labour like craftsmen and office workers, and students, research and teaching institutions resemble an interesting category of strictly hierarchically structured class societies. What makes Bourdieu's concept of practice not very attractive for my analysis is, that it is linked to statics, to a persistence of social and cultural behaviour.[26] Bourdieu's practices are power-preserving structures whereas I am interested in the dynamics of practices, in their transformation and trespassing over regional and disciplinary borders.

Science as culture is a wider, but also more blurred model of science, which points towards both the processes and the products of science and serves to link science as ideas and science as practice together. Different cultures of science are thereby determined by both different practices of doing science and different theories. But the model of science as culture also leads to new questions in the historical understanding. Is scientific culture continuous with culture of everyday life, or is there a major break? How does science as culture integrate into a broader vision of cultural history? How does it interact with other understandings of culture, like national cultures and the tensions between "fine" culture (arts, and the like) and natural science (e.g. from united to separated phenomena)? Pickering has described the nature of scientific culture as patchy, interrupted and heterogeneous, and the scientist as moving around in a kaleidoscopic culture.[27] What prevents the historian of science from being caught in the kaleidoscope of culture, where every move reveals a new perspective? As an interesting and workable model of culture as a tool of

[25] For the European centres of physics, as they were mapped by the U.S. International Education Board, see Lindqvist, 1993, p. xxv. See also Chapter 3, Section 5.

[26] See for example Wehler, 1998, p. 32. Callon (1995) groups Bourdieu in a very different model for the dynamics of science, which he calls "*competition*".

[27] Pickering in Buchwald, 1995, p. 46.

analysis within science studies, I want to mention Karin Knorr Cetina's concept of epistemic cultures within different scientific communities, like high-energy physics and molecular biology.[28] In my history writing, however, science as culture remains as a commitment to science as a cultural activity and its products as cultural products rather than "science as culture" as a category of analysis.

History writing in general has observed a new trend towards cultural history, especially in the last decade. But it is a legitimate question to ask how much new cultural history really can substitute for other approaches, as social and political history, as well as the history of ideas.[29] It might be helpful to recall that cultural history is not a new approach but spans back to the 18th century.[30] It should also be recalled that traditional cultural history has been criticised for its weak reflection of its methods, for its tendency to write apolitical history and for its "*aura of dilettantism*".[31] Together with cultural history, also the understanding of science as culture is everything but novel. Around the turn of the century and throughout the interwar period science as culture has been the leading model of science within the Norwegian scientific community itself.[32] The Norwegian scientists used the cultural argument effectively in politics of science and thereby disproved the preconception of the depoliticising effect of the cultural debate. It should be noted that the underlying concept of culture used by the Norwegian scientists linked the advance in culture directly to the idea of progress and enhanced the importance of scientific culture within Norwegian national culture and the rise of Norway among the cultural nations.[33]

We will now leave the discussion about culture to come to Pickering's third aspect of scientific practice: its materiality.

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[28] Knorr Cetina, 1999.

[29] See, for example, Wehler, 1998, and Böhme et. al., 2000.

[30] Böhme et. al., p. 44 ff.

[31] Böhme et. al., 2000, p. 47-48.

[32] See for example Sem Sæland: *Empirisk videnskap,* in Brugge et. al., *Norsk kulturhistorie bind 4*, 1940.

[33] See Chapter 3, Section 2.

2.3. History from things

How can scientific instruments teach the historian about 20th century physics?

"We are surrounded by things, and we are surrounded by history. But too seldom do we use the artifacts that make up our environment to understand the past. Too seldom do we try to read objects as we read books - to understand the people and times that created them, used them and discarded them.

In part, this is because it is not easy to read history from things. They are illegible to those who know how to read only writing. They are mute to those who listen only for pronouncements from the past. But they do speak; they can be read."

[Steve Lubar and W. David Kingery, 1993][34]

The discourse on scientific practices is directly linked to artefacts as historical sources about these practices. Practices of experimental physics cannot be separated from scientific instrumentation. Whereas end products of modern science are usually expressed in publications on paper, the instruments are part of the process to gain these end products. Together with the orientation towards scientific practice there has been a call to take the materiality of science more serious. But the commitment of historians of science to the material world of science does not imply that they actually look at real objects, or try to use these objects in any way to gain information about the practices that are connected to them. Artefacts from modern science and technology are imbedded in a text - oriented and text-dominated intellectual culture. Accordingly, historians "look" at and interpret artefacts merely through text. In a study of articles in the journal *Technology & Culture*, Joseph Corn has concluded that the vast majority of the authors, including the historians who write about technical artefacts, do not employ any material evidence.[35] Furthermore, Corn had problems to make out where authors explicitly used material evidence and what they learned from it. After questioning several historians of technology, Corn found out that most of them had personal experience with the material objects they wrote about, or with similar ones. Privately they admitted that this personal experience had a considerable influence on their history writing. Many historians of technology, Corn concluded, learned more from things than they acknowledged in their

[34] Lubar and Kingery in *History from Things*, 1993, p. viii.

[35] According to Corn, less than 15 percent of the authors employed any material evidence. Of the scholars who wrote about objects, only 30 percent employed material evidence. Corn, in Kingery, 1996, p. 37.

articles. Corn ascribes this lack of acknowledgement of personal experience with objects to the privilege of "... *the cognitive, the theorized and the abstract over the experimental, the ordinary, and the personally particularized. [The graduate] readily learns that the opposite of a "professional" publication is a personal account, and that knowledge derived from personal experience, whether tactile, visual or experimental, is not likely to be taken seriously. ...*"[36]

I am aware of that I am exposing myself to the danger of not being taken seriously: I admit that this section is to a large extent based on my personal experiences of collecting 20th century scientific instruments and employing them in my historical studies. As a part of my appointment as a post-graduate student at the Department of Physics of the Norwegian University of Science and Technology I have collected and catalogued about 1,000 scientific instruments and other objects from the department's history. Together with the department's archive at the Norwegian State Archive in Trondheim, this instrument collection represents a major resource for my historical studies. On my journeys to collect historical material I have not only visited historical archives but also a number of instrument collections.[37] I should also mention that I am a graduate from the Research Group on Higher Education and History of Science at the University of Oldenburg, where I have worked with the method of replicating historical experiments.[38] The experience from Oldenburg has shaped my later approach to historical scientific instruments. The reader might experience that my published thesis still contains relatively few references to objects and personal practice. This unbalance can be explained by the fact that it is easier to cite a text within a text, than an object or a practice. The commonplace that we live in a text-oriented intellectual culture also applies to the regulations for the format of a doctoral thesis. A presentation of my histories in the form of an exhibition or a performance would surely give different references.

Two of the most noticeable authors in the call for taking the materiality of science more seriously are Andrew Pickering and Peter Galison.[39] From

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[36] Corn, in Kingery, 1996, p 46-47.

[37] For a list of collections and archives visited in relation to this thesis, see Appendix.

[38] As a diploma thesis I have replicated some of Heinrich Hertz' experiments on the propagation of electric force. I will come back to the method of replicating historical experiments later.

[39] Noteworthy, both scholars belong to the majority of historians who write about artefacts and practice without employing material objects explicitly. Pickering admitted to me that he looked at Giacomo Morpungo's experimental set-up at Genoa only after he had finished his case study on the hunting of the quark. Pickering is not a pronounced historian of science and moves with his case studies between history and sociology. For his case study on the hunting of the quark see Pickering, 1995, p. 68 ff. Pickering, however, cites in detail Otto Sibum and Peter Heering's re-working of Joule's experiment on the mechanical equivalent of heat

Pickering's viewpoint this is mainly a critique of the concentration on the entirely social understanding of science by the Sociology of Scientific Knowledge (SSK). Similar to the actor-network approaches, represented most prominently by Bruno Latour, Michel Callon and John Law, Pickering assigns the material world its own agency, in a pair together with human agency: "... *The problem is that SSK makes it impossible to take material agency seriously. The other side of SSK's focus on human agency is precisely the invisibility of material agency. SSK, that is, is happy to talk of accounts of material agency as components of scientific knowledge, but it insists that such accounts be analyzed, like any other component, by referring them back to some field of human agency. ...*"[40]

At this point I have to disagree with Pickering. To me it raises a number of problems to give the instruments an agency *independent* of humans. Scientific instruments are cultural products and as such inextricably interwoven with human agency. Pickering's model of the mangle of practice, where human and material agency interacts, is more likely to obscure than to enlighten the complex character of the interaction between humans and nature in the experimental sciences. Like other artefacts, scientific instruments interact with humans and often develop a life of their own: as other cultural products, like a text or a piece of art they distance themselves from their creator. As a theatre play, instruments are re-interpreted in every new setting, with a new director and new actors. As every piece of technology, like a car or a bicycle, scientific instruments age. They bear their own history of use (or abuse) which can be read from its wearing down and from damage. Scientific instruments can be used by their creators, e.g. scientists who make their own instruments. But, with the increasing complexity of science and mass-produced electronic instruments, this has become less and less common. Experimental physicists, for example, are sometimes astonishingly unaware of the mode of function and the basic principles that underlie their equipment, and they often leave all repair and maintenance to technicians.[41] In these, and other, settings it can be a helpful tool to look at scientific instruments as actors equipped with agency, who

(Pickering, 1995, p. 104 ff.). Galison (1987, p. 252) calls for an archaeology of scientific instruments: "... *The history of instruments that we need must be an archaeology that uses the material culture of science to unearth buried theoretical assumptions and theoretical practices.*" As far as I understand, both Galison and Pickering advocate the use if material objects in historical studies, but do not involve in such studies themselves.

[40] Pickering, 1995, p. 10.

[41] I do not want to make the claim that this is the general rule for physicists. Many or maybe most experimental physicists know their experimental set-up by heart. It remains, however, that with the growing complexity of experimental set-ups and the growing amount of ready-made components physicists are increasingly estranged from the equipment and less likely to see through the whole set-up.

interact with humans. Within the setting of the experimental lecture around the turn of the century, for example, it makes sense to look at the demonstration experiments as actors, rather than mere requisites, of a theatre play. However, in this setting the instruments are equipped not with material, but with cultural agency, the entangled, elusive conglomerate of human existence within the world.

In order to understand the relationship between scientific practices and scientific instruments we may want to define what scientific instruments are. A narrow and sharp definition will soon prove to be unpractical. This is not merely a theoretical problem, but one that every curator of scientific instruments has to face when making decisions on what and what not to include in the collection. As a broad definition we might agree on every material object that is connected to scientific practice, still leaving abstract objects as thought models and mathematical formalism open for debate. But this definition might include pencil and paper, the office chair, the scientist's coffee mug, the car that brings her or him to work, etc. We soon realise that this definition leads to an inflation of scientific instruments and that only a pragmatic and flexible definition of the term makes sense. In the context of my thesis I will use the term "scientific instrument" for apparatus and instruments used in the context of teaching, demonstration, and experimental and theoretical investigations, being well aware of the weakness of this classification.[42]

The cultures and practices of scientific instrument building and instrument use are complex. An important aspect of the instrument-practice relationship is how instrument making and instrument use are related to each other. Sometimes the activities of building and using scientific instrumentation are separated, for example when instruments are bought ready made from instrument companies and not modified locally. Many times, however, instrumentation is designed and built locally. Instruments are often re-designed and re-built during the process of experimentation. In these cases, instrument building and instrument use - experimentation or calculation- cannot be separated. Sometimes a tension can be experienced between instrument building and instrument use. The tensions become quite visible in accelerator projects.[43]

[42] Peter Heering (1995) distinguishes between *Gerät* (device), *Instrument* and *Apparatur* (apparatus), and defines the terms the following way: "***Gerät*** *ist eine Vorrichtung zur kontrollierten Erzeugung definierter Erscheinungen,* ***Instrument*** *ist ein Werkzeug, mit dem Phänomene untersucht werden können,* ***Apparatur*** *heißt der vollständige Aufbau eines Experiments, also die Verbindung aller zu seiner Durchführung notwendigen Geräte und Instrumente sowie ihrer Anordnung.*" (See Heering, 1995, p. 26 f., as cited in Heering et. al., 2000, p. 27.) It is, however, questionable how useful this regime is in practice, since other scholars do not follow the classification.

[43] See Chapter 5, Section 7.4.

Practices and cultures of instrument building and instrument use are partly disciplinary and partly local. Moreover, scientific instrument development is not only dependent on traditions and dynamics inside a discipline or a local community itself, but also highly influenced by technological developments from other areas. Radio technology was a main stimulation of scientific instrument development during the interwar period. High voltage technology, developed for power transmission over large distances, became a major influence on accelerator development.[44] The development of the technologies of radio broadcasting and high voltage power transmission were, on the other hand, largely based on the transfer of knowledge and practices from physics. Within science and technology studies there is an ongoing debate about the relationship between science and technology, especially under the background of a scientisation of engineering and an apparent de-differentiation of the groups of scientists and engineers. The basic positions in the debate are marked as a sharp division between science and technology on one side and a lack of distinguishability between the both within a seamless web on the other side. Neither one of these extreme position seems to be able to give a valuable contribution to the study of scientific instruments and their role within science. Bernward Joerges and Terry Shinn have introduced the terms of *research technology* and *research technologist* in order to grasp the complex topology and dynamics of scientific instrumentation between science, state and industry:

> *"The theme of "instrumentation between science, state and industry" does not square well with the venerable discourse which opposes "science" and "technology" in social studies of science. In this discourse, "technology" stands for the contrary of "science": it represents the practical uses of science in society at large and is understood as separate from the somehow autonomous sphere of science. [...] This vocabulary, widespread as it may be, is not very useful for our purpose, and, for that matter, for any inquiry into the role of instruments. ..."*
>
> [Bernward Joerges and Terry Shinn, 2001][45]

On the other side, Joerges and Shinn do not agree with the "*dialectic answer*" of Bruno Latour and others, who want to abolish the distinction and explain science and technology as a seamless web. As an alternative Joerges and Shinn propose to distinguish between three different spheres of instrumentation and instrument makers: 1) inside science, 2) inside industrial production, and 3) outside science and production, but for both. Joerges and Shinn identify this

[44] See Chapter 4, Sections 5 and 8, and Chapter 5, Section 2.

[45] Joerges and Shinn, 2001, p. 4.

third type as research technology.[46] The details of Joerges and Shinn's framework can be discussed. However, it gives a workable structure for the understanding of the interaction between science, technology and scientific instrumentation, whereas the two other models - science and technology as opposites, or as a seamless web - rather obscure the situation.

The field of scientific instrument studies is remarkably divided between historians of science at academic institutions like universities and curators of scientific instrument collections at museums. Curators at museums of science and technology like to see their collections as a resource for historians to study, as an archive of three-dimensional objects. But the academic historians of science usually do not go to museums to look at the objects, and the object studies are left to the curators. Even at museums with large research departments, like the Deutsches Museum at Munich, there is a gap between historians and curators, between history writing and museum collections. In 2002 the British Society for the History of Science and the Scientific Instrument Commission of the International Union of the History and Philosophy of Science arranged a joint meeting under the title *Do collections matter to instrument studies?* which addressed these issues.[47]

In one of the talks Marta Lourenço pointed out that the historian versus curator debate is not specific to the history of science and technology, but crosses several disciplines, like ethnology, anthropology and history of art.[48] It is an interesting observation that most scholars write accounts on scientific instruments and experimental practice without employing surviving instruments as material relicts of this practice. One should expect that historians consult all accessible sources for their history writing for cross-examination. In accounts on experimental practice, historians of science usually do not question their lack of including objects in their studies. "*... Document-based historiography is still the rule in universities and material culture is terra incognita - whether in art history, social history, or history of science and technology. University professors do train their students in the use of libraries and archives, but seldom do prepare them to use museums or collections as source for research.*"[49] The practice of ignoring objects seems to be taken for granted and corresponds with a common opinion among historians: history is about words, not about things!

[46] Joerges and Shinn, 2001, p. 4.

[47] See Pantalony, 2003.

[48] Lourenço, *Working with words or with objects*? manuscript, 2002, p. 2. Lourenço supports her argument with references from art historians and museologists, as Fleming (1969), Hester (1967) and Zeller (1985).

[49] Lourenço, 2002, p. 4.

Most historians of modern science underestimate or ignore the potential value of scientific instruments in supplying the historian with information on scientific practice. These instruments can be a valuable source of information when other documentation is lacking. But studying the instrument may also clarify questions left open by the other sources, raise new questions and lead to a new interpretation. One problem for the traditional history of science to enter the endeavour of including material objects in the lists of historical sources is the lack of tradition for such studies. Object studies have to enter the curriculum. Methods of historical analysis and interpretation have to be developed. An infrastructure has to be created. Historians need to get access to instruments, most reasonably at museums. But they also need workshop facilities and laboratories where they can study and experiment. There are a number of examples where object studies have been successfully employed in history of modern science and technology. These object studies can be of varying nature: from mere looking at the instrument, to measuring it, trying to open it up to learn about its inner life, trying to use it in simple performances, like looking through a microscope, over to full scale experimental studies, where original instruments, or replicas, are used in performances to learn about scientific practice.[50] Much can be learned from other disciplines, such as archaeology, about object studies. Industrial archaeology, which started as an amateur practice, is probably the discipline that comes closest to science in this respect.[51] Archaeologists have also collected significant experience in experimental archaeology.[52] The correspondent in the context of science can be titled as "*experimental history of science*".[53]

One of the most elaborated methods of experimental history of science is the method of replicating, or re-doing historical experiments, which has been developed among others by the Research Group on Higher Education and History of Science at the University of Oldenburg.[54] In the method of replication, a historical experiment is repeated under conditions as close as possible to the original. The replication includes the use of original instruments,

[50] Corn (1995, p. 27) has made a list of five different types of approaches to technical artefacts, without claim of being comprehensive: (1) ordinary looking, (2) technical analysis, (3) simulation, (4) testing through use, and (5) archaeological science.

[51] For an introduction to industrial archaeology see for example Hudson, 1967 and Major, 1975.

[52] See, for example, Ingersoll et. al., 1977.

[53] See Kragh, 1987, p. 159 ff. Also Sibum, in Lindqvist (2000), uses this term.

[54] For the method of replication, see Heering et. al., 2000, Rieß: *Erkenntnis durch Wiederholung - eine Methode zur Geschichtsschreibung des Experiments*, in Heidelberger and Steinle, 1998, and Sibum: *Experimental history of science*, in Lindqvist, 2000. Heering et. al. also contains an overview over related approaches of replication by other scholars.

or copies true to the original, all written information about the process of experimentation, such as laboratory notes, publications, manuals and letters, original drawings or photographs, and the attempt of the historian to put her- or himself in the position of the scientist at the time.[55] The method of replicating historical experiments has, like for example experimental archaeology, many pitfalls. Sociologists and social anthropologists of science can observe current scientific practice in action. Historians, in contrast, cannot recreate the past. There are limits on how detailed the historical set-up, especially the laboratory surroundings, can be reconstructed. The historian has to be careful not to identify his or her own practice with the historical practice. That the historian does not manage to re-produce a certain experiment or a measurement value does not give an argument in itself to question the historical situation. The performance of the historian does not create new sources but gives a new interpretation of the existing sources and helps in cases of doubts. The method of replicating historical experiments is comparatively elaborate and cannot always be applied. Many experimental set-ups are too complicated and too costly to be replicated. Sometimes there is not enough historical source material for a satisfying replication. Some experimental practices are harmful or hazardous to the health of the experimenter, for example if they include open mercury, X-rays or radioactive sources.

The use of remaining scientific instruments as well as replicas of such instruments in history writing has mainly concentrated on pre-20th century science. Both collecting 20th century instruments and using them as a source differs from instruments of earlier periods. The study of instruments as a source is more established for ancient experimental and observatory science where there is a lack of written sources and other kinds of source material connected to the instrument use. Ancient astronomical instruments such as sundials and astrolabes are an example for such instrument studies. For 20th century physics there is so much other source material on experimental practices, like laboratory notebooks, oral history, photography etc. that the study of material objects seems to be unnecessary.[56] Collecting instruments from 20th century science and employing them in history writing has both its opportunities and its drawbacks. These differences between the 20th century and earlier periods in this respect result from aspects which are partly related to the fact that the 20th

[55] Peter Heering (1995) has resumed the method of replication as follows: "*Unter einer Replikation ist also die Durchführung eines historischen Experiments zu verstehen, wobei sowohl Apparatur wie auch das Verhalten der ExperimentatorIn - soweit möglich - mit den vorhandenen Informationen über das Original-Experiment übereinstimmen müssen. ...*" Heering, 1995, p. 101, also cited in Heering et. al., 2000, p. 12.

[56] Similar observations are also made by Corn, in Kingery, 1996, p. 37 and Lourenço, 2002, p. 7.

century is a very recent era and partly to fundamental changes in science and scientific instrumentation compared to earlier epochs.

The number of surviving scientific instruments from the 20th century is enormous. From earlier periods we mainly rely on existing collections and otherwise collect whatever is left over - often unsystematically or by accident. For the 20th century, museums and other collectors have to make strong selections. We have to develop guidelines for our selections and we have to legitimise them. Collecting from universities and other institutions is often troubled by cultural barriers (the historian versus the scientist) and by different ideas of what should be collected and how it should be collected. Once these barriers are overcome, taking ownership is often easy: one simply rescues the instruments from being thrown in the rubbish bin. Earlier scientific instruments have generally been used and maintained over long periods of time. Modern instruments often have a very short lifetime in active research and get thrown away when space is needed. 20th century instruments are also characterised by a vast amount of reference material that should be collected together with the objects, such as technical drawings, manuals, notebooks, photographs etc. The richness and amount of remaining 20th century scientific instruments should not be seen merely as a drawback and troublesome, but as an advantage: in the 20th century active research became a more common and respected activity for the university teacher. We can - and have to be - selective in what we want to collect and let this be representative for future generations. The amount of available instruments which cannot - and should not - all be collected by museums is also an advantage for the experimental historian of science. Once again, after communication problems are resolved, instruments can be borrowed without an anxious curator interfering.

The interwar period between WW I and II signifies a change in the practices of scientific instrument making and use, as well as in the character of scientific instruments.[57] These changes can be grouped under five fields. I do not claim that the list is comprehensive and we will see that there is some overlap between the fields. But the classification is still helpful to structure the complex changes within scientific instrumentation during this period:

1. From mechanical instruments to electrical instruments and radio technology

During the interwar period radio technology had its breakthrough in scientific instrument making. With radio technology, and other devices mainly from telecommunication engineering, mechanical principles were increasingly replaced by electric principles. For earlier periods, the precision of instruments

[57] For a more comprehensive history of 20th century scientific instruments, see Brenni, in Krige and Pestre, 1997, p. 741-756.

usually depended on mechanical precision. With the breakthrough of radio technology, the quality and characteristics of radio components, especially the vacuum tubes, play an important, if not dominating, role. These radio tubes and other electric components, like condensers and coils, have a limited lifetime. Since these components are industrially manufactured, they are more difficult to re-produce than parts of older instruments and the replicas are more likely to show different characteristics from the originals. The radio technology based devices also offer a special challenge because of their black-box character, their complexity and their microstructure.

2. From craftsmanship to Industrially manufactured components

20th century instrument development is characterised by the continuous introduction of new materials like plastics and synthetic rubbers. Many components are assemblies of different materials, glued together, pressed together etc. These materials often have a limited lifetime. Many parts of radio technology are examples for such assemblies. Similar to other modern technological artefacts, scientific instruments are often not meant to be repaired but to be thrown away. Earlier instruments, even when manufactured in larger quantities, were usually made in a craft tradition, which makes it easier to repair them or to fabricate working copies of them today. 20th century instruments are mainly mass-produced or contain mass produced vital components, which are very difficult or impossible to reproduce once the industry has changed or disappeared. Many of these components are very delicate and depend on a micro-technology industry. For the performing historian of science this means that instruments after relatively few years are not in working condition any more.

3. From scientific instruments to more complex research instrumentation

Experiments have partly become much bigger and experimental set-ups have become more complex, involving more components. In earlier periods there was a short way between the instrument maker, who was a craftsman, and the instrument user, the performing scientist. Craftsmen could have a great influence on experimental physics with their genuine design of instruments. There were also scientists who made their instruments themselves. In the 20th century, the craftsmen in the instrument shops started to produce parts of apparatus after drawings made by engineers who then put these parts together. The experimenting scientists often do not know the content of their 'black boxes'. The size and complexity of instruments and experimental set-ups sometimes makes them extremely difficult to collect and store. They usually have to be dismantled, which makes it difficult for historians of science later to analyse them in the storehouse. Once dismantled and stored these complex installations are difficult to re-assemble for exhibitions and impossible to re-animate.

4. Changes in style and materials - from glass-brass-wood to industrial instrument design

The style of an object such as a scientific instrument reflects craft traditions, the individual creator and contemporary culture. There is an evident change in the style of scientific instruments between pre-WWI instruments and post WWI instruments. Pre-WWI instruments are usually crafted in glass, brass and wood. The surfaces were carefully treated to give them a noble appearance. The instrument collections were stored in glass cabinets, which underlined their character as the department's treasure. Post-WWII instruments emit an atmosphere of plainness, simplicity and industrial design. Steel largely replaced brass, surfaces were mostly painted grey and synthetic materials like Bakelite increasingly replaced wood.

5. Sharper distinction between teaching technology and research technology

At most physics departments around 1900 there was no sharp distinction between instrument collections for teaching and research. The demonstrations in the experimental lectures contained some instruments and models which had only didactic functions. The vast majority of instruments, however, resembled laboratory instruments, even though some of them, like most instruments from electrostatics, were long outdated in the laboratory and had only historical significance. The resemblance of teaching and research instruments was partly a legacy of the 19^{th} century, where public demonstration was still a part of common research practice. Partly due to the growth of research communities, the increasing complexity of scientific installations and the black-box character of instruments during the interwar period, contemporary (interwar-period) research practice was less likely to be demonstrated in the auditorium. But the interwar period was also characterised by a rejection of merely historical references in physics teaching which were common before WWI. As a consequence physics lecturers developed new regimes of simple didactic demonstration instruments. Robert Wichard Pohl's system of lecture demonstrations, which he developed alongside with his textbooks, is an example for such a regime of didactic demonstrations.

A number of aspects mentioned under these categories illustrate that employing 20^{th} century objects in history writing and reconstructing 20^{th} century experiments feature challenges different from earlier periods. This point can be illustrated by the example of the particle accelerator, one of the most spectacular instruments of 20^{th} century physics. As a part of my source studies connected with the history of the Van de Graaff accelerator project at the Norwegian Institute of Technology during the 1930s (see Chapter 5) I have visited a number of early particle accelerators related to the machine built at Trondheim. I visited the original accelerator at the Norwegian Museum of Science and Industry in Oslo, parts from the Cockcroft-Walton accelerator from the Cavendish Laboratory at the Science Museum and a Van de Graaff accelerator of the Department of Terrestrial Magnetism (DMT), Carnegie Institution of Washington, now at the Smithsonian, Museum of American History.[58] Both the original Van de Graaff generator at Oslo and the DMT accelerator at the Smithsonian are dismantled and in storage. It takes some imagination to visualise the machines assembled and in operation. The DMT Van de Graaff generator had been abandoned by the researchers already in the 1930s. In contrast, the Trondheim generator had been in operation at the University of Oslo until 1963. Most parts of the accelerator had been re-built and modernised several times. I could only identify certain parts, like the frame and the aluminium sphere, as dating from the original machine of the 1930s. This in itself was a very valuable observation. It supported my argument that the machine was never static but constantly re-built and modified.[59]

The parts of the Cavendish accelerator at the Science Museum in London were on display. However, the Science Museum only received a small part of the original accelerator installation, namely the accelerator tube and the observation chamber. A quick survey in the museum files related to the acquisition of the accelerator parts revealed that Ernest Rutherford gave them to the museum shortly after the discovery of the first nuclear disintegration. Parts of the observation chamber were copies made at the Cavendish Laboratory. One segment of the original accelerator tube had a crack when it came to the museum. In the attempt of repairing, the glass tube broke and had to be replaced by a copy as well. My conclusion is that the pieces of the apparatus were given to the Science Museum by Rutherford in order to create an icon of modern British science which should be exhibited to the public shortly after the discovery. This part of the accelerator became obsolete for the Cavendish researchers, whereas the other parts of the set-up were needed for further investigations. A survey of John D. Cockcroft's publications shows that the later

[58] I thank Anne Marit Karlsen at the Norwegian Museum of Science and Industry and Paul Forman at the Smithsonian, Museum of American History for their efforts.

[59] See also Chapter 5, Section 8, last paragraph.

experimental set-up contained a separating magnet that was not employed in the first set-up which was sent to the Science Museum. Cockcroft also changed from the scintillation method to electric counters. These observations let me concentrate on the later set-up, which was visited by the Trondheim accelerator builders.[60]

These three accelerators which I have visited are dead machines in the sense that they will most probably never be put into operation again. The method of historical replication, as it has been developed at Oldenburg, will most likely never be applied in the history writing of accelerator experiments. I was, however, able to experience a Van de Graaff particle accelerator similar to the machines of the 1930s in operation. In the late 1930s, Odd Dahl, the constructor of the Van de Graaff generator at Washington and Holtsmark's co-operator and advisor in the construction of the Trondheim Van de Graaff generator, also designed two Van de Graaff generators at Bergen. One of them was set up at the University of Bergen in 1950. After the machine burned down in 1956 it was re-built with slight modifications. This Van de Graaff accelerator is still in operation and used in nuclear physics courses for students. My personal experiences with the Bergen Van de Graaff generator in operation are too extensive to be presented in detail at this place. I had to visit Bergen three times before the machine was working. The first time there was a vacuum leakage, the second time the pulleys of the rubber belt had to be re-adjusted. I got a striking demonstration that the Van de Graaff generators were not machines like automobiles, which you just start and drive, and not worry about until the next inspection comes up. The insight that the past cannot be recreated also counts for the Bergen Van de Graaff generator. However, being exposed to the penetrating noises of this alive accelerator and the smell of the ozone produced by the discharges was an impressive contrast to the silence of the dead machines at the museums. Since the machine cannot be used in current research and its maintenance is too costly for a mere teaching installation the years for this accelerator also seemed to be numbered.[61]

[60] I thank Alan Morton at the Science Museum for his efforts, especially for giving me access to the files related to the acquisition of the accelerator parts. For the changes at the Cavendish accelerator, as it was probably observed by the visitors from Trondheim, especially the deflecting magnet and the counters, see Cockcroft and Lewis, 1936. Fort the visit of the Trondheim accelerator builders at Cambridge, see Chapter5, Section 7.3.

[61] I am very thankful to Arvid Erdal, who operated the accelerator for me, and to Dieter Röhrich and Jan Vaagen. For the Bergen Van de Graaff generator, see Løvhøiden and Vaagen, 1978, and Odd Dahl, 1981. This machine is very similar to the Van de Graaff generator installed at the *Haukeland* clinic in 1942 (See Chapter 5, Section 6). I have given a detailed account on my experiences with the Bergen Van de Graaff generator, as well as from my visits at the Science Museum, the Smithsonian, Museum of American History and the Norwegian Museum of Science and Industry at the joint meeting between the British Society for the History of Science and the Scientific Instrument Commission of the

I would like to conclude this chapter, which started with a methodological introduction and ended with an account of personal experience, with some reflections about how academic history of science is presented. Taking the insight about the materiality of science and the importance of personal knowledge seriously also implies that we have to find new ways of telling histories of science through artefacts and personal experience. This conclusion is by no means novel but builds part of the background of the establishment of institutions like the Deutsches Museum at Munich and the Musée des Arts et Métiers in Paris. In the epilogue of his book *Towards the history of epistemic things*, the historian of molecular biology Hans-Jörg Rheinberger stated: "... *Epistemology, too, is called to become experimental if it wants to be an endeavor congenial with the practices it tries to analyze. There is still a long way to go in this direction.*"[62] Not only our analysis, also our presentation of scientific practice is called on to become more experimental. Telling histories by employing objects and including audience and personal experience is a serious challenge for the community of academic historians of science. Its realisation is clearly beyond the scope of this dissertation.[63]

International Union of the History and Philosophy of Science, *Do collections matter to instrument studies?*, at Oxford in 2002. See Pantalony, 2003.

[62] Rheinberger, 1997, p. 228.

[63] For some literature about old and new concepts of presenting the materiality of science and allowing the visitor to experience, see Lindqvist, 2000.

3. Physics in Trondheim during the interwar period

From the local to the national and transnational context

3.1. Trondheim: Centre of the world? Geographical connotations

In this chapter I want to present the local establishment and development of the Department of Physics at the Norwegian Institute of Technology (NTH) as a teaching and research institution. I want to illustrate the local and national conditions for doing physics in Norway in general and especially at NTH in Trondheim. Furthermore, I want to place these local conditions and developments into a broader transnational context. In other words: I want to place Trondheim in a broader landscape of science of the early 20th century. The concept of a historical geography of science has earlier been used to describe the local establishment of scientific ideas, scientific practices and scientific institutions as well as the global network of the travelling of entities such as different types of knowledge, material artefacts and not to forget the students, scientists, instrument makers and engineers themselves.[64] But the relationship between science and geography is not only one-sided. The sciences are not merely passively shaped by some abstract geographical preconditions but active agents in the shaping and re-shaping of these conditions.[65]

[64] See for example Livingstone, 1995. See also Bourguet et. al., 2002.

[65] This point has been made especially clear by Charles Withers in his history of geography in Scotland (Withers, 2001). We will come back to the role of the Norwegian geosciences in the formation of Norway as a nation in the next section.

Scientists in general, and especially physicists, like to explain their activities as global, non-local and non-national phenomena. Scientists describe themselves as "communist" in terms of knowledge sharing, referring to Robert Merton's well-known normative criteria of science.[66] According to the scientific ideal, scientific truth is required to be universal, independent of time, space, culture and society. A number of mechanisms are employed to guarantee the universality of scientific knowledge. One important factor is global communication: scientific results are published in international journals and in languages understood by the scientific community. International conferences are arranged and participants from other countries are invited to exchange scientific viewpoints and results. Scientists correspond by mail and discuss their work. Scientists visit each other and have sabbatical stays at foreign research institutions in order to co-operate with other scientists, to learn new experimental methods, to learn to use new instrumentation or to use equipment not available at their home-institution. Reviews are written on international developments, on new books and articles. The teaching of science is reasonably standardised and evaluated internationally. Students often spend some time of their studies at foreign institutions. Textbooks, handbooks, teaching and research instrumentation cross borders. Academic procedures, like awarding doctoral degrees, are comparable. Scientific societies have not only local but also foreign members. Every one of these practices and mechanisms were active within the physics community of the interwar period. And the Trondheim physicists were an integral part of this community.

On the other hand scientific activities are by nature local activities. They show local or national peculiarities. What scientific activities are carried out, and how they are carried out, depends to a large degree on the local conditions: local personalities, financial constraints, available premises and equipment, constraints and opportunities of teaching, etc. Scientific culture cannot be separated from society and we will always detect the influences of local cultures. Locality has different references and different scales, such as the laboratory, the physics building, NTH as an institution, the city of Trondheim, Norway as a nation, Scandinavia, Europe, the world.

The city of Trondheim can be found on almost every map of the world. It takes, however, little to realise that placing Trondheim on the map refers partly due to the fact that the city is located in the rather scarcely populated far north of Europe. At its establishment in 1910 and during the interwar period, the Norwegian Institute of Technology in Trondheim was presumably the most northern institute of technology in the world. It is hard to argue against the idea that Trondheim, at least geographically, was on the periphery of Europe's scientific community. Categories like centre and periphery are, however, a

[66] See Merton, *The normative structure of science*, 1973 (1942), p. 267-278.

matter of perspective. Its inhabitants remembered Trondheim as Norway's first capital. Located in the geographical centre of Norway, Trondheim had a, metaphorically speaking, central role in order to tie together the long-stretched country. As a part of Norway's national movement during the 19th century, the Nidaros Cathedral started to be restored and rebuilt as a national symbol. The establishment of NTH in Trondheim was part of the plan to re-animate Trondheim as one of Norway's cultural centres and a resource for Norway's modernisation and industrialisation. Trondheim was during the first decades of the 20th century a provincial city of merely regional importance. The city was mainly an administrative and trading centre for Central and Northern Norway. Its main trading commodity was fish. Trondheim could look back on academic traditions from the 18th century. The city housed one of Scandinavia's older science societies: Bishop Johann Ernst Gunnerus founded the Trondheim Society of Science and Letters in 1760. In 1767, the Society came under the patronage of the Danish-Norwegian king and acquired the title *The Royal Norwegian Society of Science and Letters* (*Det Kgl. Norske Vidensk. Selskab*).

The establishment of NTH represented a challenge for Trondheim's cultural, academic and industrial traditions. With respect to the Nidaros Cathedral and Trondheim's history, the city represented a traditional cultural and spiritual centre rather than the seed of modernity that the *Technische Hochschule* embodied. The meeting between the Royal Norwegian Society of Science and Letters and NTH represented a clash of different academic traditions. It took sixteen years until the two academic institutions established a satisfying co-operation within a reformed Science Society.[67] Trondheim was far from being a modern industrial city. Its moderate industries had mainly regional significance and did not bear signs of advanced mechanisation. A typical characteristic of many companies in Trondheim was the smooth transition between trade, craft and small industry.[68] *Trondhjems Tekniske Læranstalt*, which was founded in 1870, suited surely better to satisfy the local need for engineers than a *Technische Hochschule* with scientific ambitions.

Since 1880 Trondheim had train connections to Kristiania via Røros and since 1882 to Sweden via Meråker. Norway's cultural, political, industrial and academic life was mainly centred in and around Norway's capital, Kristiania, which changed its name back to Oslo in 1925. Kristiania was also the site of

[67] The Society had welcomed and supported the establishment of NTH in 1910. But the Science Society also wanted to have its integrity respected and resisted the attempt to be conquered by the technical research environment. After several years of reformation work, the Royal Norwegian Society of Science and Letters was in 1926 finally divided into a class of humanities (*humanistisk klasse*) and a class of natural sciences (*naturvidenskabelig klasse*). See Midbøe, 1960, vol. 2, p. 147 ff.

[68] See Kirkhusmo, 1997, p. 34 ff.

Norway's first and, during the interwar period only university. Kristiania was Norway's gateway south to Europe. Its central position inevitably shaped an unbalance between the capital and the mainly rural provinces of the country. The establishment of the Norwegian Institute of Technology in Trondheim rather than Kristiania was part of Norway's sensitive district politics. It was not an expression of a local need for engineers or research facilities but a political decision against a further centralisation of Norway's academic, cultural and industrial resources around Kristiania.

The establishment of NTH was a national project and an important move for Norway towards gaining intellectual, political and economic independence. But the role of NTH as a national centre of science and engineering also set limitations. The focus on the "national" within the Norwegian Institute of Technology made it difficult to establish the scientist's ideal: a transnational centre of science where all scientists regardless nationality meet and work together. As examples of such transnational centres of physics research during the interwar period we can mention the University of Göttingen, the Institute of Theoretical Physics at Copenhagen and the Cavendish Laboratory at Cambridge. One might object, with good reason, that also these centres of science were everything but free of national constraints. The Cavendish Laboratory, for example, with its many scientists from British colonies and ex-colonies reflected the British Empire rather than open transnationalism. After 1933, the take-over of the National Socialist Party in Germany and the expulsion and persecution of Jewish and other unwelcome scientists, the utopia of the transnational character of science, regardless race and political opinion was once again truly demolished.

3.2. Among fishermen, farmers and other folks

Doing science in Norway

What did it mean to do science in the Norwegian cultural, political, economic and social context during the interwar period? What were Norway's scientific traditions and which scientific institutions were established? In this section I want to give a short introduction to these issues.

For the history of the physical and technical sciences in Norway, two groundbreaking institutions have to be mentioned, the Kongsberg Mining Academy (*Bergseminaret på Kongsberg*) and the University of Kristiania. The Kongsberg Mining Academy was established in 1757, three years before the Trondheim Society of Science and Letters. As in other technical disciplines, Norwegian mining engineers earlier had to leave to study abroad, mostly in

Germany. Norwegian mining companies also had a tradition of recruiting German miners. The Norwegian mining engineers who graduated from the Kongsberg Academy went as well into other technical disciplines, like civil engineering, or continued their academic studies. Hartvig Caspar Christie, the University of Oslo's third Professor of Physics, and Carl Anton Bjerknes, Professor of Applied and later Pure Mathematics, were graduates from the Kongsberg Mining Academy. When the University of Kristiania opened in 1813, the mining academy was moved and integrated within the university structure.[69] With the foundation of NTH, the mining academy moved a second time and became the Faculty of Mining at the institute of technology. Around 1900 and the decade after, the discipline of physics experienced a growth at the University of Kristiania and was well established with three professors, Oskar Emil Schiøtz, Kristian Birkeland and Vilhelm Bjerknes.[70]

All three institutions, the Society of Science and Letters, the Mining Academy and the University were, in the eyes of the Norwegians, instruments to secure intellectual and cultural independence from its Scandinavian Big Brothers Denmark and Sweden. Norwegian engineers, scientists and public servants should be educated in Norway and according to Norwegian conditions. Many of the actors in the debate argued for the establishment of a distinguished Norwegian scientific and technical culture. But what should a distinctive Norwegian scientific and technical culture be like? The ambitions of the Norwegian scientists reaffirmed that there was not one-sided "science in the national context". Norwegian scientists were strong actors in shaping and re-shaping Norway as a nation, especially in respect to Norway's natural geography on one side and the strong Norwegian nationalism leading to the break-up of the Swedish-Norwegian dynastic union in 1905 on the other side. Norwegian scientists were not mere spectators in the battle for independence but active promoters in utilising science as a nation-building and identifying tool. I have used a modified version of the title of Olaf Devik's autobiography *Among Fishermen, Researchers and other Folks* (*Blandt fiskere forskere og andre folk*) to characterise the conditions of doing science in Norway, as well as the activities of Norwegian scientists to alter these very conditions.

The fourth volume of *Norsk kulturhistorie* appeared in 1940 under the title *Fra rokken til fabrikken* (From the Spinning Wheel to the Factory) and contained a chapter on *Empirisk videnskap* (Empirical Science) written by the Oslo Professor of Physics Sem Sæland. Sæland's *Empirical Science* followed immediately after Harald Beyer's *Romantikken* (The Romanticism). Norway's

[69] See among others Blom, 1957.

[70] For the history of the University of Oslo, See Collett, 1999, *Universitetet i Oslo: 1911 - 1961* (Amundsen et. al., 1961), and Holtebekk (1992) for a characterisation of the physics department.

national romanticism was a leading spirit within the national movement, which identified rural farming and fishing as the true Norwegian forms of living. The romanticism of rural pre-industrial life is usually seen as opposed to modernity and urbanisation. That the notion of "*The Romantic Experience of Reality*"[71] did not necessarily has to oppose the modern industrial state is impressively shown in Oskar Nagel's *Die Romantik der Chemie* of 1914. In Nagel's popular science book we find a laudation on the achievements of modern chemical engineering, illustrated with photos and prints of the spectacularly large plants and installations of the German chemical industry of the early 20th century. We find the magnitudes of mass production mingled with a Goetheanic *Wahlverwandschaften.*[72] Also the mercantile attitude of many of the entrepreneurs of the modern chemical industry did, according to Nagel, not contradict the romantic perception:

> " *Das Erfinden ist eine künstlerisch, schöpferische, herrliche Tätigkeit. Der wahre, große Erfinder schafft aus Instinkt, aus Trieb. Der wahre Erfinder ist durch die Erfindung genugsam belohnt, wie dem Vogel, der in den Zweigen wohnt, das Lied, das aus der Kehle dringt, reichlicher Lohn ist. Aber überdies wird dem Erfinder oft irdischer Lohn, Reichtum und Wohlstand zuteil. Es sei hier nur an den Namen Alfred Nobel erinnert...*"
>
> [Oskar Nagel, 1914][73]

The Norwegian equivalent to Alfred Nobel, as characterised by Nagel, was the physicist Kristian Birkeland whose patents on the Birkeland-Eyde process, for the fixation of nitrogen, made him a rich man and a close candidate for the Nobel Prize in chemistry. We will soon come back to Birkeland and the surrounding circle of physicists, among them his disciples Sem Sæland and Olaf Devik, who were effectively creating the image of the Norwegian physicist.

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[71] "*Den romantiske oplevelsen av virkligheten.*", Beyer in Bugge and Steen 1940, p. 307.

[72] See for example p. 5 and p. 83.

[73] Nagel, 1914, p. 68. Translation of the quotation into English: "*Inventing is an artistic, creative, magnificent activity. The true, great inventor creates out of instinct, out of urge. The true inventor is rewarded sufficiently by the invention itself, like the bird that lives in the branches, whose song, which penetrates out of its throat, is ample reward. But furthermore, the inventor is often given earthly reward, wealth and prosperity. It should here only be remembered the name of Alfred Nobel.*" I hope it is clear that I use Nagel as a (not very successful) example of a scientist who tries to bring together the opposite world views of romanticism and modern industrialism. Nagel's characterisation of Alfred Nobel hereby remains merely as a caricature.

The physical sciences in Norway were from their origin and their institutionalisation in the 19^{th} century strongly dominated by the geosciences. The Norwegian Geophysical Society (*Norsk Geofysisk Forening*) was founded in 1917. A physical society, *Fysisk Selskab*, had been founded at the University of Oslo in 1909, but it held a low profile and seems to have died away in 1926.[74] A second physical society, *Fysikkforeningen,* was first constituted in 1938.[75] A close view at the list of the original members of the Geophysical Society in 1917 reveals that a separate physical society was almost obsolete. On the list of original members we find the names of Kristiania Professor of Physics, Oscar Emil Schiøtz, the lecturer Lars Vegard, who succeeded Birkeland as Professor of Physics in 1918, as well as the NTH Professor of Physics Sem Sæland. The geophysical society's chairman was Vilhelm Bjerknes, Professor of Mechanics and Mathematical Physics at the University of Kristiania (later Oslo) from 1907 to 1912 and from 1926 to 1932. The later Lecturer of Physics at NTH, Olaf Devik, and the Kristiania Professor of Pure Mathematics, Carl Størmer, were also original members of the Society.[76] To state it clearly: the entire prominence of Norwegian physics was represented in the Norwegian Geophysical Society. If we look at the research records of these physicists at the time we understand why: Bjerknes resigned in 1917 from his chair in geophysics from the University of Leipzig to become Professor of Theoretical Meteorology at the Bergen Museum. Both Schiøtz and Sæland did not have a long research record. It was, however, their activities in geophysics that characterised their scientific careers. Schiøtz started his career as a geologist and later turned to physics when studying in Germany. He carried out systematic observations of the force of gravity along the Norwegian coast and studied lightning and earthquakes. Sæland administrated and participated in several auroral and geomagnetic expeditions as the assistant of Birkeland. Vegard and Størmer followed Birkeland and devoted their research activities mainly to the Aurora Borealis. Devik had been assistant to both Birkeland and Bjerknes and had worked with weather forecast as well as Birkeland's northern lights research.

1917 was also the year the Bergen Geophysical Institute was established as a part of the research activities at the Bergen Museum. In the interwar period *Bergens Museum* was one of Norway's most important research institutions

[74] *Fysisk Selskab* had fallen into oblivion. Only recently the journals and minutes have been discovered by Torgeir Holtsmark at the University of Oslo.

[75] *Fysikkforeningen* was a more active society and started to publish its own journal, *Fra Fysikkens Verden*, in 1939.

[76] See Devik and Thrane, 1967. Other prominent original members of the Geophysical Society were the oceanographers Fridjof Nansen and Bjørn Helland-Hansen and the meteorologist and oceanographer Harald Ulrik Sverdrup.

with names like Bjerknes, Bjørn Helland-Hansen and Harald Ulrik Sverdrup attached to it. But Bergen was not the only Norwegian centre of geophysical research. North of Trondheim, Tromsø established itself as the Northern Norwegian cultural and intellectual centre. Based on the Haldde northern light observatory, founded by Birkeland around 1900, and the Tromsø museum, Tromsø became a centre for geophysical and especially polar research. In 1928 the Norwegian Institute of Cosmical Physics (*Norsk Institutt for Kosmisk Fysikk)* opened its doors. In 1926 the International Education Board of the Rockefeller Foundation had granted the sum of $75,000, to cover the cost of the buildings and the equipment of a new observatory for the study of the Aurora Borealis, atmospheric electricity, terrestrial magnetism and allied phenomena.

In his narrative on *Empirical Science* of 1940 Sem Sæland attributed the strong dominance of the geosciences within the establishment of scientific practices and scientific fields in Norway to the lack of appropriate laboratories and scientific instruments rather than to an enthusiasm about Norway's natural geography. Even at the turn of the century, when *all* European universities had established large and well equipped physical laboratories, Norway's sole physics department still only possessed a collection of mere demonstration apparatus and four to five small rooms for experiments. Sæland argued that it was no wonder that the Norwegian physicists were driven over to either mathematics or geophysics.[77] Sæland's argumentation leads to the impression that the geosciences dominated simply because Norway was a backwards country and did not invest significantly in the establishment of modern laboratories. This oversimplified explanation is, however, not conclusive and was revoked by historians like Urban Wråkberg and Robert Marc Friedman who argued that geophysical research and expeditions were extremely costly and by no means less elaborated than laboratory investigations.[78] Friedman has pointed out the dominance of the Norwegian geosciences even on the international scale:

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[77] Sem Sæland, *Empirisk videnskap*, in Bugge and Steen, *Norsk kulturhistorie*, 1940, p. 375.

[78] Wråkberg in Lindqvist, 1993, p. 79 and Friedman in Collett, 1995, p. 9 ff.

" *At the Scandinavian geophysical meeting in August of 1918, the emerging strength and dominance of the Norwegian community was already evident. Older Swedish investigators had little that was new to contribute, and they were not as successful in nurturing a new generation of investigators. The contrast between the two communities proves interesting: in Norway, physics and chemistry remained almost dormant, while in Sweden emerging younger disciplinary entrepreneurs, such as Theo [The] Svedberg and Manne Siegbahn, had begun drawing many of the best students and resources to their respective colloidal and X-ray-spectroscopic research programs. Laboratory facilities were being developed in Sweden; in Norway they still remained almost non-existent. By the mid-1920s most of the world's geophysical science communities were envious of the Norwegian accomplishments. ...*"

[Robert Marc Friedman, 1995][79]

Urban Wråkberg refers the decline of Swedish polar research in the early 20th century to the break-up of the Swedish-Norwegian Union in 1905. With Sweden's loss of territorial claims on Spitzbergen, the geopolitical function of geoscientific research in the polar region had disappeared. "*The role of the Swedes as the principle explorers of Spitzbergen has been taken over by the Norwegians.*"[80] Wråkberg's analysis links the growth of the Norwegian polar research community directly to the decline of the Swedish one. The polar geographer Adolf Hoel, who was the head of the *Norges Svalbard- og Ishavs-undersøkelser* (Norwegian Expeditions in Svalbard and the Polar Seas), was one of the strongest advocates for the geopolitical role of Norwegian geoscientific research in the polar region. Hoel was the architect of a Norwegian polar-imperialism, with a strong connection between territorial, economic and scientific aspects and a fierce supporter of Norway's claim on Greenland during the 1920s, also known as *Grønlandssaken.*

Geopolitical and geo-strategic considerations regarding Norwegian geophysical research were most prominent in the polar region. But we do not have to leave the Norwegian mainland in order to find national considerations attached to geophysical research. Geophysical research was also mobilised to tie a country together that had a long extension from its southern to its northern extremes and quite a heterogeneous population with majorities of Sami and Kven people in certain northern districts. Geoscientific research could be mobilised to aid shaping a common Norwegian identity, as Birkeland argued in one of his propositions to the Norwegian Government:

[79] Friedman in Collett, 1995, p. 28.

[80] Wråkberg, citing Lennard von Prost, in Lindqvist, 1993, p. 94.

"...

In addition [to other arguments for a northern light observatory at Haldde] comes a non-scientific moment that, however, may way particularly heavy for the deciding authorities.

An attempt of Norwegian scientificness by such a permanent institution in the Finnmark will contribute to assert the northern parts of Norway outwards, and this will act back on the inhabitants of the place towards a national tendency."

[Kristian Birkeland, 1910][81]

More important than national identity, the geosciences aided to the exploration of natural resources, which built the cornerstone of Norway's economy. Fishing, whaling, mining and logging were important lines of business during the first decades of the 20th century. Norway also held one of the world's largest commercial fleets. Important Norwegian industries like shipbuilding, canning plants and paper mills, were closely related to these commercial lines. The large potential for hydroelectric power provided Norway with Europe's cheapest electricity and laid the grounds for an electrochemical process industry, with the Norsk Hydro Company as its most prominent representative. Again, it was Birkeland who, with the development of the Birkeland-Eyde process for the fixation of nitrogen by means of an electric arc, laid the technical grounds for Norsk Hydro. Through his entrepreneurial activities and the large gains from the Norsk Hydro initiative, Birkeland amassed large sums of money and could finance a well-equipped gas discharge laboratory where he "simulated" northern light. The huge 1,000 litre "*world room*" was by Birkeland himself described as the world's largest discharge tube.[82] Birkeland's expeditions and his gas discharge experiments, where he acquired the most modern and advanced research technologies available, show that large-scale research could be financed in Norway. The same can be accounted for Vilhelm Bjerknes' undertakings in establishing the Bergen School of Meteorology that became a world-leading centre of meteorological research. However, meteorology as well as the strong Norwegian oceanography research-community referred to well-established trades and businesses.[83]

[81] Birkeland to the Department of Church and Education Sept. 28, 1910, cited from Devik, 1971, p. 36, translated from Norwegian.

[82] See Friedman, in Collett, 1995, p. 15 f. See Andersen and Yttri (1997) for the research history of the Norsk Hydro Company.

[83] For Vilhem Bjerknes and the Bergen School of Meteorology see Friedman, 1989. Friedman elaborates especially the connection between meteorology and the importance of weather

NTH's second Professor of Physics, Johan Holtsmark, represented a kind of counter-image to the "Norwegian geoscientist" that we have portrayed so far. Holtsmark had mainly studied in Germany. Only a short period he was assistant of Vilhelm Bjerknes in Leipzig, the sole occasion that he worked on geophysical problems. Holtsmark had never participated in a scientific expedition and he was the only prominent Norwegian physicist of the interwar period who did not join the Geophysical Society. In Friedman's comparison between the Norwegian and Swedish scientific communities, which is cited above, Holtsmark resembled a Norwegian equivalent of The Svedberg and Manne Siegbahn, who established modern research fields, research practices and research laboratories. In contrast to other scientists Holtsmark did not modernise Norwegian physics through an agenda of national peculiarities but within the guiding lines of the international community. However, the focus on raw products within the Norwegian economy and the geoscientific research network affected also Holtsmark's research practices. This influence can be illustrated with two examples:

- The strong Norwegian geophysical research community had established an international network of contacts and co-operations. Holtsmark could mobilise this network also for his physics research. Holtsmark's contact to the Van de Graaff accelerator group at the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, for example, was decisive for the construction of the Trondheim Van de Graaff generator.[84]

- The dominance of raw material related and energy intensive industry in Norway reflected the lack of other industries, like machine building and an electrical industry. The electrical industries of the USA, Germany and Great Britain established large corporate research laboratories and supported university laboratories with personnel and equipment.[85] The lack of a research-supporting electrical industry was a weakness for Norwegian physics research, which increasingly relied on electrical devices and large installations. Holtsmark's turn to the state-controlled Norwegian Broadcasting Corporation

forecasting for agriculture and aviation (see p. 109 ff.). For the importance of oceanography for fishery see Friedman, p. 39-41.

[84] See Chapter 5, Section 5.

[85] See for example Hagemeyer, 1979, Jeff Hughes, in Gaudillière and Löwy, 1998, Thomas P. Hughes, 1983, p. 377 ff., Thompson, 1997 and 2002, and Heilbron and Seidel, 1989, especially p. 103 ff.

(*Norsk Rikskringkasting*) for the financing of electroacoustics research can partly be explained by the lack of private actors.[86]

The University of Kristiania and the Norwegian Institute of Technology in Trondheim were mainly teaching institutions, where research was proclaimed as a main goal but not supported with large contributions. NTH with its laboratories provided the space and infrastructure for research but not the funding for expensive research instrumentation or research assistants. The research projects at the physics department of NTH were generally supported by a number of research funds, among these were *Norges Tekniske Høiskoes Fond, A/S Norsk Varekrigsfond, Det Vitenskapelige Forskningsfond av 1919* and *Professor Kristian Birkelands fond for geofysisk forskning.*

The research funds gave only smaller contributions to research projects and could not structure and channel research efforts or finance larger research agendas. From the end of WWI, the Kristiania Professor of Mineralogy and Geology, Waldemar Christopher Brøgger, Sem Sæland and others worked towards the establishment of a Norwegian research council and research institutions according to American examples.[87] A first committee, *Centralkomitéen for videnskabelig samarbeide til fremme av næringslivet,* was founded in 1918 to organise the research co-operation between science, state and industry. In 1921 the committee changed its name to the *Raadet for anvendt videnkab* (Council of Applied Science). But the Council did not manage to overcome the disagreements between the scientists, politicians and representatives of the industry and never gained a major influence. As a result of the crisis of the Norwegian economy at the beginning of the interwar period, the Norwegian state decreased and finally withdrew its support, and in 1926 the council was liquidated. The plans for the Norwegian research council were made in the economic boom during and immediately after World War I. This boom was followed by a deep recession and money shortage during much of the 1920s. The Norwegian economy followed the main pattern of the European economic development but the crisis was more profound and delayed compared to other countries.[88] After a slight recovery at the end of the 1920s, Norwegian economy was hit by the world crisis of 1930, only recovering in the mid-1930s.

Despite the economic crisis, two industrial research institutes were founded during the interwar period, the Norwegian Pulp and Paper Research Institute

[86] For Holtsmark's co-operation with the Norwegian Broadcasting Corporation see Chapter 4, Section 5.3.

[87] For the history of the Norwegian research funds, research councils and research institutes, see Collett, 1983, and Kvaal, 1997.

[88] See Hanisch and Lange, 1985, p. 92, ff.

(*Papirindustriens Forskningsinstitutt*) in 1930 and the Canning Industries Laboratory (*Hermetikkindustriens Laboratorium*) in 1931.[89] Another Norwegian research institute, the *Christian Michelsen Institute* was established in 1930 with a donation from the inheritance of Christian Michelsen, shipowner and former Prime Minister of Norway. One major difficulty in the establishment of these research institutes, independent from both NTH and the University, was the economic crisis of the interwar period. Another problem was the availability of qualified researchers.[90] The training and availability of qualified research assistants was one argument of the NTH scientists to keep research activities at the institute of technology, instead of establishing research institutes independent of academic teaching.[91] Also Michael Aaron Dennis has pointed out in his history of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington that the lack of students at an independent research institute not only had advantages but also caused problems: "*Louis Bauer [the director of the DTM] looks like a traditional disciplinary entrepreneur, but his program lacked a crucial resource -- Students. After all, who would carry out his program? ...*"[92] We will see that students represented an essential resource for Holtsmark's research agendas at NTH's physics department. This brings us to the next section and the establishment of NTH as a teaching and research institution.

3.3. A Norwegian *Technische Hochschule*

The establishment of the Norwegian Institute of Technology

Situated on the *Gløshaugen* hill overviewing the city, the first and main building of the Norwegian Institute of Technology is widely known as *Slottet* (The castle) among Trondheim's citizens. When entering the building through its main front doorway, it reveals the sacral atmosphere of a cathedral rather than the anticipated soberness of a technical school. The striking similarities between the building and the Nidaros Cathedral was the dominant feature in Bredo Greve's architectural plan *Vis à vis Domkirken* for the technical institute. In certain aspects the influence of the Cathedral's architecture even overruled

[89] See Collett, 1983, p. 233 ff.

[90] See for example Collett, 1983, p. 74 and 91.

[91] See Collett, 1983, p. 92.

[92] Dennis, 1991, p. 153.

practical and general aesthetic considerations.[93] The symbolism of this architecture was clear-cut: the building was not only a church to house the spirits of the technical sciences, it was a Norwegian church.

When the *Norges Tekniske Høiskole* opened its doors in 1910, Norwegian independence from Sweden was only five years old. The foundation of the institute was seen as a further step towards autonomy and national liberation.[94] Plans for the technical institute traced back into the 19th century. Polytechnic schools were founded in Kristiania, Bergen and Trondheim in the 1870s, but representatives of politics and industry agreed on that mere technical schools were not sufficient to lift industrialisation. Norwegian industry was seen as far behind the leading nations in Europe. Industrialisation and exploitation of raw materials depended not only on foreign capital investment but also on the import of knowledge. Before the opening of NTH, Norwegian students had to travel abroad to study engineering subjects.

For various reasons the German model of *Technische Hochschule* was chosen for the Norwegian Institute of Technology. The *Technische Hochschulen* and the entire field of technical education were given a lot of credit for the economic growth in Germany around 1900. Most Norwegian engineers had their education from Germany, which was still the main cultural and technological influence, and its engineering was seen as superior in comparison to other nations. The German model of *Ingenieurwissenschaft* was intended to place the engineering subjects on a scientific basis and to establish academic teaching and research at a level in the *Technische Hochschulen* that was similar to the German universities. The American engineering education system, which seemed to be the only real competitor to the German system when NTH was established, was more practically oriented.[95] An engineer who graduated from NTH should not only be capable of keeping the industry at the forefront of its time, but also to develop it further.[96] To do so the engineers were required to understand, if not to advance the scientific principles the technology was based on.

The Norwegian adoption of the German *Technische Hochschule* model was also questioned. Several authors in the debate argued that the Norwegian Institute of Technology should above all be a *Norwegian* institution that should

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93 See *Teknisk Ugeblad*, September 9, 1910, p. 444-445.

94 *Teknisk Ugeblad*, September 9, 1910, p. 425.

95 See for example Olav Heggstad in *Teknisk Ugeblad*, February 25, 1910, p. 86 and Hanisch and Lange, 1985, p. 50 ff. Concerning German engineering education see also Thomas P. Hughes, 1983, p. 143.

96 Claus Nissen Riiber, 1917, in Hanisch and Lange, 1985, p. 54.

take certain apparently special Norwegian peculiarities into consideration.[97] The national factors were strong when it came to the appointment of professors. Among the first twelve Professors at NTH, three Germans were appointed because qualified Norwegians could not be found in these disciplines.[98] Also the majority of the Norwegian professors appointed were educated in Germany.

In the first decade of NTH's operation from 1910 to 1920 Norway experienced strong economic growth and there was a large demand for graduate engineers. Many more secondary school graduates, almost exclusively men, applied to the engineering faculties than could be admitted. The existing buildings were partly extended and ample plans were developed for the expansion of NTH. In 1910 one hundred students were admitted, even though NTH was only dimensioned for fifty. In 1919, the number of admitted students had risen to 175 and 120 applicants had to be refused.[99] In 1920 the world economic crisis hit Norway and the graduating semesters had large numbers of students who went into either unemployment or emigration. In 1922 the number of admitted students went down to 105 and only 24 applicants were refused. The Faculty of Mining had no applicants that year. In 1922 the overall budget of NTH started to shrink after it had been growing continuously for eleven years. The economic crisis, which lasted until the mid-1930s, led to a stagnation of NTH's expansion. First in the late 1930s new plans appeared for the extension of NTH's capacities. These plans were, however, interrupted by WWII.

NTH was during the 1920s not only characterised by the recession. The 1920s were also the decade of a broader academisation. There are especially three aspects of this development of NTH towards a stronger academisation that should be mentioned. The first aspect relates to the introduction of the *dr.techn.*-degree in 1922 and the equalisation of NTH with the University of Kristiania as a teaching and research institution. From 1924 until 1940, nineteen dr.techn.-degrees had been awarded at NTH, most of them to chemical engineers. The second aspect relates to the increase of research funds at NTH during the interwar period. NTH did not give any research funding out of its

[97] See Teknisk Ugeblad, February 25, 1910, p. 87 and September 9, 1910, as well as Sæland in Teknisk Ukeblad, July 28, 1911, p. 362 f. Sæland, however, was the only author who specified the nature of these Norwegian peculiarities. He mentioned, for example, that Norwegian engineers had to be more broadly and universally educated, whereas in Germany engineers had to be more specialised.

[98] The German professors were Adolf Watzinger, Professor of Machine Engineering, Reinhold Lutz, Professor of Machine Parts and Oil Machines and Heinz Egerer, Professor of Mechanics.

[99] See Hanisch and Lange, 1985, Devik, 1960, p. 117 ff. and *NTH-beretning om virksomheten 1910-1920.*

central budget. Research had to be financed by research funds and from other sources outside. The most important of these funds was NTH's own *Norges Tekniske Høiskoes Fond.* The NTH-fund started its activity to collect contributions in 1910 and began to grand research funding in 1915. The contributions rose from a total of NOK 6,000 to eight separate research projects in 1915 to over NOK 40,000 distributed to forty projects in 1930.[100] The number of professors in office at NTH had risen from twenty-two to twenty-seven in the same period. The number of new students admitted had risen from 130 in 1915 to 159 in 1930. Research activities had expanded at the same time teaching activities stagnated.[101] While the reports on publications of NTH's scientists covered twelve pages in the ten-year report of NTH of 1910-1920, they covered more than 18 pages only for the one-year report of 1930/31. The first research projects at the physics department were funded in 1926. From then on the NTH-fund became a contributor to basically every research project at the physics department.

The third aspect of academisation relates to the development of close relations between NTH and the Royal Norwegian Society of Science and Letters and the establishment of a separate class of natural sciences (*naturvitenskapelig klasse*) in 1926. Of NTH's twenty-seven professors, fourteen were elected into the society, along with a number of foreign members, most prominent among these Niels Bohr, but also NTH's previous Professor of Physics, Sem Sæland, by then at the University of Oslo. The disciplines that were seen as more theoretical, like chemistry, physics and mathematics, were more strongly represented than the disciplines that were seen as merely technical.[102] The meetings of the society served as a local platform to present and discuss new scientific work within the otherwise rather isolated scientific community. The Proceedings of the Royal Norwegian Society of Science and Letters (*Det Kongelige Norske Videnskabers Selskab Forhandlinger*) made publication of short papers fast and unproblematic. Longer treatise and dissertations could be published in *Det Kongelige Norske Videnskabers Selskab Skrifter*. But the practice of publishing in the proceedings of the local science society also had drawbacks: earlier most papers had been published in international journals that were widely read and recognised. The proceedings of the science society were little read outside Norway and not reviewed in journals like *Berichte der Physik.*

[100] See *Norges Tekniske Høiskoles Fond, Årsberetninger.*

[101] Hanisch and Lange (1985, p. 88 ff.) come to the same conclusion. See also speech of Professor Vogt, President of NTH, on September 1, 1936, as cited in Devik, 1960, p. 136.

[102] This domination of the apparently more scientific and theoretical subjects over the apparently more technical and practical subjects was also sharply criticised. See Midbøe, 1960, vol. 2, p. 163 ff.

3.4. Physics at NTH - from teaching engineers to a research institution

In this section I want to give an overview over the establishment and development of the physics department of NTH as a teaching and research institution. In the original scheme of 1910 the role of the physics department was limited to provide elementary physics teaching for engineering and architecture students. Together with mathematics and mechanics, physics was a part of the Faculty of Common Subjects (*Almenavdelingen*). The department had no physics students of its own, a limited infrastructure and no funding for research. At the end of the interwar period, Johan Holtsmark had managed to build up Scandinavia's first particle accelerator and a nuclear physics laboratory, an acoustics laboratory, an X-ray laboratory, and research agendas in electron scattering and spectroscopy. The establishment of a separate career of technical physics was less successful. For Holtsmark's research agendas, however, physics graduates did not seem to be necessary, with chemical and electrical engineers taking their place.

How did this transformation, from a mere undergraduate teaching institution to a centre of modern physics research, take place, and what were its main conditions? We have to consider the activities, the strategies and the personalities of the first two physics professors at NTH, Sem Sæland and Johan Peter Holtsmark. An important aspect was the planning and construction of a separate physics building that provided the space and infrastructure for advanced research agendas. Advanced research technology and research practices had to be established. Most of the research instrumentation was built at the department's instrument shop. Practices of instrument building and instrument use were closely related and often not separable.

One of the most interesting features of the development of the physics department during the interwar period is the relationship between teaching and research activities. At an institution like the Norwegian Institute of Technology, these two activities cannot be separated. Regretfully, there are only a few historical studies on the teaching-research interaction at scientific institutions during the interwar period. Presumably the most interesting and most elaborated of these is Michael Aaron Dennis' history about Charles Stark Draper and his establishment of the MIT Instrument Laboratory: "... *In the laboratory's crowded space, Draper developed a distinctive pedagogical style, while producing both students and novel measurement instruments.* ..."[103] Draper's aeronautical instruments had developed from pedagogical laboratory devices into instruments that entered aeroplanes and were finally produced as commercial aviation instruments. Dennis described teaching as a central

[103] Dennis, 1991, p. 24.

identity and approach of Draper, even as a researcher and a consultant.[104] As for Holtsmark in Trondheim, in the framework of teaching, research and consulting, the students remained Draper's mot important resource.

3.4.1. Two epochs of physics: Sem Sæland and Johan Peter Holtsmark

The development of the physics department at NTH during the first 32 years of its existence can be divided into to major time periods. The first period from 1910 to 1923 is related to the first Professor of Physics, Sem Sæland, the establishment of physics teaching for engineers and the rise of a separate physics building to overcome space limitation and to provide the infrastructure for advanced physics research and teaching. The second period from 1923 to 1942 is characterised by the appointment of Johan Holtsmark, the inauguration of the new physics building, a rise in the number of staff and the establishment of modern research agendas.

Sem Sæland was born in 1874, as the son of farmers in Sæland in Jæren, Western Norway. During his studies at the University of Kristiania, Sæland worked as Kristian Birkeland's assistant, where he helped to organise and participated in northern lights expeditions and geomagnetic observations. During his studies he went for shorter periods to Edinburgh and to the Meteorological Magnetic Observatory in Potsdam. Sæland's most prominent research stay at a foreign institution was under Philip Lenard at the physics department of the University of Heidelberg. Lenard was an old friend of Vilhelm Bjerknes, from the time when Bjerknes was assistant of Heinrich Hertz at the University of Bonn.[105] Sæland's article on the so-called metal-radiation from the Heidelberg-period was his sole publication in general physics.[106]

In September of 1909, Sæland was appointed Professor of Physics at NTH, 35 years old and three years after he had graduated from the University of Oslo with the *embedseksamen*. As six of the first twelve professors appointed at NTH, Sæland did not carry a doctorate degree. The physics department's instrument maker, Thorvald Reed, and the first teaching assistant, Kristoffer Glimme, a graduate from the University of Kristiania, were both appointed in

[104] Dennis, p. 123.

[105] Lenard remembered Sæland as one of the co-workers in investigations of phosphorescence effects. See Lenard, approx. 1943, p. 71, and p. 66 for Lenard about Bjerknes.

[106] See Sæland, 1908.

1910. Sæland set up the experimental lecture according to the example of Lenard at Heidelberg, which had impressed him much.[107] Sæland established a well-equipped collection of teaching instruments for demonstration in the lectures, but there was no infrastructure for research. Especially the lack of laboratory space hindered experimental investigations. One of Sæland's assistants, the Swedish physicist Gudmund Borelius from the University of Lund published the first scientific paper from experimental investigations carried out at the physics department in Trondheim, *Elektrostatische Methode zur Bestimmung des Potentials eines Elektrolyten*, in the *Annalen der Physik* in 1913. Borelius, however, reported about problems leading to the interruption of the experiments in Trondheim and their later termination in Lund.[108]

Sæland was a popular and inspiring lecturer, and was favoured among his students. He became NTH's first president form 1910 to 1914 and was the foremost supporter of the Trondheim Student Society (*Studentersamfundet i Trondhjem*), and a frequent speaker at its meetings and festivities.[109] In 1915 Sæland was elected as a crossbench member of the Norwegian Parliament (*Stortinget*) from 1916 to 1918 with the enhancement of Norwegian military defence on his program. In 1918 he travelled to England and the United States to study industry-oriented physics laboratories, and the new physics building was raised from 1923 to 1925 according to his plans. In 1923, however, Sæland was appointed Professor of Physics at the University of Oslo. In the commemorative address to Sæland's death in 1940, Sigvald Schmidt-Nielsen remembered that Sæland himself recognised that the time had come for him to leave NTH and to leave it to a younger physicist to take advantage of the new building and to fill it with research activities.

Sæland continued his career as a research administrator and politician at the University of Kristiania. He was chairman of the Norwegian *Raadet for anvendt videnskap* from 1921 to 1926 and president of the University of Oslo from 1927 to 1936. During his time as president, the new university complex at Blindern was raised. Sæland was chairman of the Broadcasting Program Commission (*Programrådet*) of the Norwegian Broadcasting Corporation from 1930 until his death.[110] He also held public offices in the board of directors of the Christian Michelsen Institute, *Handelshøiskolen*, the Council for Technical

[107] See, for example, Devik, 1960, p. 291. Carl Ramsauer described the style of lecturing of his mentor Lenard in detail and recalled the great impression Lenard's lecturing made on Sæland. See Ramsauer 1949, p. 107 ff., p. 109 for Sæland.

[108] See Borelius, 1913. The investigations became Borelius doctoral thesis in 1915. See *Teknisk fysik i Sverige*, Tekniska fysikers förening, 1982.

[109] See Chapter 4, Section 3.1.

[110] See Chapter 4, Section 1.

and Industrial Research (*Rådet for teknisk-industriell forskning*), and the *Norsk varekrigsforsikrings fond.* In 1940, at the age of 66, Sæland died of a heart disease, Tachycardia or more specific Pyknocardia, which was most probably caused by chronic mercury intoxication.[111]

Sæland's successor, Johan Peter Holtsmark, was only 29 years old when he was appointed Professor of Physics in 1923. Holtsmark was born in Kristiania in 1894 as the son of Margrete and Gabriel Holtsmark. Both his father and mother had studied science and mathematics. Gabriel Holtsmark went for post-graduate studies to the University of Würzburg and submitted a thesis about X-ray physics in 1902. In 1911, Johan graduated from secondary school with the *artium*, when he was only 17 years old. After one year of studies at the University of Kristiania, Johan followed his father's footsteps and went to Wilhelm Wien at the University of Würzburg, where he stayed until 1914, and were he carried out the experiments for his first article, *Versuche über die Lichterregung durch Kathodenstrahlen in Wasserstoff*, published in the *Physikalische Zeitschrift*. After a couple of years in Kristiania, Holtsmark went to Leipzig were he was Vilhelm Bjerknes' assistant from 1916 to 1917, the only occasion that Holtsmark worked with geophysical problems.[112] From 1917 to 1918 he was assistant of Peter Debye at the University of Göttingen. In 1918, being 24 years old, Holtsmark submitted his doctoral dissertation, *Intensitätsverlauf in Serienspektren*, to the University of Oslo, and a theoretical paper titled *Über die Verbreitung der Spektrallinien*, where he explained the broadening of the spectral lines due to the Stark effect. This groundbreaking paper, based on suggestions of Debye, became one of Holtsmark's most recognised contributions to physics.[113] Holtsmark's experimental dissertation and the theoretical paper showed characteristics which identified his professional career: like his mentor Debye, he mastered experimental and theoretical physics at the same time. Furthermore, he had shown his understanding of modern physics, especially atom theory and quantum mechanics, and his abilities to contribute to its development. From 1919 to 1920 Holtsmark had a research stay at London. In 1920 he was awarded a scholarship of the University of Kristiania, and in 1921 he was appointed as *amanuensis* (lecturer).

When Oskar Emil Schiøtz resigned from his chair in physics at the University of Kristiania, Holtsmark applied for the position. He lost the competition with Sæland for the chair at Kristiania, but only because the faculty decided to abstain from calling in a commission to evaluate the candidates on

111 See Schmidt-Nielsen, 1940 and Hylleraas, 1941-1942.

112 See Friedman, 1989, p. 91 and 122.

113 Holtsmark, 1919. See also Franck, 1920, and Born, 1933, p. 444 ff.

scientific grounds: Sæland was needed mainly for his administrative and political skills rather than for his scientific qualifications. Sæland's reputation as an inspiring and popular physics lecturer contributed to resolve the doubts.[114] In return, Holtsmark was appointed to the chair in Trondheim. In addition, Olaf Devik (1886 - 1987) was appointed on the newly established position of a *dosent* (lecturer) to cover the teaching obligations at the Norwegian Teacher College, which had opened in 1922.[115] In 1925 the physics department could finally move into the new physics building that gave ample space for new research undertakings.

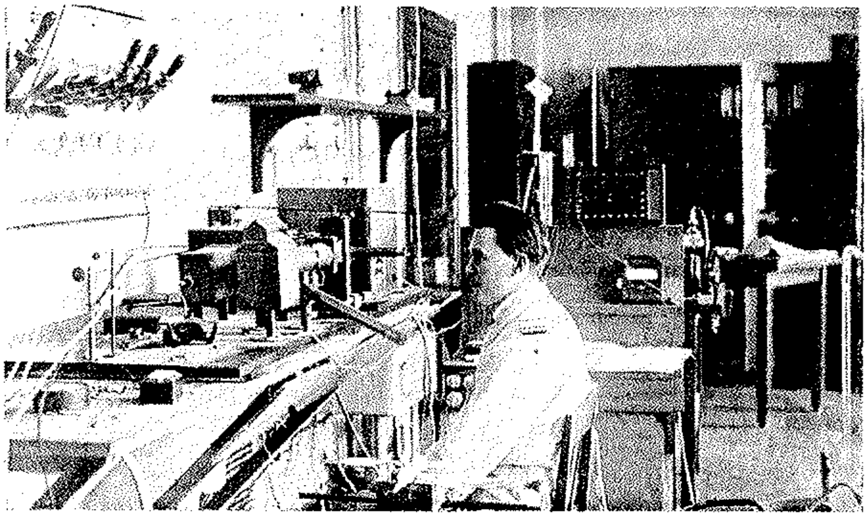

Fig. 3.1: Professor Holtsmark working in his laboratory (Photo: Brochmann, *Hvor Norges fremtid bygges*, 1927, p. 79).

Holtsmark's own research at NTH, as well as his entrepreneurial activities in establishing a number of different research agendas, which were followed by his assistants, are treated in great detail in the following chapters. During a

114 See *Kristania Universitet - Årsberetninger 1921-22*. Lars Vegard, the other Professor of Physics at Kristiania and Holtsmark's mentor in his dissertation, however, protested sharply against the procedure of Sæland's appointment.

115 For Devik's appointment and his competition with Holtsmark, see Chapter 5, Section 3.

research stay at Niels Bohr's Institute of Theoretical Physics at Copenhagen in 1927, Holtsmark published, together with the Swedish physicist Hilding Faxén, his other groundbreaking contribution to physics, *Beitrag zur Theorie des Durchgangs langsamer Elektronen durch Gase*. In this article Faxén and Holtsmark presented the first satisfying quantum mechanical theory of the scattering of slow electrons by atoms of noble gases, also known as the Ramsauer effect.[116] In the 1930s, after some years of intensive work on electron scattering, Holtsmark turned his main research interest to technical acoustics.

After Sæland had died in 1940, Holtsmark was appointed as his successor on the Chair of Physics at the University of Oslo in 1942. When he moved, he took with him the accelerator laboratory, parts of the acoustics laboratory and a number of assistants. In the post-war period Holtsmark continued his acoustics activities, supported the establishment and growth of nuclear physics and initiated research agendas in solid state physics at Oslo. He was also the first Norwegian representative in the planning around the European accelerator laboratory CERN. Holtsmark died in 1975, 81 years old.[117]

Johan Holtsmark was presumably the most important renovator of the Norwegian physics community during the interwar period. However, Holtsmark did not acquired the same popular status as Svein Rosseland or Egyl Hylleraas, who are famous for their affiliations with the Copenhagen and Göttingen schools of quantum mechanics. Whereas Rosseland and Hylleraas were pure theoreticians, Holtsmark established modern research laboratories and experimental research practices in Norway. Holtsmark was more than an entrepreneur in a technical sense: he was said to be not especially popular as a lecturer, but Holtsmark was most successful in inspiring students for scientific research and creating an environment for these young scientists to pursue their own independent agendas.

[116] See Chapter 4, Section 8.1.

[117] For Holtsmark, see Ormestad, Tangen and Wergeland, 1944, Wergeland, 1974, and Hole, 1976.

3.4.2. Continuity and change in scientific instrument making

" *The head of the instrument maker's shop at the physics department, Thorvald Reed, came as an instrument maker already in the summer of 1910 and was through 43 years the steady point in the department's daily activity. He became, so to say, one with the whole department's work and had a personal relationship with everyone working at the department. He was a first class professional, had several study stays at foreign institutions and happened to take in a more and more central position in the department's activities. It was his advice one would seek when something should be planned, and it was almost always him who got the work started because he was both willing and able to do so...* "

[Olaf Devik, 1960][118]

Scientific instruments are one of the bases of experimental physics research and teaching. The fundamental changes in the practices of scientific instrument making and instrument use during the interwar period are a central theme of this dissertation. I will therefore give a brief introduction to scientific instrument making and instrument makers at NTH's physics department. We can locate three different groups of actors within scientific instrument making. The first group were the traditional instrument makers who came from the craft. The well respected trade of instrument making involved skills in metalwork, woodwork and glasswork. Instrument making was taught, like in other traditional crafts, from master to apprentice and could involve technical schooling, but no academic training. The second group were physicists who made their instruments themselves, sometimes without any assistance from the instrument makers. These physicists had acquired the basic skills of scientific instrument making. Devik was an example of a physicist at NTH who carried out most, if not all of the basic instrument making himself.[119] However, it was more typical that scientists designed and built instruments in co-operation with the instrument makers at the shop. At NTH in Trondheim this co-operation between instrument makers and physicists seems to have always worked smoothly.[120] A third group of actors that emerged in scientific instrument

118 Olaf Devik, N.T.H. femti år, Teknisk Ukeblad, Oslo, 1960, p 292.

119 See Chapter 5, Section 3.

120 At other institutions the relationship between scientists and the instrument shop could be strained. According to Thomas D. Cornell, the tensions between the accelerator group at the Carnegie Institution of Washington's Department of Terrestrial Magnetism, consisting of Tuve, Hafstad and Dahl, and the Department's instrument shop resulted in the accelerator group rigging up its own workshop. See Cornell, 1986, p. 286 ff.

making at the NTH physics department during the 1920s were electrical engineers. The way that telecommunication engineers, with a background in amateur radio, revolutionised scientific instrument making with new practices and devices, like technical drawings, circuit diagrams and, especially, radio technology, is a major theme in Chapter 4 and 5 and need not be discussed here.

The first instrument maker at the physics department of NTH was Thorvald Reed. When Reed was appointed in 1910, together with Sæland and the assistant Glimme, there was no research agenda, and the physics department's sole task was to organise physics teaching for the engineering students. Teaching activities, however, relied fundamentally on instruments. One of Sæland's first acts as Professor of Physics was the acquisition of a comprehensive collection of several hundred scientific instruments that were shown and partly demonstrated during the experimental physics lectures. Most of these instruments were bought from instrument companies all over Europe, but a considerable number were made in the local shop. A remaining collection of 65 photos shows the set up of the instruments for the respective lecture.[121] The physics lectures were given twice a week and the set-up of the experiments in the auditorium was usually started several days ahead.

In the original scheme it was planned that one of the regular assistants would prepare the demonstrations and assist during the lectures. This practice proved to be impracticable. The assistants changed too often and did not manage to acquire the essential skills. It was necessary to appoint an experienced demonstrator who also knew the institute's collection. In practice, Reed was made the lecture assistant.[122] From 1932 onwards Reed was officially listed as lecture assistant in the yearly reports of NTH. It was Reed, the craftsman with no academic schooling but much practical experience, who was the successful actor in the lecture demonstrations, and who made the instruments speak, whereas the academically trained assistants failed. The choice of the instrument maker Reed as lecture assistant was no peculiarity of Trondheim. Sperber, the chief mechanic of the University of Göttingen's physics department, was Robert Wichard Pohl's lecture assistant and his main co-operator in the development of a novel system of lecture demonstrations.[123] I was surprised that even nowadays, when I visited the lecture demonstrations at the physics departments of universities of Göttingen, Heidelberg and

[121] See archive *NTH-Fysisk institutt*, Ua: 1 and Uc: 1, Statsarkivet i Trondheim. Most of these instruments are still part of the collection of the physics department at Trondheim.

[122] See Devik, *Budgetforslag for 1924/25 for den Tekniske Høiskoles Fysiske Institutt*, Privatarkiv Olaf Devik, Riksarkivet i Oslo.

[123] See, for example, Archilles, 1977, p. 157. Pohl also acknowledged Sperber in the foreword to his textbooks. See Pohl, 1931.

Darmstadt, I found the lecture assistants to be craftsmen and not academically trained personnel.

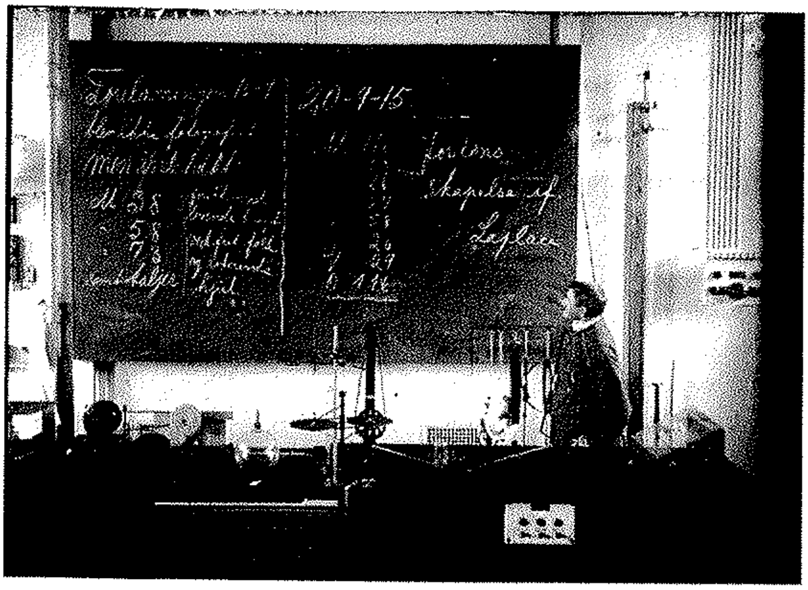

Fig. 3.2: Set-up of demonstration experiments in the physics lecture at NTH with Thorvald Reed, September 20, 1915 (Photo: Statsarkivet i Trondheim).

After the Norwegian Teacher College opened in 1922, Reed started to teach a course on metalwork to the schoolteacher students. When the physics department moved to the new physics building, in 1925, a second instrument maker, Anton Skancke, was appointed. In 1928, a third instrument maker, Toralf Nielsen, was appointed. Reed remained the head of the instrument shop until he died in 1953, 69 years old and one year short of retirement age. He had lived through three generations of physics professors at NTH and represented continuity in a time of change within physics, last but not least in its practices of scientific instrument making.

3.4.3. The new physics building and the spatial conditions for doing physics

One main requirement to establish advanced research agendas in experimental physics at NTH was the availability of appropriate premises for laboratories. Since the end of the 19th century, institutionalised and professionalised laboratories were established in all research fields of physics. The accessibility of such appropriate laboratory spaces were a prerequisite if scientists wanted to conduct research as part of the international community. The importance of the architecture of scientific workspace for the conduct of scientific work had recently attracted more attention of historians of science.[124]

One of the reasons that very little research was carried out at the physics department of NTH before 1925, was simply that space for research laboratories was not available. The physics department was located in a building together with the Faculty of Electrical Engineering.[125] The department's premises covered around 650 m^2, including a lecture theatre for 110 students. All laboratory space was needed for student exercises. These laboratories could be used for research in semester breaks, but did not allow permanent research installations. The remaining premises included the professor's and the assistant's offices, the instrument collection and, last but not least, the instrument shop.[126] The instrument shop in the basement, however, hardly satisfied legal labour standards and resulted in, or at least contributed to, the instrument maker Reed reporting sick for longer periods.[127]

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[124] See, for example, Galison, 1997, p. 816 ff. and Galison and Thompson, 1999.

[125] See Fig. 3.3.

[126] See *NTH - Beretning om virksomheten 1910-1920*, p. 180 f.

[127] See *Stortings-proposisjoner nr. 1, hovedpost V, bevilgning til den tekniske høiskolen*, 1913, p. 62, and 1916, p. 16.

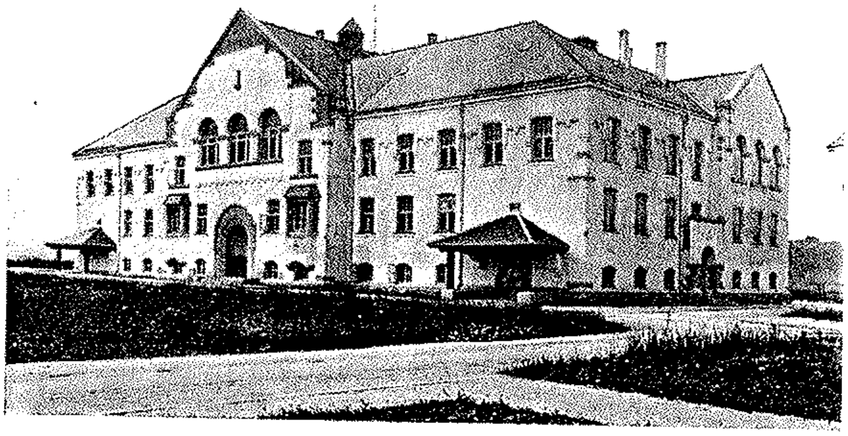
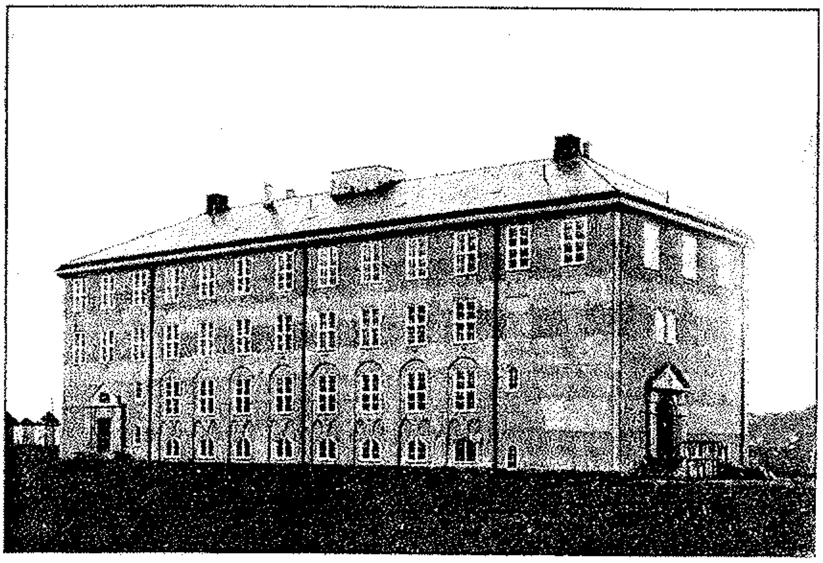


Fig. 33. FYSISK OG ELEKTROTEKNISK LABORATORIUM

Fig. 3.3: The physical and electrotechnical laboratory of NTH around 1910. The premises of the physics department were located within the right side of the building (Photo: *NTH - Beretning om virksomheten 1910-1920*, p. 175).

Soon after his appointment, Sæland started to work on plans, first for an extension of the existing building and later for a separate physics building. The new building should house extended teaching premises for separate career training for technical physicists as well as laboratories to conduct experimental research. Sæland collected information about physics departments at comparable institutions in Europe and, in 1919 went on a journey to the USA where he studied modern American research institutions. The Norwegian Parliament approved of the construction of the new physics building in 1918, during the economic boom. The beginning of construction was, however, delayed until 1923, when the recession had hit Norway, and the building was finished and inaugurated in 1925.[128] The physics building was the only new building that was constructed at NTH during the interwar period and was an impressive result of Sæland's indefatigable efforts. The building, on four floors, provided a floor space of 1,800 m^2, excluding staircases and corridors, almost a tripling of the previous space, and changed the spatial conditions for laboratory research fundamentally: from a situation of being very limited on space, the physicists suddenly had to fill a lot of laboratory and workshop space with activities.



Fysisk institutt. Fasade.

Fig. 3.4: The new physics building in 1925 (Photo: *NTH - Beretning for 5-året 1920-1925*, p. 200).

[128] See *NTH - Beretning for 5-året 1920-1925*, p. 200-208.

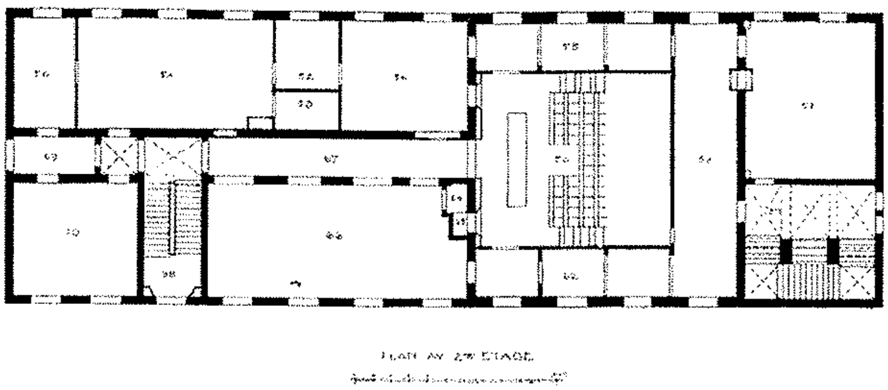


Fig. 3.5: Plan of the second floor of the new physics building. The second floor was occupied of premises for teaching as well as Holtsmark's office and laboratory. No. 56 was the large auditorium that continued through the third floor (*NTH - Beretning for 5-året 1920-1925*, p. 206).

The new building was planned by Sæland, but taken into use by his successor Holtsmark and the lecturer Devik. Holtsmark's ideas about the research agendas to be established in the new building differed fundamentally from Sæland's. In the tradition of Norwegian geophysical research Sæland had planned to establish a geomagnetic and a meteorological station. Holtsmark did not follow up the establishment of these.[129] Georg Brochmann described the activities in the new building in 1927: Devik and the assistant Bjørn Trumpy had their respective high-voltage and spectroscopy laboratories on the first floor. Holtsmark had his office and his spectroscopy laboratory on the second floor.[130] On the third floor, in the premises originally designated to the meteorological station, the second assistant Haakon Brækken had set up an X-ray laboratory. In the basement Reed, and the second instrument maker, Skancke, had a well-equipped workshop with all essential metal working machines, a small

[129] Concerning Sæland's ambitions in geomagnetism and the establishment of a geomagnetic station, see Schmidt-Nielsen, 1940, p. 73 and *Norges tekniske høiskoles fond 1915-1934* (1935), p. 73. In a letter to Sæland of January 10, 1925, Holtsmark declined to take over the work with the geomagnetic station (Archive *NTH-Fysisk institutt*, Eb: 5, Statsarkivet i Trondheim). Concerning the meteorological station, see Holtsmark, manuscript for *Beretning for 5-året 1920-1925* (1925), Archive *NTH-Fysisk institutt*, Statsarkivet i Trondheim. Brochmann (1927, p. 80) reported that Devik carried out meteorological observations from the observation platform of the physics building.

[130] See Fig. 3.1.

blacksmith's shop and a carpenter's workshop. The teaching premises were also well described by Brochmann. However, he left out to mention the only woman working in the building, the office worker Fanny Aavatsmark.[131]

The space available in the physics building allowed the provision of rooms for other members of the Faculty of Common Studies as well as for the Academic Radio Club, which was founded mainly by electrical engineering students. The co-operation between Holtsmark and members of the Academic Radio Club had major consequences for the development of scientific instrument making and the establishment of new research agendas, and we will come back to this in great detail in Chapter 4. The largest new research agendas established in the 1930s were technical acoustics and accelerator based nuclear physics. Both required laboratory installations over several rooms and structural changes. The accelerator laboratory consisted of two rooms, the generator room and the observation room, with the accelerator tube passing through a hole in the wall. The size of the generator room limited the potential of the accelerator fundamentally and the arrangement of the observation room, next to rather than beneath the generator room, was a major disadvantage.[132] The acoustics laboratory spread over three rooms with test-fields in the wall and the flooring. The acoustics and the accelerator laboratory at the physics department of the 1930s gave notice of what the next generation of these laboratories would require: new buildings and a special laboratory architecture.[133]

3.4.4. How to do physics without physicists? Chemical and electrical engineers at the physics department

One of the most striking features of Holtsmark's entrepreneurial activities of establishing advanced research agendas was that he did not appoint physics graduates, but chemical and telecommunication engineers as research assistants. This had to do mainly with the lack of physics graduates at NTH and Holtsmark's skills in attracting and appointing talented research assistants from the schools of chemical and telecommunication engineering.

[131] Brochmann, 1927, p. 71-80. Concerning Devik's high voltage laboratory, see Chapter 5, Section 3.

[132] See Chapter 5, Section 7.

[133] NTH's next particle accelerator laboratory was built within an extension of the physics building in 1951. The acoustics laboratories of NTH were built in 1960s, together with the establishment of a Department of Acoustics within the Faculty of Electrical Engineering.

The career of the *technischer Physiker* was introduced at the German *Technische Hochschulen* after WWI, and the *Deutsche Gesellschaft für technische Physik* was founded in 1919. In accordance with the model of the *Technische Hochschule*, also the career of physics engineering at NTH should be related to the German technical physicist.[134] Gudmund Borelius, who had been assistant at NTH's physics department in 1913, was appointed Professor of Physics at the *Kungl. Tekniska Höskolan* (KTH) in Stockholm in 1922. Simultaneously with Holtsmark in Trondheim, Borelius projected a separate career of technical physics according to the German model. The career at KTH was established in 1932 and the number of admitted students had gone up to 16 in 1935.[135] The first plans at NTH were made by Sæland in 1922. In 1925 Borelius was consulted by the Trondheim planning committee for the career of technical physics, with Holtsmark, Reinhold Lutz, Professor of Machine Parts and Oil Machines, Claus Nissen Riiber, Professor of Organic Chemistry, and Ragnar Sigvald Skancke, Professor of Telecommunication Engineering (*svakstrøm*) as its members.[136] The planning committee drafted a proposal to the *Professorutvalget* of NTH, which was submitted on February 19, 1926.

The new career was finally established in 1929 on a rather provisional base. The curriculum was set together out of a handful of physics courses, such as the general physics lectures and the laboratory courses, which were compulsory for every engineering student, supplemented with optional courses like acoustics, X-ray physics and optics. Other courses had to be taken at other departments.[137] Compare to the well-organised schools of the other departments, the study plan for the technical physicist was rather erratic and not so appealing. One of the major disadvantages of the career was the lack of a theoretical physicist at NTH. The student contingent was set as two per semester to begin with. But not even this small number was filled up. Up to World War II only a handful of technical physicists graduated from NTH, and none of them was appointed as

134 The terms *teknisk fysikk* and *teknisk fysiker* are usually translated as *engineering physics* and *engineering physicists*. I will, however, stay with the terms *technical physics* and *technical physicist* in order to articulate the relatedness of the Norwegian grades to the German rather than the English or American system. Concerning the foundation of the *Deutsche Gesellschaft für technische Physik*, see Gehloff, Rukop and Horst, 1920. Concerning technical physics and the technical physicist, see Ramsauer, 1948. See also Chapter 4, Section 4.2.

135 See Tekniska fysikers förening: *Teknisk fysik i Sverige*, 1982.

136 See letters Borelius to Holtsmark, June 2, 1925, Holtsmark to Borelius, June 4, 1925 and Borelius to Holtsmark, September 1, 1925, all archive *NTH-Fysisk institutt*, Eb: 2, Statsarkivet i Trondheim. A proposal for the new career was sent by Holtsmark to the *Professorutvalget* on January 17, 1925.

137 See *Under Dusken* 15/30, September 21, 1929. See also *Komiteen til oppretelsen av en linje for teknisk fysikk* to *Professorutvalget*, February 1926, Eb: 1.

assistant by Holtsmark. The first graduate from technical physicist was Knut Strøm Gundersen in 1932, who had been admitted to civil engineering in 1928. In 1933, Gundersen was appointed technical director in his fathers' well-established instrument company *Gundersen & Løkken,* which produced optical, hydrometic and mathematical instruments.[138]

Altogether, it has to be concluded that the career of the technical physicist, as it was established at NTH in 1929, was, in contrast to the Swedish experiences at KTH, not a success. But Holtsmark managed to do without physics graduates in order to establish his research agendas. A number of research frontiers were shared between physics and chemistry and electrical engineering, respectively, and the graduates of these disciplines could successfully be transformed into physicists. Examples for shared research frontiers between chemistry and physics were radioactive research, spectroscopy and X-ray structural analysis. Electroacoustics represented a shared research frontier between physicists and telecommunication engineers. Electrical engineering became also important for accelerator building.

The first graduate from chemical engineering appointed as assistant at the physics department, who I was able to trace, was Nelius Holte Moxnes in 1920. Moxnes was assistant at NTH until 1922, when he left for the USA, where he worked for Western Electric. In 1924 Moxnes came back to Norway and was appointed as an assistant at the physics department of the University of Oslo.[139] The second chemical engineer who was appointed as an assistant at the physics department was Bjørn Trumpy in 1922. In 1927, Trumpy defended the first doctoral thesis in physics at NTH with the title *Über Intensität und Breite der Spektrallinien.* In 1929 he received a Rockefeller scholarship to study modern physics in Copenhagen and Göttingen. In 1934 Trumpy was appointed Professor of Terrestrial Magnetism and Cosmic Radiation at the Bergen Museum and later Professor of Physics at the University of Bergen. Trumpy was a convincing example that a chemical engineer from NTH could successfully be transformed into a physicist. Other chemical engineers who worked as assistants at the physic department and later submitted their doctoral thesis in physics were Wilhelm Holst, Harald Wergeland, Sverre Westin and Njål Hole. Three of them, Wergeland, Westin and Hole were, after WWII, appointed as professors at the NTH physics department. A number of students

[138] *Gundersen & Løkken* built the differential analyser at the Institute for Theoretical Astrophysics at the University of Oslo in 1939, which was at the time the world's largest differential analyser. See *Vi fra N.T.H.*, 1950, p. 425 and Chapter 4, Section 8.1.

[139] Moxnes later had a research stay at the University of Göttingen and submitted a doctoral thesis with the title *Quantitative chemische Analyse mittels der Absorption der Röntgenstrahlen.* See Hylleraas, 1956, and Brochmann, *Vi fra N.T.H. de første ti kull 1910 - 1919*, 1934, p. 289.

entered the physics department even before they graduated: they carried out the experimental investigations for their final thesis in the physics' laboratories. Most famous of these students was the later Nobel Laureate Lars Onsager. Another chemical engineering student who carried out the work for his thesis at the physics department's X-ray laboratory was Westin. Also students from telecommunication engineering carried out investigations for their final thesis at the physics department, with Vebjørn Tandberg as the most prominent one.[140] The telecommunication engineers were mainly appointed as assistants to construct new research instruments and only three of them stayed in academia at NTH, Reno Berg, Roald Tangen and Matz Jenssen.[141]

The most nonconformist assistant of Holtsmark was Haakon Brækken who built up the department's X-ray laboratory. Brækken started to study technical physics at the Technische Hochschule in Munich in 1923 and came to NTH in 1924, where he registered in chemical engineering. Physics remained his main interest and he was appointed assistant at the physics department in 1926 without having graduated. Brækken developed novel methods and instruments in X-ray crystallography and published a large number of papers. However, he faced problems not possessing a graduate degree when he submitted his doctoral thesis *Über die Kristallstrukturen einiger Verbindungen AB3*. The appointed committee accepted the thesis but demanded that Brækken should pass an exam. Why Brækken never met for the exam remains unclear. In 1931, Brækken went on an eight months study stay at the Bureau of Mines in Washington, D.C. where he learned about new methods of ore exploration. Back in Trondheim he took over the work with establishing the Institute of Geophysical Ore Exploration (*Geofysisk Malmleting*). In 1937 Brækken went on leave from his position as laboratory engineer at NTH to become director of the institute which by then had moved out of the premises of the physics department.[142]

Only at the outbreak of WWII did Holtsmark finally appoint two assistants with a degree in physics, Helmut Ormestad and Hans Vilhelm von Ubitsch. Both had graduated from the University of Oslo. Ormestad carried out model

[140] For Tandberg, see Chapter 4, Section 6. For Westin and Holst, see Chapter 4, Section 8.1. For Wergeland and Hole, see Chapter 5, Section 7.4. and 8. For Trumpy, see Chapter 4, Section 4.1. Unfortunately there is no statistical material about how many students from chemical and telecommunication engineering carried out their experimental investigations at the physics department.

[141] For Berg, see Chapter 4, Section 5. For Tangen, see Chapter 5, Section 7.4. and 8. For Jenssen, see Chapter 4, Section 3.2.

[142] The Institute of Geophysical Ore Exploration was established as an initiative of Holtsmark and NTH Professor of Geology Thoralf Vogt. Brækken was also married to Holtsmark's sister, the painter Karen Holtsmark. For Brækken, see Hole, 1972 and 1982, and archive *NTH-Fysisk institutt*, Y-Haakon Brækkens arkiv, Statsarkivet i Trondheim.

experiments for the large orchestra studio of the Norwegian Broadcasting Corporation as his *Hovedfag*-thesis in 1940, with Holtsmark as his advisor. von Ubitsch had carried out his *Hovedfag*-thesis with Bjørn Trumpy in Bergen and was appointed by Holtsmark on the Van de Graaff accelerator project in 1941.[143]

3.5. Trondheim and the international topography of physics

How did the physicists at Trondheim orient themselves within the changing landscape of physics during the interwar period? The relatively small physics department at Trondheim was a newcomer located in the geographical periphery of Europe. The Norwegian scientific community was rather small compared to its neighbours Sweden and Denmark and other larger and more powerful European nations, such as Germany, Great Britain and France. As we have seen earlier, geoscientific research dominated in Norway and held an internationally high and partly leading position. Laboratory research in physics, in contrast, remained rather weak. Both Stockholm and Copenhagen had managed to establish themselves as international centres of physics: The Royal Swedish Academy of Sciences in Stockholm awarded the Nobel Prizes in Physics and Chemistry. Young researchers like Manne Siegbahn and The Svedberg established internationally leading research laboratories.[144] The most famous and, presumably, most important international scientific research centre of Scandinavia was the Institute of Theoretical Physics in Copenhagen, under the directorship of Niels Bohr.[145] Comparatively large numbers of foreign scientists and students visited these institutions. This international character was never established if even aspired to at the University of Kristiania or the Norwegian Institute of Technology in Trondheim.

Scandinavia played a special role in enabling Norwegian scientists to enter the international scene. The relationship to the larger Scandinavian brothers Sweden and Denmark was ambivalent. On the one hand, Norway wanted to gain and maintain independence. On the other hand, Norway, Sweden and Denmark shared a to a large extent common culture and language. There was a strong sense of a Scandinavian identity that made it easier for Norwegian

[143] For von Ubitsch, see Chapter 5, section 8. For Ormestad, see Chapter 4, Section 5.3.

[144] See, for example, Lindqvist, 1993.

[145] There is a vast amount of literature about Bohr, the Copenhagen Institute and its importance for the development of theoretical physics during the interwar period. See, for example, Robertson, 1979 and Aaserud, 1990.

scientists to try out their skills and findings in the more family-like Scandinavian community. The *Scandinavian Meeting of Natural Scientists* was one of the forums of the Scandinavian community. Swedish and Danish scientists were often chosen as outside members in doctoral committees and committees to appoint professors at the University of Kristiania or at NTH. Niels Bohr and the Institute of Theoretical Physics at Copenhagen were of special importance for Norwegian physicists during the interwar period. Bohr emphasised Scandinavian co-operation and invited Norwegian physicists more regularly than other nationalities. At Copenhagen, Norwegian physicists could be part of one of the world's most influential and dynamic schools of physics. Jan Vaagen has described this special relationship between Norwegian physicists, Niels Bohr and the Copenhagen Institute.[146] Vaagen has divided the Norwegian physicists in the masters (*lærmestre*) and trainees (*lærsvenner*) in their relation to Bohr. The masters were the senior generation of physicists, usually Bohr's generation or older, like Vilhelm Bjerknes and Sem Sæland. During the interwar period they were well established in the Norwegian academic community. Both Bjerknes and Sæland were powerful actors within the politics of Norwegian science, which reflected their relationship with Bohr. The older generation of Norwegian physicists did not participate in the development of quantum mechanics and their correspondence with Bohr was situated on a level of science organisation. The younger generation, the trainees, came to Bohr in order to participate in the research activities and to profit of the research dynamics of the international community at the Copenhagen Institute. The first and most famous of these young Norwegian physicists, who came to Copenhagen in 1920, was Svein Rosseland, a former assistant of Bjerknes at Bergen. Rosseland stayed several years at Copenhagen and became a close co-operator of Bohr, as well as the Swedish physicist Oskar Klein. Other Norwegian physicists of the interwar period who visited the Institute of Theoretical Physics and had a research stay were Johan Holtsmark, Bjørn Trumpy, Egil Hylleraas and Harald Wergeland. Three of these, Holtsmark, Trumpy and Wergeland came from the physics department of NTH.[147]

Germany had traditionally a major cultural influence on Norway. German science and engineering had a high reputation among Norwegians. Norwegian scientists and engineers had studied at German universities and institutes of technology. Norwegian scientists were appointed on chairs at German universities. Vilhelm Bjerknes was appointed as director of the Geophysical

[146] Vaagen, 1985.

[147] We will come back to the importance of Bohr and the Copenhagen Institute for the Van de Graaff accelerator project at NTH in Chapter 5, Section 4 and 7.3. The history of Holtsmark and Faxén's derivation of the first satisfying quantum mechanical theory of electron scattering at Copenhagen in the summer of 1927 is included in Chapter 4, Section 8.1.

Institute at the University of Leipzig in 1912. In 1929 Victor Moritz Goldschmidt was called to the Chair of Mineralogy at the University of Göttingen. The first NTH physicists had studied at least partly in Germany. Sem Sæland's sole contribution to general physics derived from a research stay at the University of Heidelberg. Holtsmark had mainly studied at German universities and was assistant of Bjerknes in Leipzig and Peter Debye in Göttingen. Holtsmark kept his connections and travelled frequently to Germany to visit institutions and colleagues. He also sent his students, including Wilhelm Ramm, Westin, Berg and Wergeland, to Germany. Wergeland stayed for some time with Werner Heisenberg at the University of Leipzig.[148]

As pointed out earlier, the *Norges Tekniske Høgskole* was established according to the German model of *Technische Hochschule*. This had consequences especially for the way the engineering curriculum was organised at NTH. Sæland had Philip Lenard's lectures at Heidelberg as his model of lecturing physics. The demonstration experiments were the dominating element in Lenard's as well as in Sæland's experimental lectures. Most lecture demonstration instruments were bought from Germany. German companies like *Max Kohl* and *E. Leybold's Nachfolger* dominated the market of demonstration and other teaching instruments during the first decade of the 20th century. Furthermore, most textbooks at NTH were German. When asked by the Norwegian Parliament in 1933 whether NTH could buy more English literature, the answer was that NTH used only German textbooks, and that the knowledge of the English language among the engineering students was too poor to allow English textbooks to be introduced.[149] Holtsmark continued to follow a German model of physics teaching in his lectures. He adopted Robert Wichard Pohl's lectures from Göttingen and introduced Pohl's textbooks in the 1930s. Holtsmark continued to acquire German demonstration equipment for the experimental lectures and adopted Pohl's system of lecture experiments. When Sæland and Holtsmark planned to introduce the career training for technical physicists at NTH in the 1920s, the German model of the *technischer Physiker* was followed. Norwegian was usually not understood outside the Scandinavian countries, and scientific articles had to be written in one of the international languages of science, French, English or German, if they should be taken notice of internationally. The orientation of Norwegian scientists towards the German community expressed itself also in the fact that Norwegians predominantly published in German.

Until 1933 Holtsmark published all his scientific papers directed to an international audience in German. In 1933, however, he started to publish in

148 See Chapter 5, Section 7.3.

149 See *Forhandlinger i Stortinget* (nr. 87), March 17, 1933, p. 690-691.

English. The English publications were partly directed towards the British scientific community and partly towards the USA. In the middle of the 1930s, the British physics community became increasingly interesting in terms of Holtsmark's research interests in electron scattering and nuclear physics. Holtsmark went to London and Cambridge in 1934 and his assistants Westin, Ramm and Berg visited London, Cambridge and Manchester in 1935.[150] Around 1930 the dominant position of Germany started to decline and the American scientific community became increasingly important. There were a number of reasons why the USA around this time started to take over as the world's leading scientific community and the centre of gravity of scientific research moved from Europe to the American continent. The strength and domination of the American research community were clear-cut in both of the large research agendas of the NTH physics department during the 1930s, technical acoustics and accelerator based nuclear physics. In the USA, acoustics research was mainly carried out in large corporate laboratories and the European acousticians had little to compete with. Still, it was the German community of acousticians that was strongest on this side of the Atlantic.[151]

In accelerator development, in contrast, the German physicists had little to contribute and the race was mainly decided between the British Cavendish Laboratory and a growing number of American groups. Whereas the Cavendish Laboratory successfully aimed at a relatively small installation, several American groups, especially the Berkley cyclotron laboratory and Robert J. Van de Graaff at MIT in Boston, moved towards large accelerators of hitherto untried dimensions.[152] There were several reasons why Germany was backwards in the development of particle accelerators. The German *Ordinarius*-tradition created many small regional groups and made it difficult to establish large research activities like the Lawrence Berkley Laboratory. Co-operation between electrical engineers and physicists was not common. Potential talents for accelerator development in Germany, such as the electrical engineer and inventor of accelerator designs Rolf Widerøe, and radio tinkers like Manfred von Ardenne, were not mobilised.[153]

150 See Chapter 4, Section 8.1. and Chapter 5, Section 7.3.

151 See Chapter 4, Section 2. For a comparison between the German and the American community see Hagemeyer, 1979.

152 See Heilbron and Seidel, 1989.

153 Bagge and Diebner have written about why nuclear physics and especially accelerator development has been neglected in Germany during the 1930s. See Bagge, Diebner and Jay, 1957, p. 9 ff. For von Ardenne, see von Ardenne, 1987. See also Richter, 1972, concerning research financing in Germany during the interwar period and the several publications of Burghard Weiss concerning German accelerator builders and projects.

In 1933 the national socialist government drained the German physics environment, and many of Germany's foremost scientists were forced to leave the country. Nuclear physics was partly condemned as modern, "non Aryan" physics. Walther Bothe, Germany's foremost experimental nuclear physicists, had to resign from the Heidelberg Chair of Physics under the pressure of Philip Lenard. Bothe moved to the Kaiser Wilhelm Institute of Medical Research, where he built, together with Wolfgang Gentner, Germany's first particle accelerator.[154] Also Werner Heisenberg, who was in the 1930s working on nuclear theory, was blocked from taking over the Chair of Theoretical Physics after Arnold Sommerfeld at the University of Munich.

The American scientific community profited immensely from this brain drain through German and other European scientists who immigrated to the USA. However, not only German, but also Norwegian scientists and engineers immigrated to the USA. The Norwegians did not immigrate because of the political situation, but for economic reasons and better work conditions in the USA. Especially during the 1920s it was difficult for Norwegian engineers to find employment in their home country. In 1924 alone, about 200 Norwegian engineers immigrated to the USA.[155] Most of the émigré engineers were civil engineers and the School of Civil Engineering was known as the "Norwegian American School" (*Den norske Amerikalinje*).[156] Also among the chemical and electrical engineers the numbers of émigré engineers were high. Several Norwegian scientists made careers in the USA, like Svein Rosseland, Harald Ulrik Sverdrup, Odd Dahl and Lars Onsager. Bjørn Trumpy had an offer but declined. Sverdrup declined the first offer of a position at the Department of Terrestrial Magnetism in 1930 but accepted the directorship of the Scripps Institution of Oceanography in 1936.[157] Svein Rosseland and Odd Dahl would be convinced to return to Norway in order to strengthen the local scientific development. Onsager stayed in the USA.

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[154] See Schmidt-Rohr, 1996.

[155] Hanisch and Lange, 1985, p. 295.

[156] Hanisch and Lange, p. 102.

[157] Sverdrup returned to Norway after WWII and became Professor of Geophysics at the University of Oslo in 1949. See Oreskes and Rainger (2000) for Sverdrup's appointment at the Scripps Institution and the denial of security clearance of Sverdrup by the American Navy during WWII.

4. The Age of Electroacoustics

Acoustics, the Academic Radio Club and the electric amplification of science

4.1. Science, technology and society in an era of change:

Radio broadcasting, talking motion pictures, electric amplification and acoustic manipulation

Elektroakustikkens tidsalder - The Age of Electroacoustics was the title of an article published in the Norwegian amateur radio journal *Norsk Radio* in 1930. From about 1930 electroacoustical devices and electroacoustically produced, manipulated and amplified sound seriously entered public and private spheres. Public radio broadcasting had started in America around 1920 and soon became a mass medium.[158] In Europe the development of public radio broadcasting was more conservative and more regulated. The Norwegian Broadcasting Company (*Kringkastingsselskapet A/S*) was first founded in 1925. By then the Norwegian radio amateurs had already been active and organised for several years. It was not before the 1930s that radio broadcasting would become a true mass medium in Norway.

Like radio broadcasting, another medium based on electroacoustic technology, the sound motion picture, was first developed on the other side of the Atlantic. In October of 1927, the Warner Bros. studio at Hollywood

[158] For the beginnings of American broadcasting, see Susan J. Douglas, *Inventing American Broadcasting 1899-1922* (1987). Douglas identified 1922 as the year a "*radio boom*" swept the United States (Douglas, p. XV and 303 ff.). See also H. F. Dahl, 1999, p. 17 ff. for a general introduction.

released the first feature-length talking motion picture, *The Jazz Singer*. This time it took only two years until the first sound motion picture entered Norwegian motion picture theatres: *The Singing Fool* was shown at the *Eldorado* cinema theatre in Oslo in the summer of 1929. In the 1930s many public meeting spaces were also wired with electroacoustic amplification systems for speech and music, like lecture halls, theatres, amusement establishments, sports fields and even public squares. One such version of the public exposure to electroacoustically amplified speech was public orations of the European dictators like Hitler and Mussolini to the broad masses. The propaganda machines of the European interwar dictatorships knew well how to monopolise and utilise the novel electroacoustic media technology in order to make it a powerful tool for mobilising the masses. After the Nazi take-over in 1933, Hitler's speeches dominated the program of a politically synchronised German *Reichsrundfunk*. In the 1930s radio and other electroacoustical means of communication had clearly become a medium of political power.

The general public viewed much of the research conducted in the 1920s and 1930s physics laboratories as rather distant from everyday life. Raman spectroscopy, X-ray crystallography and nuclear physics seemed to have, at first sight, little impact on the life of average citizens. Especially the research related to the new theories of quantum mechanics and relativity was judged as *unanschaulich* (non-vivid, undiscriptive, abstract).[159] These modern theories led to scientific results that were far removed from everyday experience, they were abstract and generally little understood. The research technology used in the laboratories was situated in its time but would otherwise bear little resemblance to everyday technology. Acoustics was different. Everyone living in urban surroundings could observe the effects of the acoustical treatment of architectural spaces. Whether the acoustical experience of a room was positive or negative, pleasant or unpleasant, could be judged and discussed in public. Acoustical experiences depended on the hearing habits of people, which responded to fashions and varied significantly over time. Acoustics is closely linked to music, an important expression of human culture. How music was performed and experienced could vary strongly. Consequently, ideas about the acoustical properties of places for music performance could differ significantly for different communities and individuals. Scientific expertise could not be established in the public space in the same manner as in the secluded laboratories. It was usually not the acousticians, but the musicians and the listeners who would have the last word over judging the acoustical qualities of a concert place. [160] Moreover, electroacoustic technology, which pushed the new

[159] See, for example, Paul Forman's work on quantum mechanics in Germany during the Weimar Republic, summarised in von Meyenn, 1994.

[160] See for example E. Thompson, 1992.

acoustics research, invaded public spaces and even everybody's home. People outside the laboratory world had little use for high-vacuum pumps, Geiger-Müller counters or X-ray tubes. Electroacoustic research instrumentation like microphones, loudspeakers and amplifiers were, in contrast, rather common.

The most common electroacoustic home equipment of the interwar period was by any measure the radio. From its earliest beginnings radio technology was linked to the physics community. The physical bases of wireless communication were found in Maxwellian electrodynamics of the 1870s and Heinrich Hertz' experiments on the propagation of electromagnetic waves through free space in the late 1880s. After Hertz, a number of physicists had worked to realise a communication system based on the Hertzian waves. The understanding of the development of wireless telegraphy as an activity of physicists was well acknowledged by the decision of the Royal Swedish Academy of Sciences to award the 1909 Nobel Prize in Physics to Guglielmo Marconi and Karl Ferdinand Braun. However, the involvement of physicists in radio broadcasting in Norway, like in other countries, was not limited to the technology. The physics community had clearly understood the potential of wireless telegraphy for communication. Vilhelm Bjerknes, who had been Hertz' assistant at Bonn in the early 1890s, had started to organise weather forecasts in Western Norway. Wireless telegraphy was needed both to obtain weather data from far-away locations, as well as to communicate the weather forecast for shipping and fishery.[161] On other occasions Norwegian physicists also became consumers rather than producers of radio technology. Popular scientific lectures were broadcast from the University of Oslo in the lecture series *Universitetets radioforedrag* since 1927. Sem Sæland, Professor of Physics and President of the University of Oslo from 1927 to 1936, was appointed chairman of the Broadcasting Program Commission (*Programrådet*) from 1930 until his death in 1940.[162] With the establishment of a broadcasting station in Trondheim in 1930, the Norwegian Institute of Technology also started a program of popular lectures (*Høiskolens radioforedrag*) featuring Olaf Devik as the representative of the small Trondheim physics community.

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[161] Friedman, 1989, p. 183, and H.F. Dahl, 1999, p. 20. See also Devik, 1971, p. 93 and 107.

[162] H. F. Dahl, 1999, p. 96, 367. The first lecture from the University of Oslo was, however, already broadcast in 1925. See *Universitetet og radio*, *Hallo-Hallo* 1, no. 9, November 20, 1925. See Douglas, 1987, p. 309-310 for radio extension schools of American colleges and universities in the 1920s.

4.2. From mechanics to radio engineering: Acoustics as a changing discipline

" *Auf dem Gebiet der Akustik sind in den letzten Jahren außergewöhnlich große Fortschritte erzielt worden, wobei der Anstoß weitgehend durch rein technische Probleme gegeben wurde. Es liegt hier ein Musterbeispiel dafür vor, wie eng reine und angewandte Physik heute miteinander verbunden sind und wie stark sie sich gegenseitig beinflussen und befruchten. Die reine Akustik ist in erster Linie durch technische Fragestellungen aus ihrem Dornröschenschlaf erweckt worden, und die technische Akustik verdankt ihren Aufschwung zum großen Teil der Tatsache, daß sie auch alle Errungenschaften der reinen Physik in ihre Dienste gestellt hat.* .."

[Erich Waetzmann, 1934][163].

"... *When I [Johan Holtsmark, around 1929] commenced getting a sound laboratory in order at the physics department at Trondheim, technical acoustics was still at its beginning.* ..."

[Johan Holtsmark, 1940][164]

Historians of science have so far directed their attention mainly towards the establishment of modern acoustics in the 19th century. The above quotes by Waetzmann and Holtsmark challenge the common opinion that acoustics was a science mainly developed in the 19th century and only marginally changed in the 20th century. Comprehensive histories of 20th century science have so far failed to address acoustics research and the large changes in both the body of knowledge and the research practices that occurred in this field.[165] Like other

[163] Erich Waetzmann, *Handbuch der Experimentalphysik Band 17, Technische Akustik* (1934), *Vorwort*. Translation of the quotation into English: "*In the field of acoustics, extraordinary progress has been achieved during the last years, where the impetus has been given mainly through technical problems. It is hereby given an example of how close pure and applied physics are connected to each other today and how strongly they influence and inspire each other. Pure acoustics has been awoken out of its long sleep mainly through technical problems, and technical acoustics owes its upswing a great deal to the fact that it has put into service all acquisitions of modern physics.*"

[164] Johan Holtsmark, *resume av videnskapelige arbeider*, November 15, 1940, Niels Bohr Archive, translated from Norwegian.

[165] See for example Brown, Pais and Pippard, 1995, Krige and Pestre, 1997 and Kragh, 1999. Beyer, 1999, provides a comprehensive history of acoustics of both the 19th and 20th century which pays much attention to the research dynamics and the large variety if different research fields within 20th century acoustics. For the history of electroacoustics, see also

experimental research fields of the 20th century, changes and progress in acoustics research cannot be understood without paying attention to the profound changes in its research technology, mainly during the 1920s and 1930s. The interwar period was the time when electrical technology, especially radio technology, entered scientific laboratories. With the electrical research instrumentation, electrical engineers began to play a dominant role in scientific instrument making. With the appearance of the engineer in instrument design and building, the relationship between the instrument maker shop and the scientist was re-defined. With the help of electric circuits, mechanical measurement devices were altered into complex measurement systems and scientific practices in the laboratory, and the laboratory itself, changed significantly. Acoustics was for good reason the first discipline to be taken over by the novel electrical instrumentation originating from wireless, and to be re-shaped into the field of electroacoustics. From the moment when wireless communication started to broadcast the human voice instead of telegraph signals, radio was inseparably connected to acoustics technology. Radio was the embodiment of an electroacoustical technology with the transformation of acoustical signals into electric vibrations in the studio, the broadcasting of these vibrations through the ether and their re-transformation into acoustical signals in the receiver. Through electrical devices and the presence of electrical engineers, the teaching and theoretical understanding of acoustics changed. In the latter half of the 19th century, mechanical analogies would explain the behaviour of electrical principles and machines.[166] In contrast, the 1920s and 1930s were characterised by the emergence and circulation of electrical analogies, especially equivalent circuit diagrams, which were used to represent acoustical systems.

It is usually agreed that modern acoustics was born in the second half of the 19th century.[167] The classical works of acoustics by Hermann von Helmholtz, John Tyndall, Lord Rayleigh and others were written during this

Hunt, 1954. A history of architectural acoustics in America from 1900-1933 is given by Emily Thompson, 2002.

166 Apart from the well-known examples in Maxwell's *Treatise on Electricity and Magnetism* of 1873 historians have paid little attention to the widespread use of mechanical analogies in late 19th century electricity and magnetism research and teaching. A number of examples are found in Oliver Lodge's *Modern Views of Electricity* of 1892 and *Dr. J. Fricks Physikalische Technik oder Anleitung zu Experimentalvorträgen sowie zur Selbstherstellung einfacher Demonstrationsapparate*, including hydromechanical models of Wheatstone bridges, Leyden jars, electric motors and streamline models of electric and magnetic fields. The most prominent Norwegian example of these hydromechanical models were Carl Anton Bjerknes hydrodynamic analogies of electricity and magnetism, see Vilhelm Bjerknes, 1909.

167 Pantalony, 2002, and Beyer, 1998, p. 55 ff.

period. Helmholtz' research in acoustics in the 1860s was oriented towards the physiology of the human hearing and the perception of music. It has to be placed in the context of Helmholtz' program to base physiology on physical concepts.[168] The entire development and research dynamics in acoustics during the last half of the 19th century has to be seen as a part of the project of unifying all fields of physics within a mechanical worldview. As Heinrich Hertz, one of the most recognised physicists of the late 19th century, had put it: "*All physicists agree that it is the task of physics to ascribe all phenomena of nature to the simple laws of mechanics. ...*"[169] In contrast with electrodynamics, where Hertz had made crucial contributions, acousticians proved to be very successful in reducing all known sound phenomena to the simple laws of mechanics. All acoustical phenomena could be explained as mechanical vibration of matter. Following the assumption that all riddles of sound were solved, many researchers abandoned acoustics research in the 1890s. The study of sound seemed to have not much new to offer to academia. Despite technical developments like the telephone and the phonograph, acoustics was judged not to have great industrial importance.[170] In the first two decades of the 20th century acoustics continued to be academically, by and large, a disregarded subject.[171]

There were basically two interconnected reasons that triggered the re-birth of acoustics in the mid-1920s. Both had to do with the development and propagation of electroacoustic technology:

- Electroacoustics entered acoustics instrumentation. The novel electroacoustics had to offer more powerful and more accurate devices for experimental research than the old mechanically based equipment. Furthermore, these electroacoustic devices were new and exciting and could stimulate young scientists who were experienced in amateur radio. By 1925 everyone was interested in the new possibilities and application of the novel tools from electrical science.[172] The development of acoustics research instrumentation will be treated in the following section in greater detail.

[168] See among others Pantalony, 2002, p. 58.

[169] Hertz, 1894, p. XXIII, translated from German.

[170] See Pantalony, 2002, p. 45 and 49.

[171] R. Bruce Lindsay, 1945, cited by Beyer, 1998, p. 177. There were, however, exceptions, for example underwater acoustics: "*The study of underwater sounds was increased as a result of two modern catastrophes-the sinking of the Titanic in 1912 and the onset of World War I in 1914. ...*" (Beyer, p. 197).

[172] Beyer, p. 177.

- New communication and media technologies, such as radio broadcasting and sound motion picture, were technically based on electroacoustical devices. At the same time they also required a good deal of acoustic research in order to be realised. In the 1920s and 1930s the motion picture industry and radio broadcasting were among the most important clients for acoustics research and consulting. Acoustics, a discipline that seemed to be boring and sufficiently explored, suddenly presented a lot of new opportunities. It is in this context we have to understand Holtsmark when he stated that research in technical acoustics in the 1920s was just at its beginning. Most of the new acoustics research was not carried out at universities but in corporate research laboratories. Especially in the USA electroacoustical media technology put new demands on acoustics. Broadcasting studios and film studios had to possess certain acoustical qualities in order to carry a certain acoustical impression to the listeners. These acoustical properties were often reached by employing acoustically engineered materials and construction designs. But acoustical manipulation did not stop with efforts to change the physical construction of architectural spaces. In recording studios for broadcasting and sound motion picture, electrical manipulation of sound was used in order to produce a certain sound image artificially. Consequently, certain *acoustical situations* were not *real* but produced artificially in the electroacoustical sound laboratory.

In the first half of the 20th century the field of acoustics started to split up into several sub-disciplines according to its different applications. More or less separate research fields like ultrasonic sound, underwater sound, bioacoustics and psychological acoustics developed. With reference to the research in Trondheim we will mainly concentrate on architectural acoustics, the acoustics of construction materials and other acoustical issues connected to radio broadcasting and sound motion picture theatres. Related to these issues were also the fields of noise control and physiological acoustics as well as psychological acoustics. There was a strong connection between the fields of architectural acoustics, the study of the properties of construction materials, the construction of scientific instrumentation and the development of technology for production, recording and reproduction of sound for media-technology such as radio, sound motion picture and the electric amplification of sound for speech and music. Internationally there were several heavy players moving into the scene of electroacoustics and communication technology research. Largest, and in the Norwegian context most important were the institutions in the USA and Germany.

In the 1920s and 1930s the USA were undisputedly leading in electroacoustics research and development as well as in communication and media technology. Most of the research in the USA was not carried out at universities or public research institutes, but at corporate laboratories. The world's largest research institution in this field was the Bell Telephone

Laboratories of the American Telephone and Telegraph Company (AT&T). Throughout most of the 20th century AT&T held a private monopoly of telephone services in the USA and made its own subsidiary, Western Electric, into its sole source for the purchasing of telephone equipment. Apart from telephony, AT&T was also involved, if not leading, in the research & development of other electroacoustical technologies in America, such as radio, sound recording and sound motion picture.[173] *The Acoustical Society of America* was founded in 1928. Characteristically, the majority of its members did not belong to public institutions but were affiliated with the industry. Most of the Society's members were Americans, but a significant number of foreign scientists and engineers represented the international community. The Acoustical Society of America soon became the most powerful acoustical society and its *Journal of the Acoustical Society of America* became the most important scientific journal in the field.

The German scene of acoustics research during the 1920s was clearly second compared to the USA. The Siemens & Halske Company supported Germany's largest number of research and development laboratories. The Siemens laboratories were, however, splintered into many small units. In 1925 Siemens' central research laboratory employed 140 scientists and engineers, which was only a tenth of the research staff at the Bell Telephone Laboratories.[174] The *AEG Forschungsinstitut* was established in Berlin in 1928 under the leadership of Carl Ramsauer with the mission to strengthen fundamental research within the corporate laboratories. In contrast to the Bell Telephone Laboratories, Siemens and the *Allgemeine Elektrizitätsgesellschaft* (AEG) engaged in a broad variety of electrical manufacturing, and communication technology only made a small portion of their concern. Control over radio broadcasting in Germany was monopolised by the state and executed by the *Telegraphentechnisches Reichsamt* of the *Reichspost*, founded around 1920.[175] In 1923, the *Telegraphentechnisches Reichsamt*, which was also responsible for telephone and telegraph service in Germany, employed 125

[173] The Bell Telephone Laboratories were organised in 1925 to consolidate research laboratories from AT&T and Western Electric. For the telephone monopoly of AT&T, see Claude Fischer, 1992. For the development of American Broadcasting, see Douglas, 1987. For sound recording in America, see Morton, 2000. For the development of sound movie by AT&T and Hollywood film companies, see Thompson, 1997. For numbers of researchers and other employees at the Bell Laboratories and other research & development laboratories, see Hagemeyer, 1979, Chapter II, Section 1, especially Table 2 and 4. For the development of digital computers at the Bell Laboratories in the late 1930s, see Ceruzzi, 1983, Chapter 4.

[174] Hagemeyer, 1979, Chapter II, Section 1.1., Table 2.

[175] Hagemeyer, 1979, Chapter II, Section 1.3.

scientists and engineers in its research and development laboratories, which was a comparatively low number.

Karl Willy Wagner, the director of the *Telegraphentechnisches Reichsamt*, left the *Reichsamt* in 1927 in order to initiate the *Heinrich Hertz Institut für Schwingungsforschung*. The foundation of the *Heinrich Hertz Institut für Schwingungsforschung* was an explicit attempt of Wagner and others in the German research community to catch up and compete with the Americans. *The Heinrich Hertz Institut* was, however, far from being a copy of the structures and practices of American research institutions. The strong links between acoustics, communication technologies like telegraphy and telephone, radio broadcasting and electric sound generation and amplification lead to the emergence of the interdisciplinary research field of *Schwingungsforschung* (oscillation and vibration research) in Germany.[176] The *Hertz Institut's* declared goal was to bridge the gap between the different fields of oscillation research such as mechanical vibrations, electromagnetic oscillations and acoustics.[177] Erwin Meyer, who became Germany's most recognised acoustician, was the head of the Department of Acoustics at the *Heinrich Hertz Institut*. Another scientist at the *Heinrich Hertz Institut* was the telecommunication engineer Helmut Schreyer who influenced Konrad Zuse on the design of his electrical calculating machine.[178] Many important articles in acoustics were published in the *Elektrische Nachrichtentechnik*, which was an expression of how closely related acoustics and telecommunication engineering was at the time.

Characteristically for Germany, the research and development undertakings of the German electrical industry were much closer connected to the public academic institutions, especially the *Technischen Hochschulen*, than in the USA. In the USA the new type of acoustics emerging in the 1920s was generally identified as electroacoustics, referring to the new type of electroacoustics instrumentation and the use of electrical analogies. In Germany, in contrast, the notion of *technische Akustik* (technical acoustics) was more common, referring to its predominantly applied character.[179] The lines between the *Technische Hochschule Berlin-Charlottenburg* and the *Heinrich*

[176] See Hagemeyer, 1979, p. 54 and p. 70.

[177] Salinger, 1930.

[178] Schreyer motivated Zuse to build an electrical calculating machine based on relays instead of a mechanical machine. Schreyer also worked on his own electrical calculating machine at the *Heinrich Hertz Institut*. For a detailed account on Zuse's calculating machine and Schreyer's contributions see Ceruzzi, 1983, Chapter 2, *Computers in Germany*. See also Schreyer manuscript, 1977. For Schreyer at the *Heinrich Hertz Institut*, see internet-page by Peter Noll: *Helmut Schreyer*, 2001.

[179] See for example Waetzmann, *Handbuch der Experimentalphysik Band 17*, *Technische Akustik* (1934), as cited above, and Hunt, *Electroacoustics* (1954).

Hertz Institut were not sharply drawn. Scientists at the *Heinrich Hertz Institut* were at the same time professors and lecturers at the Technische Hochschule. Also Carl Ramsauer, director of the *AEG Forschungsinstitut*, was from 1931 appointed as Honorary Professor at the *Technische Hochschule Berlin-Charlottenburg*.

With the appearance and quick dominance of electroacoustical devices, electrical engineers were entering the scene of acoustical research. But whereas electrical instrument building was seen as a domain of electrical engineers, the scene of acoustical research was still to a large degree dominated by physicists, as in the USA by Paul Sabine, Vern Knudsen and Carl Eyring. The situation was somewhat similar in Germany, where technical acoustics and electroacoustics was seen as a field of applied physics rather than engineering. This viewpoint was supported with the appointment of Erwin Meyer on Göttingen's prestigious Chair of Applied Physics in 1947. In 1943, Carl Ramsauer characterised electroacoustics as a field of physics that was in the process of breaking away and becoming its own technical discipline.[180] There was, however, a certain distance experienced between acousticians and other parts of the physics community. The formation of the *Acoustical Society of America* in 1928 was partly an expression of this distance since some acousticians did not see themselves as well represented in the *American Physical Society*.[181]

180 Ramsauer, 1943, 1949 p. 3: "... *Die Elektroakustik ist zur Zeit dabei sich von der Physik loszulösen und eine selbstständige Technik zu werden.* ..." See also Fig. 4.1.

181 Beyer, 1999, p. 232.

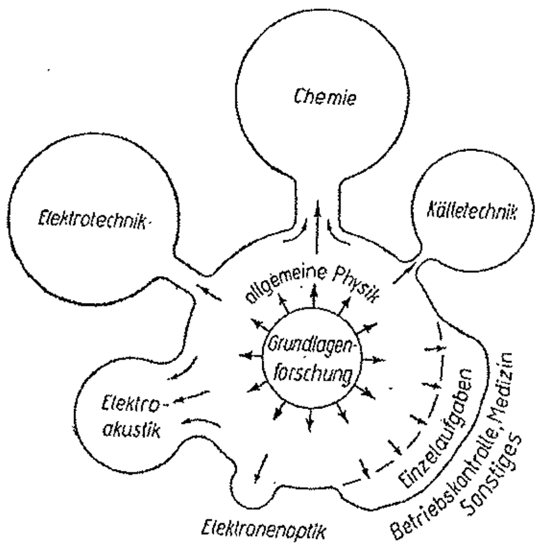


Fig. 4.1: Ramsauer's diagram about the relation between pure research, applied physics, technology and chemistry (Ramsauer, 1943 (1945) p. 3). In the diagram electroacoustics represented a field of physics that was in the process of breaking away and becoming its own technical discipline. It was largely agreed in the scientific community that technical acoustics and electroacoustics was still a part of physics. Ramsauer's views about the relationship between science and technology as well as other disciplines like chemistry were, however, highly controversial. See, for example Richard Vieweg, 1948. Vieweg named the figure ironically *Ramsauersche Molluske* - Ramsauer's molluscs (Vieweg, 1948, p. 16).

4.2.1. Electroacoustics and the focus on instrumentation

Research and teaching in acoustics as well as its conceptual understanding during the 19th and the first half of the 20th century were closely linked to acoustics' research and teaching instrumentation. It is therefore necessary to take a closer look at the dynamics of acoustical instrument development from the 19th century up to around 1930. Physics cabinets and acoustic laboratories in the 19th century were filled with acoustical precision instruments based on carefully crafted mechanics. The tuning fork became the first precision tone generator, and the Helmholtz resonator the first precision tone detector. Other important instruments were siren disks, introduced by Cagniard de la Tour, as well as pipes and whistles. Instrument makers like Rudolph Koenig developed these into precision measurement and demonstration apparatus like the tuning fork tonemeter and the harmonic analyser. With devices like the rotating mirror, the manometric flame capsule, the Lissajous comparator and the Chlandi plates, vibrations could be made visible.[182] The most important sound detecting instrument was, however, the human ear. Instruments like Helmholtz' resonators embodied refined theory and served to propagate the mechanical understanding of sounds, like Helmholtz' theory of timbre.[183] Instruments played a major role in the understanding of acoustics as well as in its pedagogy. Physics teaching collections at schools and universities usually contained a large amount of these mechanical-acoustical instruments, which elegantly showed the character of sounds as a form of mechanic vibration.

When acoustics had its comeback as an academic discipline in the 1920s and 1930s, there was a strong focus on revolutionary instrumentation in acoustical research, which bore little resemblance to the earlier apparatus crafted in brass, steel and wood. Basically all the mechanical-acoustical instruments were replaced by electroacoustical devices. These electroacoustical artefacts surely did not appear out of a vacuum. Most of them had already been invented by the end of the 19th century or around the turn of the century. These early electroacoustical instruments were not sensitive, powerful or accurate enough to compete with mechanical precision instruments or the human ear. Accordingly, they were little used in acoustics research. During the following decades, the development of electroacoustical devices was pushed by the progress of telephony and radio, and military research during World War I. By the mid 1920s electroacoustical instrumentation was powerful, accurate and sensitive enough to rule out all the mechanical-acoustical devices. Moreover, they represented a novel and modern research technology. Previous mechanical instrumentation was linked to precision craftsmanship and the manufacturing of musical instruments. Modern electroacoustical instrumentation was inextricably interwoven with the powerful electrical industry and the progress of mass media. Whereas the old acoustics was linked to high culture, the new acoustics was linked to industrial production and mass culture.

Robert Beyer has identified six important electroacoustical devices, which were well developed by 1925 and which laid the ground for the new acoustical research: the microphone, the loudspeaker, the amplifier, the vacuum tube, the electrical oscillator and the cathode ray oscilloscope.[184] The transforming of mechanical into electrical measurement principles became probably most visible with the development of the oscilloscope, which transformed from a

182 Pantalony, p. 70, 27, 46-47, 144 ff. and 80 ff.

183 See Pantalony, p. 99, for the citation of Gaston Bachelard's famous statement in this context.

184 Beyer, 1998, p. 178.

rotating mirror device that dissolved mechanical vibrations into the cathode ray oscilloscope that dissolved electrical signals. It is beyond the scope of this chapter to go into the historical development of all these devices. Regarding the mechanical-acoustical instruments, the accuracy and performance of their mechanical parts was of major importance. In contrast, the performance of the electroacoustical devices depended on electrical circuit design and on the electrical performance of the different components that were usually mass-produced. An important and critical factor for the features of many electroacoustical devices was the performance of the amplifier tubes used in their circuit.

We might add a couple of instruments from sound recording and playback technology to Beyer's list of important electroacoustical devices. The gramophone, developed from Edison's purely mechanical phonograph, had its comeback by the electromagnetic or piezoelectric pick-up. Gramophone records with test tones were widely used in acoustics measurements. Magnetic recording was developed from the late 1920s, but rather as commercial business devices than as a research technology. Also optical systems, which were generally used on the sound tracks of the talking motion pictures, did not seem to play a significant role in acoustics research of the 1920s and 1930s.[185]

Many of the electroacoustical instruments could be bought ready-made. It was much more common, however, to buy mass fabricated components such as amplifier tubes, coils, condensers, relays, etc., and to assemble the instruments in the workshop. The suppliers for this new type of instrumentation, or instrumentation components, were usually not the traditional scientific instrument companies, but local radio suppliers. The practice of self-construction of scientific instruments in the manner of amateur-radio was used for several reasons. Building the equipment yourself was always cheaper than buying. The electrical engineers engaged in instrument making assembled the devices in a tradition of amateur radio. Descriptions of new instruments and circuit designs turned up in amateur and professional journals long before these instruments could be bought locally. This was particularly true for new developments from America. Ordering instruments from across the Atlantic to Norway, for example, was a difficult and time-consuming affair.

The electrical instrumentation of acoustics did not only have an influence on experimentation but also on ways of thinking about acoustics. In the 19th century, the mechanical world picture was dominant. Acoustics as a system of truly mechanical phenomena was a standard example to support the mechanical worldview. This partly explains the large amount of acoustical apparatus in demonstration collections of physics teaching institutions. Electroacoustics did

185 For the history of sound recording technology and culture in America, see David Morton, 2000.

not alter the character of sound as an inherently mechanical phenomenon, as it was discovered in the previous century. However, acoustics research and consulting became invaded by electrical instrumentation, by electrical manipulation of sound and, not to forget, by electrical engineers. The electrical engineers were trained to understand complex technical systems in integrated circuits. In electrical instrumentation, sound was transformed into electrical vibrations and transmitted as electrical signals. In the sound laboratories of Hollywood and the broadcasting studios as well as in research laboratories, acoustical effects were produced purely electrically. This electrification of the acoustical laboratory did not leave the representation of acoustic phenomena unchanged, as they were presented in publications, textbooks and classrooms. Electrical engineers and physicists trained in electrical instrumentation could understand acoustical phenomena much easier when they were translated into equivalent circuit diagrams. Tables were compiled to translate every acoustical variable into an equivalent electrical one. The schematic organisation of the equivalent circuit diagram was able to offer a structured presentation of complicated affairs. The equivalent circuit diagram also made it easy to design real circuits for the electrical generation and manipulation of sound. Consequently, electroacoustics became much more than a research technology and evolved from the laboratory into a new way of thinking about acoustics.[186]

We will now turn from the general introduction to the local history of how practices of electroacoustics research instrumentation became established at the physics department of NTH. We will begin with the local establishment of amateur radio practices and the foundation of the Academic Radio Club.

4.3. The boys in the radio attic: The Academic Radio Club and the Student Society

The history of amateur wireless telegraphy can be traced back to around the turn of the 20th century and thereby to the very beginnings of wireless technology itself.[187] During the following decades, many young boys and male teenagers eagerly got involved in the building of wireless apparatus such as crystal detectors and spark transmitters. Countless numbers of amateur radio clubs were founded around the world. In these clubs the amateurs organised

[186] See Hunt, 1954, Thompson, 1997 p. 623 f., and Beyer, 1999 p. 282 ff. for the use of equivalent circuit diagrams in the study of music instruments.

[187] See, for example, Douglas, 1987, p. 187 ff.

with fellow enthusiasts in order to share their activities, such as constructing their own radio transmitters and receivers and communicating with other radio amateurs all over the world. To talk in real time through the ether was a fascinating experience. Most radio amateurs were, however, more enthusiastic about the technical than the communicative aspects of radio broadcasting. The development of a strong identity and peculiar communication codes emerging from amateur broadcasting conventions laid the grounds for a rather closed society of radio amateurs, or *hams*. With the strong focus on the technical aspects of radio the amateur clubs were predominantly boys clubs, largely shut off to girls. The amateur radio movement was arguably strongest in the USA where the amateur activities were the least restricted and public radio broadcasting had already started around 1920.[188] In European countries like Germany, the Netherlands and Norway public radio broadcasting came later and authorities heavily restricted amateur activities, at time it was an altogether illegal activity.[189] In Norway, it was illegal to listen to radio from 1914 until 1924, but in the 1920s the prohibition was not observed and the law was not enforced.[190]

The first Norwegian amateur radio club was *Norsk Radio Klub*, founded in Kristiania (later Oslo) in 1922. Within the next few years amateur radio clubs were founded throughout the country. Mainly electrical engineering students founded the Academic Radio Club (*Akademisk Radioklubb*) at NTH in November 1923. In 1924, different Norwegian clubs organised themselves in the *Norsk Radio Forbund*. In 1928 the *Norsk Radio Relæ Liga (NRRL - Norwegian Radio Relay League)* was founded with 28 members and became the Norwegian representative in the *International Amateur Radio Union (IARU)*. The Academic Radio Club was neither bigger nor more active than other amateur radio clubs in Norway. What distinguished the Academic Radio Club from other amateur radio clubs was that their members were *professional* electrical engineering students. Many of the electrical engineering students of the 1920s had received their enthusiasm for the study subject through their teenage amateur radio-activities. They moved around in an academic environment and would soon belong to the elite of Norway's growing electrical industry and technical-administrative complex.[191]

188 For the history of American amateur radio, see Douglas, 1987, p. 187 ff. and 292 ff.

189 See for example Manfred von Ardenne, 1987, p. 47 ff., particularly p. 55-57 and p. 62-63.

190 H. F. Dahl, 1999, p. 33 ff.

191 See Dahl and Svendsen, 1995 and interview with Tangen, 1990. Jeff Hughes has described the amateur radio scene of the 1920s at Cambridge University as far more ambitious than the *ordinary* radio amateur. "... *Being an amateur in Cambridge was a serious business*" (Jeff Hughes, 1993, Chapter 4, Section 3). There is, however, no evidence for a similar kind

In 1923, the same year the Academic Radio Club was founded, two chairs related to radio were assigned at NTH. Ragnar Sigvald Skancke was appointed as the first Professor of Telecommunication Engineering (*svakstrømteknikk*) in July 1923. Skancke had already been lecturer in electrical engineering at NTH from 1917 to 1918. In August 1923 Johan Peter Holtsmark was appointed as Sem Sæland's successor to the Chair of Physics. Only 29 years old, Johan Holtsmark was NTH's youngest professor. In the early years of the Academic Radio Club, Holtsmark was not much older than many of the students engaged in the club. Thorleif Dovland, the student who founded the club in 1923, was only three years younger than Holtsmark. In the first two years of its existence there was little activity to report from the Academic Radio Club. The number of members, however, had already grown to 65 by 1924.

In 1925, when the new physics building in Trondheim was opened, the radio amateurs were allowed into the spacious premises to organise their activities. Probably more important and more effective was that they were allowed to invade the physics workshop with amateur radio technology. Holtsmark as the head of the department did not only tolerate, but participated actively in the amateur radio-activities. We will come back to this aspect later.

Even though technical aspects dominated the activities of the Academic Radio Club, the radio amateurs were also a social community and an integral part of the student social life. The Academic Radio Club was a part of the Trondheim Student Society (*Studentersamfundet i Trondhjem*).

4.3.1. The spirits of the Trondheim Student Society

When the Norwegian Institute of Technology encountered Trondheim in 1910, the Mid Norwegian city advanced from its provincial character to become the national centre for engineering expertise and engineering education. It also became a student city. Every year, a new vintage of fresh students from all over Norway invaded the city and would call it, at least for the next four years, their home. Besides their studies in the lecture halls, at the drawing boards and at the workbenches, the youngsters were also searching for a social life and not the least, a social identity as engineering students. The role model for student life, student culture and student identity was given by the University of Kristiania (later Oslo) and the Kristiania Student Society. The engineering students at Trondheim, about 500 km north of Kristiania, Norway's cultural and political

of elitism regarding non-academic radio amateurs among the members of the Trondheim Academic Radio Club.

metropolis were, however, eager to develop their independent cultural and academic traditions. The first students of NTH, arriving in summer of 1910, soon understood the need for a local student society.

Studentersamfundet i Trondhjem, the Trondheim Student Society was founded already on October 1, 1910. It became the social heart of academic student life. With the support of NTH's first president, Sem Sæland, the Student Society expanded its activities at a steady pace. In 1912, the Society bought the first Student House in the centre of the city. The Student Society's activities were central in creating a common identity of being an engineering student in Trondheim. The Student Society was also creating an academic atmosphere and academic traditions. NTH soon became known for its rich student social life. Former NTH students later frequently remembered the life at the Student Society as the best and even most important part of being an engineering student in Trondheim. The Student Society also constituted a powerful and effective network among the students who would later move into key positions in Norway's industry and technical-administrative complex. Social ties from the student times often lasted throughout life and could be re-activated or mobilised when needed. A strong common identity characterised the brotherhood of NTH graduates, largely created through the academic and social activities of the Student Society.[192]

The Student Society's Saturday Meetings (*Lørdagsmøter*) balanced the general absence of humanist agendas in the engineering curriculum with debates about social, cultural and political issues, often with invited national and international speakers. Many activities, like theatre plays, revues, festivities and musical arrangements were organised in clubs, or gangs, as they were called. The Academic Radio Club was one of these gangs. The Academic Radio Club, however, was different from the other clubs inasmuch as it connected the technical world of radio engineering with the student social life. Other gangs like theatre or the student choir generally lacked such strong engineering affiliations. In the following section we will look more closely at the activities of the Academic Radio Club within the Student Society. The student magazine *Under Dusken* was started in 1914 and served as a student organ for news and debate. *Under Dusken* occasionally reported on the Academic Radio Club meetings.

[192] See especially *Vi fra N.T.H. - de neste ti kull 1920 - 1929* (1950), and the comments of many of the NTH-graduates about the importance of the student life and the brotherhood at the Student Society.

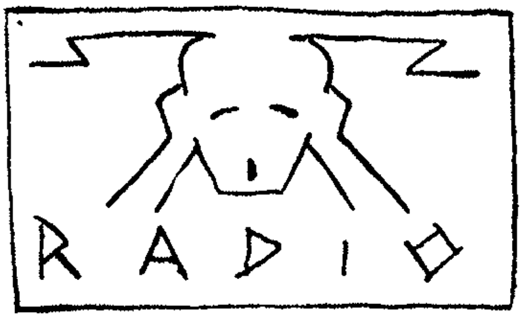


Fig. 4.2: Engraving used in the column *Akademisk Radioklubb* in the Trondheim student magazine *Under Dusken* (UD 13/25, no. 4, 1927, p. 62).

A festivity week, the Student Week (*UKA*) was arranged for the first time in 1917 and became an annual activity to raise money for the Society and particularly for a planned new and bigger building. The new Student House was built in the late 1920s and opened in October 1929 in the presence of the Norwegian crown prince as the most prominent guest. The Student Society was mainly a social meeting place for NTH's students. Membership and participation was, however, not limited to students alone but also open to NTH's professors and lecturers as well as to the academic bourgeoisie of Trondheim.[193]

The student world of NTH was almost exclusively male dominated. There was no legislation that would prohibit women to study engineering subjects, but the career was not too appealing to teenage girls. Up to the 1930s only nine female engineers had graduated from NTH. In many semesters female students were not represented at all. Characteristically enough, the female students of NTH were enrolled in only two departments. Until 1929, seven women had graduated in chemical engineering and two in architecture.[194] Chemistry was a discipline that seemed to have appeal to women since a number of female

[193] But the Trondheim Student Society was far from open to everybody. Students of the Norwegian Teacher College (*Norges Lærerhøiskole*) in Trondheim wanted to join the Student Society, but they were refused. See Brochmann, 1935, p. 355-356, and Kirkhusmo, 1982, p. 66-68. Kirkhusmo refers to little contact and a certain tension between the students at the teacher college and at NTH. The students at the Teacher College were not seen as academics since many of then laced the *artium*, which was the Norwegian school-graduate degree to enrol as a university or NTH-student. Not surprisingly, the teacher college students on their behalf did not appreciate the "tone or milieu" of the NTH Student Society.

[194] See *NTH-beretninger*.

chemists, mainly from the field of radiochemistry, had managed to reach international recognition. The most known and most recognised of these was Marie Curie, who won the Nobel Prizes in both Physics and Chemistry in 1903 and 1911. One of Marie Curie's students was the Norwegian Ellen Gleditsch. The University of Kristiania appointed Gleditsch as lecturer in radiochemistry in 1916 and she became a professor in 1929. Other recognised female radiochemists of the interwar period were Marie's daughter Irène Joliot-Curie and Austrian Lise Meitner. These examples suggested that a career as a woman chemist was possible. Also at the architecture department of NTH, the appearance of women was not totally uncommon. Apart from the few regular female students some young women from Trondheim families participated in the architecture department's classes in freehand drawing, watercolour painting and nude painting. However, until WWII most departments at NTH went on without any female students. This was particularly true for all subjects associated with machine engineering. As a consequence of the absence of female students, the Student Society was run exclusively by male students. For the festivities young women from Trondheim and around were invited. The first invited female speaker in the Society was the writer Sigrid Undset in 1914. Undset received the Nobel Prize in Literature in 1928. In 1917, one of the first female chemical engineering students, Margot Dorenfeld, was elected into the Student Society's executive committee. Dorenfeld resigned shortly after her election but remained active in the Student Society.

Quite a few names affiliated with the physics department can be found among the active members of the Student Society. Sem Sæland was one of the Society's main supporters in its initial stage. He was well known for his talent as a public speaker and his abilities as an organiser and science politician. For Sæland, the Student Society was critical in the project to establish an academic culture in Trondheim similar to Kristiania and to make NTH one of the main culture-bearing institutions of the young country.[195] Here the technical and industrial engineering sciences could meet with the fine arts and political and cultural discourses. For his merits Sæland was honoured with the highest order of the Student Society, the knighthood of *De sorte Faars Ridder Skab*. He was titled *The Governor of The Valley of the Knights*.[196] Olaf Devik involved himself in more practical matters of the Society after he came to NTH as a lecturer in 1922. He became a member of the Society's executive committee in 1926 and was deputy chief of the financial committee in 1930 when the new Student House had opened.[197] Some members of the Student Society's

195 See for example Rønneberg, 1960, p. 236.

196 Brochmann, 1935, p. 420.

197 Brochmann, 1935, p. 226 and p. 323.

executive committee became assistants at the physics department. Haakon Brækken, who built up the X-ray laboratory, was a member of the executive committee in 1927.[198] Fredrik Møller, who according to Helmer Dahl had built loudspeakers at the physics department, was a known actor in the student theatre and head of the theatre during the student week of 1927.[199] Møller also built the spotlight system for the stage of the new Student House.[200] Helmer Dahl was a member of the executive committee in 1931 and president of the Student Society in 1934, when he already was a research assistant.[201] Wilhelm Ramm, who headed the construction of the Van de Graaff accelerator at the physics department from 1934 to 1936, was a member of the Student Society's executive committee in 1933.[202]

A number of the NTH professors engaged in the Student Society and were popular personalities, such as Adolf Watzinger, Professor of Machine Engineering and Johan Vogt, Professor of Mineralogy and Geology. Professor Holtsmark, Sem Sæland's successor on the Chair of Physics, did not engage himself to the same extent in the academic student life of the Student Society. There is no reference to Holtsmark's presence at any of the Student Society's meetings. The publicity of the Student Society's meetings did not seem to have met Holtsmark's personal style of social activity. But behind the scenes Holtsmark became a steady but silent supporter of what seems to have become in the 1930s one of the Student Society's most active clubs, the Academic Radio Club.

198 Brochmann, 1935, p. 227.

199 Brochmann, 1935, p. 287, Devik, 1960, p. 316 and Dahl in Solum, 1976, p. 37.

200 Møller constructed a new type of light regulator and transformer that became his diploma thesis. See Rønneberg, 1960, p. 130, p. 150.

201 Brochmann, 1935, p. 349, p. 371.

202 Brochmann, 1935, p. 327.

4.3.2. Wiring the Student Society:
The Radio Club in-between the technical and the social

In Georg Brochmann's book about the Trondheim Student Society of 1935, the telecommunication engineer Matz Jenssen wrote the following about the Academic Radio Club:

> "*THE RADIO CLUB. - Then the stage [of the Student Society] has a little neighbour state which is called The Radio Club; it is often co-operating with Stage Management, but otherwise maintains strongly its integrity and sovereignty. Like other small states in a similar position it can look back on an adventurous and honourable history. This began in the radio-year of The Lord [19]23 with « The Academic Radio Club »; in '26 the club built a provisional broadcaster which was heard all over Northern Europe - with an input of 0,3 kW! This is worth to be remembered, among other things because the word « Broadcaster »* [*Kringkaster* in Norwegian] *came from this, after broadcasting station* [Kringkastingstasjon], *since the radio announcer became so tired of it that he resolutely shortened the word.*
>
> *... It became the radio folks' duty to look after the Student Society's telephone- and loudspeaker arrangement, apart from having their small short wave transmitter and their private apparatus. The attic became a workshop where the space was utilised until its last bit, and from there, new cables and new loudspeakers constantly originated, each one bigger and stranger than the other. And sound there was; it is told with the claim of trust that the largest loudspeaker got the concrete dome to vibrate noticeably!- After a while the club also took over other assignments, the illuminated advertising for the student's week* (studenteruken) *was, for example, their achievement. One should have seen the guys at work, on the roof of the samfundet on a real bitter November night, in order to understand what voluntary work means.*
>
> *As perceived, the Academic Radio Club ceased from being a club in the usual sense; should one give a name to it, would it have to be Working-Club, because it carries on work as a sports club carries on sports, as passionate, as unselfish, and with the same sense for amateur values. ...*"
>
> [Matz N. Jenssen, 1935][203]

Jenssen was a member of the Student Society's executive committee in 1933, together with Wilhelm Ramm, who later worked for Holtsmark on the construction of the Van de Graaff accelerator. Jenssen graduated from

[203] Matz N. Jenssen, *Daglig liv i "Samfundet"*, in Brochmann, 1935, p. 399-400, translated from Norwegian.

telecommunication engineering in 1934 and worked until 1937 for Haakon Brækken at the newly established Institute of Geophysical Ore Exploration (*Geofysisk Malmleting*), which was an offspring of the physics department. He also worked among other places, at the Christian Michelsen Institute in Bergen and the Tandberg Radio Factory before being appointed first Professor of Radio Techniques at NTH in 1950.[204] Jenssen's career biography was in several ways representative of many of the electrical engineering student members of the Academic Radio Club who became assistants for the many activities of NTH's physics department under Holtsmark.

Jenssen's narrative shows that the activities of the Academic Radio Club in the 1930s had by large exceeded pure amateur radio activities. The club had conquered other realms of the Student Society, such as the wiring of the Student House with a telephone system and an ever-extending electroacoustic amplification system as well as electric illumination of the stage and other spaces. The radio amateurs had supplied the new Student House with one of Norway's first electroacoustic amplification systems, which they assembled at the physics department's workshop. With the help of this amplification system, a telephone tale by Odd Nansen from New York was broadcasted for the opening of the new Student House on October 1, 1929. The transmission of this telephone tale from New York over the Atlantic to Trondheim attracted even international attention.[205] These accelerating activities were later organised in other groups and gangs.

Through these activities, the Academic Radio Club bridged the gap between the material engineering culture of NTH's laboratories and workbenches and the social and artistic life of the Student Society. The link between the engineering practices on one side and the social and artistic practices on the other side was constituted by wiring the Student House with modern communication and entertainment technology, illuminating its stage, amplifying its debates, theatre plays and concerts and enriching its festivities with electroacoustically amplified music. In its way, the Student Society's wiring with electroacoustic technology exemplified in a microcosm what happened in the Norwegian society and else where at large. Electroacoustic technology as means of communication, mass media and mass entertainment increasingly entered public and private spheres. In yet another way, the acceleration of activities of the Academic Radio Club at the Student Society into the wiring of other realms than radio represented the changes of scientific instrument making at the physics department. At the physics department, the

204 Paasche, 1969, p. 163.

205 Weedon, *FK-historie,* and *Under Dusken* 15/30, no. 4, 1929, p. 79. Odd Nansen was Fridjof Nansen's son and a senior member of the Student Society. According to Weedon at least one of the Stockholm newspapers reported about the transmission.

young electrical engineers with amateur radio background did not stay with radio technology alone either but soon moved over into equipping all fields of physics research with radio technology based instrumentation. First, the radio amateurs moved into the adjacent field of electroacoustics, but soon proceeded into other fields of research far from radio, like electron scattering and, most spectacular, the building of a Van de Graaff particle accelerator.

4.3.3. A cheerful co-operation: The Academic Radio Club at the physics department

> " *The Academic Radio Club was not organised rigorously, and there were few formalities. We were almost a gang, where things organised themselves while moving on. A few meetings were organised at the electrical engineering department in the evening hours, but most often at the physics department. The latter held a unique position, because Professor Sæland had managed to get it build it large, actually larger than NTH needed. The conditions were therefore spacious in a physical sense, but also in a figurative sense. Professor Holtsmark was tolerant and liked to see that there were things happening. So there was good deal of radio activity throughout the evenings. Several assistants were also given assignments in radio technology as regular work. The workshop was good and the mechanics regarded us with favour. Instrument maker Reed should be mentioned, he was the true intendant. That it became such a cheerful co-operation between the radio club and the physics department, it is to a large amount the work of Reed. Once in a while it went, of course, too far, as when one of the students almost moved into a laboratory and washed his shirts and socks there, and hung them up on a line. Then it was stopped. We had to stick to technology. ...*"
>
> [Helmer Dahl, 1976][206]

In 1925, NTH's physicists moved into the new, long awaited physics building. From being very limited on space in the old building, which was shared with the electrical engineers, the physicists suddenly came into a situation where they had to fill a lot of rooms with activity. Together with the physicists, the Academic Radio Club was also allowed to take advantage of the new spacious laboratories and workshops. The first four years of the Academic Radio Club's presence at the physics department between 1925 and 1929 were of special

[206] Helmer Dahl in Solum et al., *Akademisk Radioklubb - 52 år - « en historie med slagside »*, 1976, p. 36-37, translated from Norwegian.

importance, both for the consolidation of the radio club's activities as well as for the transformation of scientific instrument making and physics research. The enthusiastic radio amateurs invaded the physics workshop with radio technology and other artefacts from electroacoustics. Most of the devices were, in the tradition of amateur radio, self-made according to technical instructions taken from amateur radio and electrotechnical journals. The invasion of the workshop by the new type of technology and by new practices of instrument making was not only tolerated but actively supported by Holtsmark. 1929 marks a change in the relation between the physics department and the Academic Radio Club in two respects. The new Student House was finished and most of the amateur radio activities moved over to the attic of the new building. Relationships with the physics workshop were maintained, but the era of the close presence of the Academic Radio Club had terminated. More important for the research and teaching agendas of the physics department, Holtsmark had by now transformed the interest, the activities and the practices of amateur radio into professional scientific activities.

In 1925, two events animated activities in the Academic Radio Club. In March 1925, *Kringkastingsselskapet A/S* was founded and broadcasting was started from the Oslo studio in April. In summer of 1925 it was difficult not to notice the advertisement for the first national radio exhibition organised by the Norwegian Radio Association (*Norsk Radioforbundet*) in Oslo that September. The success of the Oslo exhibition motivated the members of the Academic Radio Club to organise a similar exhibition in Trondheim together with the local radio dealers. The exhibition took place from January 30 to February 7, 1926 in the premises of the Trade and Industry Association (*Trondhjems Haandverks og Industriforening*). The plan to get official radio broadcasting started in Trondheim before the exhibition opened failed. The Academic Radio Club instead assembled a provisional broadcasting station at the premises of NTH. The transmitter was mounted in the attic of the electrical engineering building. The antenna was mounted at the backside of the same building. The studio and the monitor receiver and modulator room were placed in the basement of the new physics building.[207] Among the students running the broadcasting station were Reno Berg as a radio announcer and Erik Julsrud as an operator of the transmitter. Both became Holtsmark's assistants at the physics department afterwards. The station, that had an input of 300 watt, was put together with components borrowed from the electrical engineering laboratory as well as from radio dealers and the Norwegian Telegraph Authority (*Telegrafstyret*).

Technically the provisional station was a big success. A large number of reports were sent in from radio amateurs in Norway as well as from Sweden

[207] See Fig. 4.3. and 4.4.

and the United Kingdom, commenting the clear intelligibility of the Trondheim station.[208] The exhibition as well as the provisional station, however, failed to reach its main goal, to attract considerable attention for a permanent broadcasting station at Trondheim. The subscription of sufficient capital for a broadcasting company failed and the project was stranded. In April 1926 the Academic Radio Club received its licence for an amateur station with the signature *LA1K*. *LA1K* did not go on the air before 1927 and was then installed in one of the small test houses behind the physics building. Trondheim only got its first official public broadcasting station, *Tyholt Kringkaster*, only in 1930.[209]

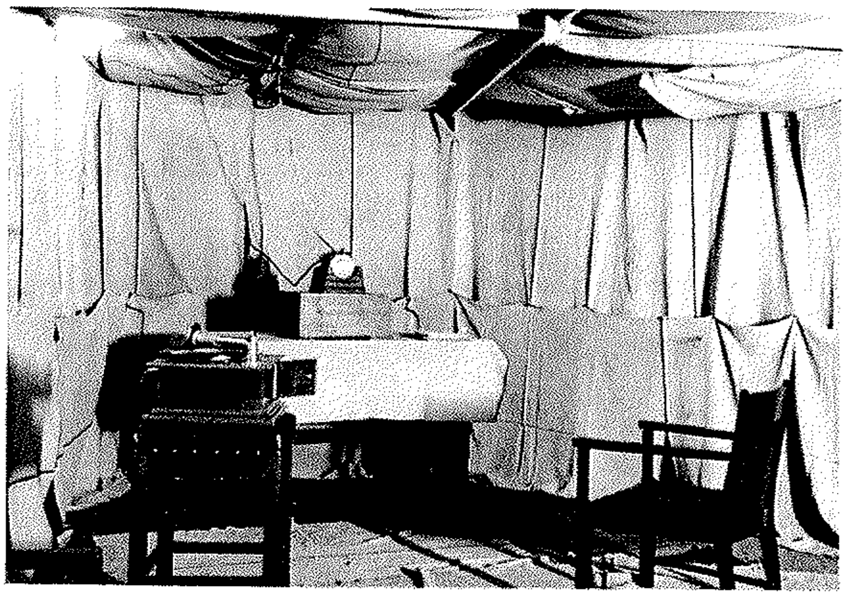


Fig. 4.3: Trondheim temporary broadcasting station, 1926. Broadcasting studio in the basement floor of the physics department. Reverberation time was diminished as much as possible by covering the walls and ceilings with woollen blankets, which was common at the time (Photo: Erik Julsrud, Erik Julsrud's photo collection at the Norwegian Museum of Science and Technology).

[208] See for example Solum et. al., 1976, p. 24-26.

[209] See Solum et. al., 1976, p. 18 ff. and H.F. Dahl, 1999, p. 151 and 178-180.

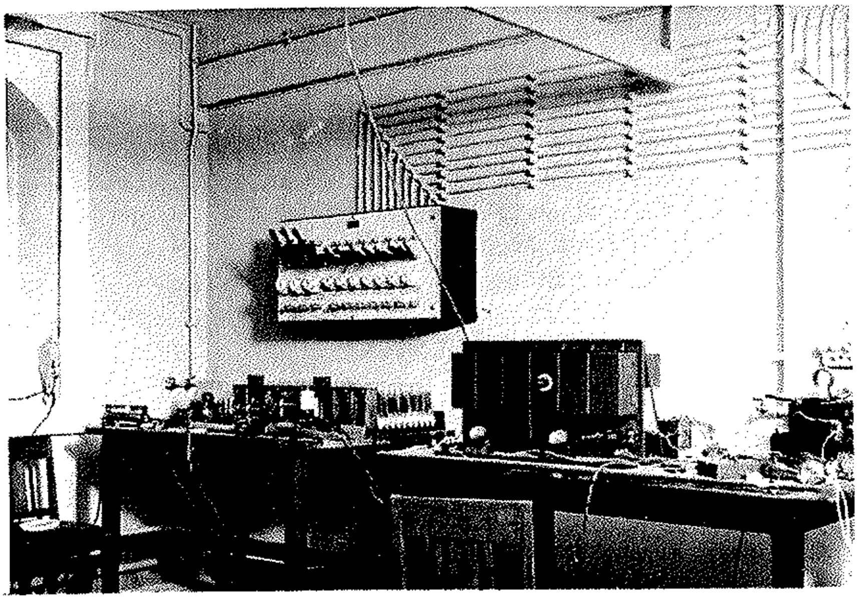


Fig. 4.4: Trondheim temporary broadcasting station, 1926. Monitor receiver and modulator in the basement floor of the physics department (Photo: Erik Julsrud, Erik Julsrud's photo collection at the Norwegian Museum of Science and Technology).

The instrument building activities of the electrical engineers organised in the Academic Radio Club were not limited to the assembly of radio transmitters and receivers. In 1927, the electrical engineering students Olav Færovik and Kaye Weedon built the first electrodynamic loudspeaker at the physics' workshop. Færovik and Weedon had read in the journals *Experimental Wireless* and *Wireless World* about the novel loudspeaker design developed by Chester W. Rice and Edward W. Kellog at General Electric. Holtsmark provided the funding for the parts and the work. The *Rice & Kellog* loudspeaker was built at the local workshop and tested in the physics auditorium. It proved to have sound reproduction qualities superior to all loudspeakers commercially available in Norway. The self-made loudspeaker, together with a small amplifier, was also used by Bjørn Trumpy in a series of lectures during the student week of 1928, which came to be known as Trumpy's *knallforelesninger*.[210]

[210] See Weedon, 1928, *Moderne Kjeglehøittaler.*

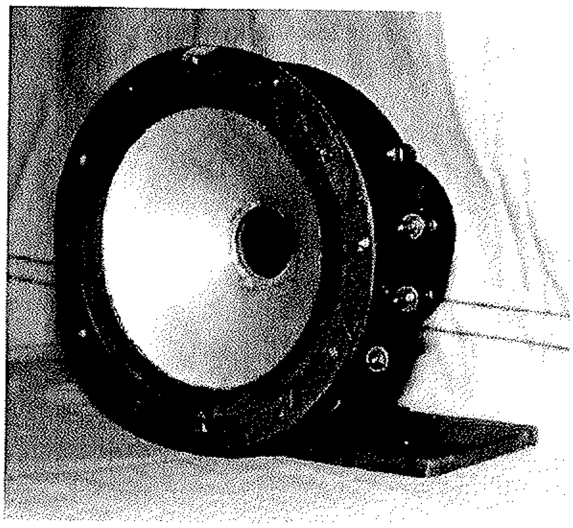


Fig. 4.5: First electrodynamic loudspeaker built at NTH's physics department by Kaye Weedon and Olav Færovik in 1927 (Photo: Roland Wittje).

Erik Julsrud and Holtsmark developed close ties in this period. Julsrud and another electrical engineering student, Olaf Engan, started to manufacture instruments for Holtsmark in 1925.[211] After Julsrud graduated from electrical engineering in 1926, he was employed by both Holtsmark and the electrical engineering department for shorter periods between 1927 and 1930.[212] Julsrud seemed to have been most interested in amplifier design. Together with another student, Lars Hvinden-Haug, he built the first sound amplifying system that was used in the new Student House in 1929. Like Weedon, Julsrud published frequently in the Norwegian radio amateur magazine *Norsk Radio*. In 1928, Holtsmark and Julsrud co-authored an article about low frequency amplification together. In 1929 Holtsmark published an article about high frequency amplification, this time without Julsrud.[213] Other recognised scientists wrote in

[211] Holtsmark to NTH treasurer, May 1, 1929.

[212] Amundsen, 1950, *Vi fra N.T.H.*, p. 141. From the summer of 1928, Julsrud was employed for one year as Bjørn Trumpy's deputy when Trumpy was studying with a Rockefeller scholarship in Copenhagen and Göttingen. See Trumpy to Holtsmark, July 7, 1928, Eb:1.

[213] Julsrud, 1927 and 1928, Holtsmark and Julsrud, 1928,and Holtsmark, 1929.

Norsk Radio as well. Olaf Devik wrote *A Bit about the Ether* in 1925, and the Oslo professor and northern light researcher Carl Størmer wrote about *Ether Vibrations* in 1927. Themes from general physics attracted serious interest among the radio amateurs. In 1929, for example, the article *Atom Smashing* informed *Norsk Radio* readers about the attempts to split atoms by means of accelerated particles. But all these articles from other scientists were reports from a distinct world of physics rather than interventions into the world of the radio amateur. Holtsmark's articles were different: going into the technical details of amplifier design, Holtsmark's articles bridged the gap between academic physics and the practices of amateur radio.

In 1929, Holtsmark communicated one of Julsrud's articles to the proceedings of the Royal Norwegian Society of Science and Letters in Trondheim. The article by Julsrud marked the transition away from amateur radio and towards a professionalisation of the electrical engineers' activities at the physics department. The radio amateurs would continue to use the physics' workshop to construct equipment. Some of them would be given small jobs by Holtsmark or they would carry out the practical work for their diploma thesis in electrical engineering in the physics workshops and laboratories. After they had graduated, they were increasingly recruited to build a novel kind of research technology based on electrotechnics and radio technology. The first research field the electrical engineers would supply with the novel research technology was acoustics. The new electroacoustic instrumentation of the acoustics laboratory was closely related to amateur radio technology and the wiring of the Student House with an amplifying system. After some years the electrical engineers as instrument builders also involved in other research fields. The Van de Graaff accelerator that was constructed at the physics department between 1934 and 1937 was mainly designed and built by telecommunication engineers with background from the Academic Radio Club. We will come back to the Van de Graaff project in great detail in the next chapter. The transition from amateur radio to professional scientific activities has so far been referred to the establishment of acoustics as a research field and the engagement of electrical engineers in scientific instrument making. There was, however, a third aspect in the professionalisation of the amateur radio and electroacoustics activities at the physics department that should not be neglected in its importance; the establishment of acoustics as a novel course for engineers.

4.4. Electroacoustics becomes a teaching subject

The Norwegian Institute of Technology during the interwar period has to be understood primarily as an engineering education institution. Research activities of the teaching staff were acknowledged, but no independent research agenda was supported on a large scale. Because of the strong presence of teaching, research activities at NTH, like technical acoustics, have to be analysed in the teaching context. In order to establish research activities in technical acoustics, it was highly advantageous, if not necessary for Holtsmark to link these to teaching. Since research activities were not supported in their own right, new academic positions financed out of NTH's central budget could only be accomplished by an increase of teaching obligations. Consequently, a growth of the physics department's permanent academic staff could only be achieved by increasing or adding teaching agendas. Within the concept of the unity of teaching and research, these teaching agendas should be closely related to the research agendas of the department. To do high quality teaching, Holtsmark argued, like many others in and outside NTH, that one had to do high-quality research in order to stay on top of scientific development. Some students should also be given the opportunity to pursue independent research after graduating. According to Holtsmark's view, NTH should be more than just an engineering school, where the students would merely internalise textbook knowledge and standard engineering practices. Similar to its role model, the German *Technische Hochschule*, NTH should be an academic institution, whose teachers and graduates should be part of the scientific endeavour of developing new knowledge and new practices. The unity of teaching and research was a key element of this philosophy.[214]

The establishment of technical acoustics and electroacoustics as a taught course had several facets to it. Technical acoustics was a promising subject for the physics department, both with respect to the profile of the Norwegian Institute of Technology, as well as a response to technical and industrial developments around 1930. There was a growing demand for electrical and civil engineers with knowledge of electroacoustics and architectural acoustics. In 1926, the formerly uniform electrical engineering curriculum was divided into two different branches: *sterkstrøm* (electrical machine, alternating current and electrical plant engineering) and *svakstrøm* (telecommunication engineering, including radio, telephony and telegraphy).[215] For the

[214] The issue of the teaching-research relation is also discussed in Chapter 3, Section 4.

[215] See Devik, 1960, p. 74-76. In the interwar period NTH still followed clearly the German engineering education system and the German *Technische Hochschulen,* who divided their electrical engineering curricula into *Starkstromtechnik* and *Schwachstromtechnik*, instead of

telecommunication engineers, electroacoustics was a self-evident subject for the curriculum. Through the establishment of a course on acoustics for telecommunication engineers, Holtsmark strengthened the position of physics teaching at NTH beyond the introductionary physics courses that were compulsory for all engineering students. Holtsmark used the establishment of the new physics course to procure a permanent appointment for his assistant Bjørn Trumpy, by then threatened with the loss of his limited contract. Teaching an advanced acoustics course also increased the contact of the physics department with senior telecommunication engineering students. This presumably contributed to the recruitment of diploma students and research assistants, Holtsmark's most important resource for his research agendas. Beyond attracting students from telecommunication engineering, technical acoustics was a promising area of operation for technical physicists.[216]

There should be no misunderstanding; acoustics was not a novel subject within physics teaching at NTH. The science of acoustics was part of every classical physics curriculum as it was taught in compulsory basic physics lectures for engineers in the beginning of the 20th century. Demonstration collections for physics lectures contained a large number of acoustical demonstration instruments, all developed in the 19th century.[217] In the general physics course, acoustics was taught as a purely mechanical discipline, generally within the section on mechanics. The physics lectures of NTH were no exception. For the demonstration collection, Sem Sæland acquired all the classical lecture demonstration instruments of 19th century acoustics, such as organ pipes, whistles, siren disks, tuning forks, Chlandi plates, Lissajous comparators, and not to forget the large Koenig manometric flame analyser with the Helmholtz resonators and a rotating mirror. A set-up for one of Sæland's classical acoustics lecture can be seen in Fig. 4.6.

following the American engineering education system and the American notations *Power Engineering* and *Electrical Communication Engineering*. See also Hagemeyer, 1979, p. 87.

216 As mentioned in Chapter 3, Section 4.4. the terms *teknisk fysikk* and *teknisk fysiker* are usually translated as *Engineering Physics* and *Engineering Physicists*. I will, however, stay with the terms *Technical Physics* and *Technical Physicist* in order to articulate the closeness of the Norwegian grades to the German rather than the English or American system.

217 Compare this chapter, Section 2.1.

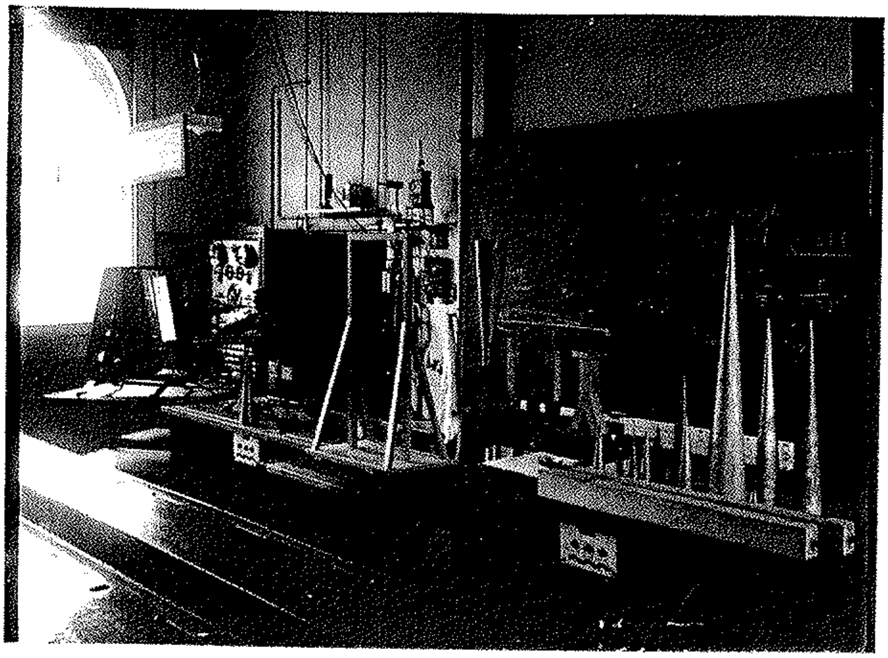


Fig. 4.6: Set-up of acoustics demonstration experiments for Sem Sæland's physics lecture at NTH, October 18, 1915. The person in the photo was the physics department's instrument maker Thorvald Reed (Photo: Statsarkivet i Trondheim).

The picture shows the dominance of demonstrations in the acoustics lecture, typical for all early 20th century experimental physics lectures. The mechanical character of the acoustics teaching in the 1915 introductory physics lectures reflected the mechanical principles that had inspired the demonstration instruments. Sæland also acquired a small number of electroacoustical demonstration devices around 1910; two models of telephones and a microphone. These electroacoustical devices were, however, part of the electricity and magnetism curriculum and not of the acoustics teaching.

There is less evidence to estimate how acoustics teaching in the introductory physics curriculum at NTH changed after Johan Holtsmark took over in 1923. Holtsmark's lecture scripts which he published in 1926, did not contain the fields of mechanics or acoustics.[218] Holtsmark probably left the entire teaching of mechanics during the 1920s either to lecturer in physics Olaf Devik; or Professor of Mechanics, Hans Hendrik Rode; or lecturer in

[218] Holtsmark, 1926.

mechanics Edgar B. Schieldrop.[219] In 1932 Holtsmark introduced the German textbook series by Göttingen physicist Robert Wichard Pohl as standard textbooks for the introductory physics course.[220] Pohl's textbooks followed the tradition of grouping acoustics and mechanics together and treating acoustics as a purely mechanical discipline without giving reference to the emerging electroacoustics. Also the novel acoustics demonstration instruments developed by Pohl and sold by the scientific instrument company Spindler & Hoyer, were purely mechanical and did not bear any reference to the growing amount of electroacoustical devices.[221] Holtsmark seems to have followed Pohl's textbooks precisely during his lectures. He had a large number of slides made of Pohl's textbook illustrations in order to display them in the auditorium. Holtsmark also acquired a number of Pohl's purely mechanical acoustics demonstration instruments.

The advanced course on acoustics for telecommunication engineers given by Bjørn Trumpy and later Reno Berg was quite different from the acoustics taught in the introductory physics lectures. Trumpy's lecture resembled much of the German approach of technical acoustics (*technische Akustik*), representing the new type of acoustics that emerged in the late 1920s and the 1930s.

4.4.1. Acoustics for electrical engineers

Bjørn Trumpy was not the scientist who is usually associated with acoustics activities at the Trondheim physics department. The chemical engineer and physics assistant Trumpy had completed his *dr.techn.*-thesis about the width and intensity of spectral lines in 1927. In the following years at NTH, he continued his research in spectroscopy and was awarded a Rockefeller scholarship in 1928 to study with Max Born in Göttingen and Niels Bohr in Copenhagen. His international contacts to the centres of quantum mechanics and his reputation in modern spectroscopy brought Trumpy an offer for a

[219] A lecture script for a course on mechanics dating from the 1920s is found in Olaf Devik's private archive at the Riksarkivet i Oslo. In the late 1920s the lecturer in mechanics, Edgar Schieldrop also gave a lecture course on Einstein's theory of relativity (Devik, 1960, p. 94).

[220] Archive *NTH-Fysisk institutt*, Eb:1, Statsarkivet i Trondheim.

[221] See Pohl, *Physical principles of mechanics and acoustics*, 1932 and Spindler & Hoyer, *Liste 64, Apparate zur Mechanik und Akustik*, about 1930.

professor's position at the Ohio State University, which he did not accept.[222] But where does electroacoustics come in?

Trumpy's engagement in the teaching of electroacoustics can be traced back to a series of lectures he gave during the Student Week (UKA) in 1928 at the Student Society, also known as the *knallforelesninger*. In the lectures, Trumpy used the Rice & Kellog loudspeaker built by Weedon and Færøvik and a radio-tube amplifier built by the chemical engineering student Tor Holaker.[223] Following the success of the *knallforelesninger*, Trumpy started an informal lecture course in acoustics in 1929. According to Holtsmark, it was the telecommunication-engineering students who requested for the lecture course.[224] In 1930, Holtsmark initiated the establishment of a course in acoustics as a regular part of the telecommunication-engineering curriculum. Holtsmark's arguments in his letter to NTH's president Olav Heggstad reveals that there was more behind the initiative than establishing a popular as well as necessary taught course. Trumpy's academic position as one of the department's teaching assistants was not only low in status and moreover poorly paid: the appointment was also limited to a maximum of ten years. Trumpy, who was appointed in 1923, would inevitably lose the assistant position in 1933. Holtsmark, who wanted to keep Trumpy, argued that his efforts in teaching acoustics should be rewarded and Trumpy should be given a permanent academic position that was better paid.[225] Accordingly, the course was established and Trumpy was promoted to the permanent academic position of a *Laboratory Engineer*.

Trumpy published his script of lectures on acoustics in 1930, and Reno Berg wrote the second volume in 1938. Trumpy's lectures were rich on analogies between electrical and acoustical oscillations. He used analogies between electrical and mechanical differential equations and crafted a table where he gave a translation from the acoustic variables *force, speed, displacement, mass and elasticity* into the electric *variables tension, current, charge, self-induction and capacity*.[226] Trumpy also used the analogy between acoustic and electric wave propagation for the explanation of acoustic filters.[227]

222 See Statsarkivet i Bergen, *Arkiv fra Bergens Museum*, Trumpy's application as Professor of Terrestrial Magnetism and Cosmic Radiation in 1934.

223 For the Rice & Kellog loudspeaker, see also this chapter, Section 3.3. The technical aspects of Trumpy's demonstration and Holaker's amplifier are given in Weedon, *Moderne kjeglehøittaler*, *Norsk Radio* 6 (1928), p. 85.

224 Letter Holtsmark to President of NTH, October 23, 1930, Eb:1.

225 Letter Holtsmark to President of NTH, October 23, 1930, Eb:1.

226 Trumpy, 1930, p. 13-14.

227 Trumpy, 1930, p. 52 ff.

All in all, Trumpy's lectures showed all characteristics of electroacoustic thinking in physics by not only referring to electroacoustical devices but also explaining acoustic phenomena through analogies from electrodynamics. The use of the analogies from electrodynamics and equivalent circuit diagrams was useful to the electrical engineers in several ways. First, the electrical engineers were used to thinking in electrical units, oscillating electrical systems, electrical filters and electrical circuit diagrams. The option for the electrical engineers to imagine acoustical phenomena as equivalent circuit diagrams eased their understanding of acoustics. Second, in electroacoustical systems, acoustical signals had to be transformed into electrical signals and vice versa. To understand acoustical phenomena as equivalent circuit diagrams would also help the engineers to build electroacoustic devices and to generate and manipulate sound with these.

The acoustics lectures by Trumpy and later Berg, were a success in the way that they enhanced the importance of physicists in engineering teaching at NTH and added an important subject to the curriculum of the telecommunication engineers. Through acoustics teaching, the physics department also gained a new permanent academic position. But Holtsmark's ambitions in establishing acoustics as a teaching agenda did not stop here. Technical acoustics teaching and research should be a step towards establishing a separate career for physics students at the Norwegian Institute of Technology: the *technical Physicist.*

4.4.2. Acoustics as a strategy to establish the *Technical Physicist*

From the opening of the Norwegian Institute of Technology in 1910, the first Professor of Physics, Sem Sæland, developed plans to expand the physics department from a mere service department for teaching physics to engineers to an active research institution. The plans included a separate career for technical physics as well as research laboratories for advanced studies. Because of economic constraints, especially during the recession after WWI, Sæland did not manage to get the physics building to house the teaching and research activities constructed before the mid 1920s. The spacious physics building, the only larger new building finished at NTH during the interwar period, was a major achievement of Sæland. The building was taken into use by Holtsmark in 1925. The first proposal for the establishment separate physics degree was made by Sæland in 1922.[228] Since NTH was modelled on the German *Technische Hochschule*, its physics education would also follow the German

[228] See *Under Dusken* 15/30, 21.September 1929.

technischer Physiker. The career of the technical physicist was introduced at the German institutes of technology after WWI and the *Deutsche Gesellschaft für technische Physik* was founded in 1919. The technical physicists were basically following the same curriculum as the university physicists. Their work field was, however, supposed to be more application and industry oriented. Technical physicists were to be employed in the research & development sector of industry, rather than in higher education or other sectors of public service, where university physicists were usually found. The technical physicist was located in-between science and engineering, someone able to negotiate between academia and industry.[229]

The physicists' argumentation for the need of a degree for technical physicists was complicated by the oscillating and partly recessive economy of the interwar period. On one hand, the demand for physicists in the industry was increasing both in Norway and in other countries. A physicist educated at the Institute of Technology would be better adapted to work in industry than a physicist educated at the university. But the job market was weak for engineers in Norway throughout the 1920s and in the beginning of the 1930s. Many Norwegian engineers immigrated to the USA.[230] Electroacoustics, however, was an expanding sector with most of its research & development carried out in corporate laboratories, which was the imagined working environment of the technical physicists. For scientists with a background in electroacoustics the job opportunities seemed undoubtedly growing, particularly in the emerging Norwegian radio industry. Accordingly, acoustics would be one of the advanced teaching subjects in the technical physics curriculum.[231]

Official support for Holtsmark's plans of a separate degree for the technical physicist was not strong enough during the interwar period and the separate curriculum was only established after WWII. The appointment of a theoretical physicist was, according to Holtsmark, especially indispensable for the curriculum. In 1929, however, a somewhat compromised version of a technical physics degree was established. Students could start in a related engineering discipline and change to technical physics during the last years by taking some special courses and writing their diploma thesis at the physics department.[232] This career was not very popular and until WWII only a handful of engineers were graduating as technical physicists. The interwar period arrangement for

[229] See Ramsauer, 1948 and Gehloff, Rukop and Horst, 1920. See also Chapter 3, Section 4.4.

[230] See Hanisch and Lange, 1985, p. 92 ff.

[231] Holtsmark, letter to president Heggstad, October 8, 1930, Eb:1. See also *Den nye linje, Under Dusken* 15/30, no. 2 September 21, 1929, p. 17-18. Optics and X-ray techniques were mentioned as other advanced teaching subjects of the technical physics curriculum.

[232] See *Under Dusken* 15/30, 21.September 1929.

technical physics was not a success. The technical physicists were, however, dispensable for Holtsmark's research agendas in acoustics. With great success Holtsmark recruited telecommunication engineers as assistants for the task of building electroacoustic instrumentation as well as for carrying out acoustic investigations.

4.5. From the radio amateur to the professional acoustician

Research, engineering and consulting in acoustics at NTH

" *My third and we can say decisive meeting with room-acoustics was when the sound motion picture came in the end of the 1920s. This coincided with the development of radio and studios and so forth, and it was a very hectic time with intensive work from many sides to get sound motion picture usable in the shortest possible time and to get usable broadcasting studios for radio. ... What we in particular got in touch with was first, the problems with loudspeakers in the cinemas, and second, the fit of studios and cinema theatres for usable room-acoustics. These were altogether interesting problems and the whole thing was so new that we were forced to do a great deal ourselves to get these things in order. ...*"

[Johan Holtsmark, 1968][233]

The starting point for professional research in acoustics at NTH's physics department can be determined around 1929. The timing is by no means random but coincided with other developments around 1929, when international research in the new electroacoustics was being organised. The Acoustical Society of America was founded in December 1928 and in 1931, when Holtsmark joined of the Society, it already had 632 members. The *Heinrich Hertz Institut für Schwingungsforschung* in Berlin, first conceived in 1927, opened its doors in 1930. In Norway, the demand for acoustical planning and manipulation of architectural spaces was increasing. The first sound motion picture that arrived in Norway was *The Singing Fool* directed by Lloyd Bacon. It was shown at the *Eldorado* cinema in Oslo, in the summer of 1929. The *Eldorado* was the first Norwegian cinema to install sound equipment. Radio broadcasting was beginning to mature in Norway at the same time. With a steadily growing number of listeners, radio advanced from a special activity of radio enthusiasts to a mass medium. Demands were increasing, not only on the

233 Holtsmark, Manuscript *Noen erindringer...*, 1968, p. 2, translated from Norwegian.

contents of the radio programs but also on their technical quality. Research and consulting in technical acoustics offered a lot of opportunities around 1929. However, the most important ingredient that enabled entry into acoustics research in Trondheim was the experience Holtsmark and his assistants had collected in the previous years with electroacoustical instrumentation in the amateur radio context.

It can be said that the boundary between amateur radio and professional acoustics in Trondheim was passed in 1929, when Erik Julsrud published his first scientific paper, *Die gleichmässige Verstärkung eines schmalen Hochfrequenzbereiches* in the proceedings of the Royal Norwegian Society of Science and Letters in Trondheim. In 1929 Holtsmark also published a three pages article in the *Teknisk Ukeblad*. Besides informing the reader about the new acoustics laboratory at NTH he sketched out what he saw as the main aspects of technical acoustics: 1. The construction of devices to generate or to receive sound, 2. The pre-calculation of the acoustics of auditoria, concert halls and so far, and 3. Sound insulation.[234] These three aspects represented the core of Holtsmark's research agenda in technical acoustics. Holtsmark published the physics department's first article on acoustics research, *Zur Definition der Schalldurchlässigkeit von Wänden*, in 1930. The experience from amateur radio and from wiring the Student Society with electroacoustical devices was an important element of this transition because of the strong focus on instrumentation in the new acoustics research itself. It was through these amateur activities, that the Trondheim acousticians had learned to build and control electroacoustical instrumentation, like loudspeakers, amplifying circuits and electrotechnical high frequency filters. Similar to other research fields at NTH's physics department at the time, most of the scientific instrumentation was made in the department's own shop. It is therefore not surprising that until 1939, all of Holtsmark's assistants involved in the acoustics activities were telecommunication engineers with a background from the Academic Radio Club.

Holtsmark's most active assistants of the first years in acoustics research were Reno Berg and Vebjørn Tandberg. Berg, who we already know as one of the students who operated the provisional broadcasting station at Trondheim in 1926, carried out most of the acoustical measurements throughout the 1930s. He also came to stay in academia at NTH. From publications, correspondence and Holtsmark's written memories we get the picture that his own contributions to the acoustics research were mainly theoretical, conceptional and organisational, whereas his assistant Berg carried out the practical measurements and experiments. Papers of purely theoretical content were published by Holtsmark alone, whereas papers containing experimental data

[234] Holtsmark, *Akustiske problemer* (1929), p. 281.

were mainly co-authored by Berg and Holtsmark, on some occasions by Berg alone. There is no documentation indicating that Holtsmark actually engaged in practical matters of acoustics instrument building or experimentation. Tandberg, who was the radio club's chairman in 1929, was the main maker of electroacoustical devices until 1933. He constructed loudspeakers, condenser microphones and the Trondheim acousticians' first specific precision measurement instrument, which was an automatic reverberation and sound intensity measurement apparatus.[235] While research and consulting in acoustics was solely carried out by Holtsmark and Berg, a larger number of telecommunication engineers were assigned for shorter periods to instrument building. Oddvar Johannesen and Eilif Bjørnstad built a registering decibelmeter for the Norwegian Broadcasting Corporation (*Norsk Rikskringkasting*) between 1935 and 1937. Other engineers involved in electroacoustics instrumentation and radio technology were Helmer Dahl and Roald Tangen.

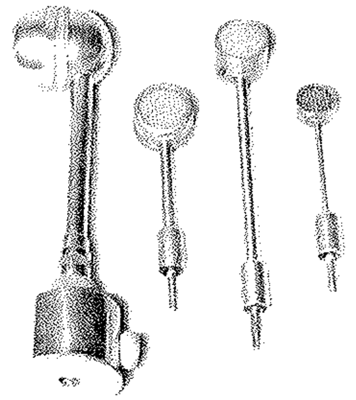


Fig. 4.7: Condenser microphones built at NTH's physics department in the 1930s (Photo: Roland Wittje).

[235] We will come back to Tandberg later in this chapter, Section 6.

A great majority of the research papers by Berg and Holtsmark were written in German and published in the proceedings of the Royal Norwegian Society of Science and Letters. Some were published in other Norwegian professional and trade journals. Only one of the papers made it to an international journal: an article by Holtsmark and Tandberg about the automatic reverberation measurement apparatus was published in the *Elektrische Nachrichtentechnik* in 1933. That a majority of the papers were written in German, and not in Norwegian, made them intelligible for the non-Scandinavian world. Sending pre-prints to researchers working in the same field was still a common way of scientific communication. However, publishing in Norwegian based journals seriously limited the circulation of the papers.[236] Research and consulting in acoustics at NTH was mainly directed towards the Norwegian society and industry. There was no large electrical industry in Norway that would finance research laboratories, like they did in the USA or Germany. The only Norwegian chair in telecommunication engineering (*svakstrøm*) was held by Holtsmark's colleague Ragnar Skancke at NTH. Skancke's research field was not radio or electroacoustics but telephony. Holtsmark could therefore move into these research areas without local or even national competition. The only other Norwegian scientist who seriously involved himself in acoustics research at the time was Olaf Devik at the Christian Michelsen Institute at Bergen. Devik, until 1932 a physics lecturer at NTH, hired Helmer Dahl, one of Holtsmark's earlier assistants. Helmer Dahl was also a veteran of the Academic Radio Club. In the mid-1930s Devik worked together with Dahl on electroacoustical navigation aids for Norwegian shipping and fishing. Devik and Dahl worked far from architectural acoustics, which was Holtsmark's field. In architectural acoustics and acoustically engineered construction materials and designs, Holtsmark remained the undisputed Norwegian authority.

The Norwegian-based character of Holtsmark's consulting activities and the limited circulation of many of the acoustics research papers did not stop him and his assistants and collaborators from cultivating international contacts. With Holtsmark, Berg, Julsrud and Møller as members of the Acoustical Society of America, Norway had the strongest representation among the Scandinavian countries. From 1933 onwards, Holtsmark reviewed articles from

[236] Articles of proceedings of the Royal Norwegian Society of Science and Letters were, unlike the *Journal of the Acoustical Society of America* or the *Elektrische Nachrichtentechnik*, for example, not reviewed in the German *Physikalische Berichte*. In Germany Holtsmark's research on architectural acoustics was noticed to some extent. In Josef Engl's *Raum und Bauakustik* of 1939, Holtsmark was referred to in regards to sound insulation measurements. Papers of the proceedings of the Royal Norwegian Society of Science and Letters, however, did not make it into Engl's reference list. The only publication listed was Holtsmark and Tandberg's paper on the reverberation apparatus of 1933, mentioned above (Engl, 1939, p. 291 and p. 358 and Holtsmark and Tandberg, 1933).

Journal of the Acoustical Society of America for the German *Physikalische Berichte*. He maintained contacts with the German acoustics community, particularly with Erwin Meyer, Germany's foremost authority in the field, at the *Heinrich Hertz Institut für Schwingungsforschung* in Berlin. In February 1931, shortly after its opening, Holtsmark visited the *Heinrich Hertz Institut* to study its methods of acoustical investigations.[237] In the summer of 1935, Berg went on a longer study tour to England and Germany, together with Wilhelm Ramm and Sverre Westin. Ramm and Westin were assistants of Holtsmark who were working on a Van de Graaff particle accelerator and on electron scattering. It was characteristic for Holtsmark's program of organising various different research agendas at the same time to send the assistants working in different fields on a joint study tour. Holtsmark himself usually visited several different research activities and facilities on his international journeys.[238] For the acoustical planning of the new broadcasting house of the Norwegian Broadcasting Corporation (*Norsk Rikskringkasting*) at Marienlyst Holtsmark studied broadcasting houses in other countries, like Germany and Great Britain. Holtsmark was also a Norwegian delegate to international congresses that negotiated acoustical units, limits for noise and other matters regarding acoustics.[239]

In 1938 Holtsmark published a series of nine short theoretical papers about the physiological loudness and excitation of the basilar membrane of the ear.[240] At first sight Holtsmark's physiological investigations do not seem to fit well into his research agenda of technical acoustics. But physiological acoustics had been a research field that in the 1930s had increasingly been taken up by scientists engaged in technical acoustics, electroacoustics and communication engineering. Through the development of amplifier technology in radio and other electroacoustic technologies, broader frequency bands could be transmitted. The acoustical properties of the terminal equipment had to be improved in order to transmit the whole frequency band to the listener. Technical acoustics in the human space could not ignore how humans perceived sound. Diverging ideas of speaking and listening had to be integrated in a more closed research field.[241] Also in telephony, the human ear represented a main component of the transmission system. Georg von Békésy, the 1930s most

[237] Letter Holtsmark to President of NTH, November 24, 1931, Eb:1.

[238] Reno Berg had most probably a research stay at Meyer's acoustics department during summer of 1935. See Holtsmark's request to Meyer June 4, 1935. I do not have documentation confirming Berg's stay.

[239] Holtsmark in *Hallo-Hallo*, 1937.

[240] See Holtsmark, 1938, all D.K.N.V.S.

[241] See Hagemeyer, 1979, p. 145-146.

recognised scientist within the field of physiological acoustics, worked at the research laboratory of the Hungarian Post Office.[242] The number of articles published in the *Journal of the Acoustical Society of America* and the *Elektrische Nachrichtentechnik* clearly expressed the interest acousticians and corporate laboratories showed for the physiological aspects of hearing.[243] Holtsmark did not seem to have followed up his interest in the theoretical aspects of physiological acoustics after 1938. In 1940, however, he conducted speech intelligibility tests with students in the physics auditorium.[244]

Before we go deeper into other aspects acoustics research and consulting at NTH, a few words about the financing of the research are necessary. Similar to other research activities, there was little funding available out of NTH's central budget for acoustics' research assistants or research instrumentation. Holtsmark's main assistant Reno Berg was appointed from 1932 onwards as one of the department's teaching assistants and took over acoustics teaching after Bjørn Trumpy had left for the professor's position at the Geophysical Institute in Bergen in 1934. All other assistants as well as additional instrument makers in the workshop, and all costs related to the buying and making of scientific instrumentation had to be financed from other sources. Holtsmark established a mixed financing system, based on funding from various research foundations and the contributions from consultancy clients. The funding by the research foundations, among them the *Norges tekniske høiskoles fond* and the *A/S Norsk Varekrigsfond*, allowed Holtsmark and Berg to ease the pressure of strong dependence on consulting assignments. The consultancy clients were usually interested in solving current technical problems and not in financing long term basic research, which remained Holtsmark's main concern. To put it differently: the clients were usually interested in solving their problems whereas Holtsmark was interested in investigating these problems in their own right and in establishing strategic research agendas. The short-term assignment on current problems proved to be disadvantageous for Holtsmark in order to put the research activities at the acoustics laboratory on a solid and continuous financial base.

242 In 1961, von Békésy was awarded the Nobel Prize in Physiology or Medicine for his findings in physiological acoustics. See Nobel Lectures, Physiology or Medicine 1942-1962 and Beyer, 1998, p. 264 ff.

243 See, for example, lists of references in Holtsmark's articles. Articles on physiological acoustics cited by Holtsmark were also published in *Physical Review* and in the *Annalen der Physik*. Holtsmark cited, in contrast, only a few articles from journals of physiology.

244 See account on honorarium paid to students, January 1940, February 19, 1940 and February 24, 1940, NRK archive. The context of the speech intelligibility tests is unknown to me. The tests were possibly connected to the planning of the new large orchestra studio of the Norwegian Broadcasting Corporation.

In Holtsmark's elaboration of a strategic plan for the establishment of research scholarships at NTH's physics department in 1940, Holtsmark specified three research assistants as his desired number of workforce for the acoustics laboratory.[245] By 1940, Holtsmark had, however, already found a relatively convenient solution for his funding problem. Holtsmark's largest client was *Norsk Rikskringkasting* (NRK).[246] In 1939, after at least six years of continuous consulting Holtsmark managed to receive an annual basic contribution from NRK that allowed him to operate more independently.[247] The correspondence with NRK also reveals another financial aspect of Holtsmark's consulting activities. Holtsmark not only billed the wages of his assistants, but also included a consulting fee for his own work. The consulting fees Holtsmark billed for himself were considered as rather high by NRK, bearing in mind his appointment as professor at NTH. Holtsmark replied, however, that the fees were a legitimate compensation for his time spent on the task. Even though not documented, it can be assumed that Holtsmark also received an income from other consulting assignments. Consulting and the corresponding income from consulting fees were rather typical for NTH professors from the engineering disciplines.[248]

[245] Holtsmark to Olaf Devik, November 24, 1940.

[246] In the following sections I will use the convenient abbreviation *NRK* for *Norsk Rikskringkasting* or its English name, the *Norwegian Broadcasting Corporation*. Following H. F. Dahl, I would like to call to attention that this abbreviation, NRK, was yet not established as a common abbreviation during the 1930s (H. F. Dahl, 1999, p. 14).

[247] The more complicated relationship between Holtsmark and NRK, which was, like NTH, a public institution, will be discussed in greater detail in Section 5.3. of this chapter.

[248] Consulting of NTH professors for the Norwegian industry is discussed in both Hanisch and Lange, 1985, and Andersen and Yttri, 1997. Industry consulting of NTH engineering professors seems to have been widely uncontroversial and publicly supported rather than criticised. The contacts through consulting would prove the professor's proximity to the Norwegian industry and his ability to solve practical tasks. The neutrality of professors with strong industrial contacts could, however, be questioned. This was done at NTH in the case of the Professor of Machine Parts and Oil Machines, Reinhold Lutz. Around 1930, Lutz was accused by parts of the Norwegian motor industry to support German diesel engines versus Norwegian glow-head engines. Lutz, who was German, had considerable consulting activity in this field. See Hanisch and Lange, 1985, p. 121 ff. There is one prominent German case where excessive consulting activity for one company was used as an argument for the dismissal of a professor. Wolfgang Gaede was in 1933 dismissed from his Chair of Physics at the *Technische Hochschule Karlsruhe*. Gaede was accused of having abused the department's laboratories to conduct secret research in vacuum technology for the *Leybold* scientific instrument company. At the time of the coming into power of the German Nazi regime local rivals of Gaede pushed the accusations forward. Taking into account the common consulting activities of German professors particularly at the *Technischen Hochschulen*, the accusation of Gaede was a mere pretence. See Unzeitig, 2000, p. 74 ff.

4.5.1. Taking the laboratory into the real world
Architectural acoustics and the consulting scientist

I have divided Holtsmark's activities regarding investigations and consulting in room acoustics into two different categories: first architectural acoustics as investigation of the propagation of sound in architectural spaces and second the laboratory testing of acoustical properties of construction materials and construction designs. This division is by no means obvious and the borderline between the two categories is provisional. Acoustical properties of rooms and buildings depended on their shape and size. But they also depended on the acoustical properties of the construction materials and construction designs that were used. The main acoustical properties of these materials and constructions were their ability to reflect, transmit or absorb sound. In the 1920s and 1930s there was a growing tendency to manipulate the acoustical characteristics of a room, given by its shape and size, through the use of acoustically engineered materials and constructions. Most common sound manipulations were the adjustment of reverberation time, the removal of sharp echoes, and sound insulation. The division between architectural acoustics on the one hand and the testing of materials and construction designs on the other is, however, justified by the very different approaches as well as research and consulting practices that were connected with the two.

Architectural acoustics implies going out into the field, or we might say the *real world* as opposed to the artificial laboratory environment. Holtsmark and his assistants' investigations and consulting activities were related either to existing buildings and their possible modification, or to the planning of new buildings. Cinema theatres were frequent among existing buildings that had to be modified regarding their acoustical properties. With the arrival of sound motion pictures, many cinema theatres that had earlier been used for silent motion pictures exhibited insufficient acoustical properties to be used for the presentation of the upgraded medium. Long reverberation times, sharp echoes and inappropriate timbres left the electrically amplified sound of the motion pictures unintelligible and unpleasant. Holtsmark's largest acoustics consulting assignment in the 1930s was indisputably his participation in the planning of the new broadcasting house of the Norwegian Broadcasting Corporation, which we will come back to later.

In both cases, the planning of new and the modification of existing buildings, the result of the investigations would be written in the form of a report including suggestions of how desired acoustical characteristics could be achieved. These consulting works did not need to include acoustical measurements. In the cases where the investigations included measurements, the acoustical laboratory had to move out into the field. The building or room in question itself became the laboratory. This had consequences for the scientific instruments being used as well as for the research practices. The acoustical laboratory was moved out of NTH's physics laboratory and literally taken all over Norway.[249] Measurement instruments therefore had to be made compact, portable and robust, so they would withstand travelling over longer distances. The reverberation measurement apparatus built by Vebjørn Tandberg in a travelling suitcase around 1931 (Fig. 4.8.) is the embodied example of an instrument built for the travelling scientist. Moreover, instruments would have to be easy to assemble and to set up at the location. The stabilisation of the *laboratory* in the field and the extraction of reproducible results was by no means trivial. Measurements of the same room by different scientists could yield very different results.

Consulting in architectural acoustics was an inherently interdisciplinary task. It involved the ability to co-operate with architects, construction engineers, and most important of all, the users of the premises. Acoustical properties of a building had no value in itself but were entirely dependent on the uses for the premises. In acoustics consulting, a never ending list of concerns had to be considered, such as the multipurpose use of premises, aesthetic and architectural factors, construction statics, construction budgets, fashions, state regulations, and so forth. It was not the acoustical planning and manipulation alone that was the principal issue. In construction planning, acoustics was only one of many side issues that was in service of the main question, the practical use of the premises. Holtsmark's consulting reports and suggestions in architectural acoustics were clearly shaped by this complex context and mark his abilities to situate the acoustical concerns in order to make them address the proposed uses of the building.

[249] Some of the rhetoric is borrowed from Bruno Latour, *The Pasteurisation of France* (1988). Sociologists of science have written widely about the differences between laboratory studies and fieldwork.

Fig. 4.8: Reverberation measurement apparatus built by Vebjørn Tandberg around 1931. One copy was made for NRK, the present one in the photo was kept at NTH's physics department (Photo: Roland Wittje).

The testing of construction materials and construction designs regarding their acoustical properties, on the other hand, differed radically from the work of the acoustician in the field. Testing of materials was conducted in the laboratory, and under controlled conditions. In the laboratory one variable of a well-defined material or construction design could be singled out and investigated systematically. NTH's physics department's sound laboratory for material testing was a permanent set-up. The conditions for investigations were stable, so different materials could be compared under the same conditions. In other words, a very important premise for experimental physics research, reproducibility, could be established. The problems of reproducibility of architectural acoustics in the field became evident when architects tried to reshape acoustical characteristics of buildings with outstanding qualities like the *Leipziger Gewandhaus*, and failed. Consequently the reports written from material testing in the laboratory were very different from Holtsmark's consulting reports for architectural acoustics in the field. The testing reports could be more standardised. Both the multi-technical and the social context of construction planning could be largely ignored in the laboratory. Out in the field, or the "real world", acoustical properties were merely one concern subordinated under the primary concern of "use" of an architectural space. Only in the laboratory, testing of the acoustical variables, like reflection, absorption and transmission, could become the main, if not the sole concern of investigation.

The distinction between laboratory research and fieldwork is important. However, as indicated above the distinction cannot always be strictly maintained regarding Holtsmark and Berg's research practice. Instead what we see is a complexity of interactions. In several cases the Trondheim acousticians were granted permission to use construction sites for a more extensive series of tests, often inconsistent with the consulting task. The half-finished construction sites were hereby transformed into laboratories. This relocation of the laboratory from the physics building to the construction site was mainly for practical reasons. Comparative laboratories were not available at NTH at the time.[250]

The birth of scientific architectural acoustics is usually credited to Wallace Sabine and his investigations of reverberation time. His results were first applied in the construction of the Boston Symphony Hall in 1900. In 1898, after three years of measurement in different premises of Harvard University, the young assistant professor of physics developed his famous empirical reverberation equation. According to Sabine's hyperbolic equation, reverberation time depended on the room's volume, its surface area and the collected absorption of its surface material. Sabine's findings of 1898 fell into the time period from 1890 to 1920, which is otherwise characterised as an uninteresting period for acoustics research.[251] Situated before the age of electroacoustics, Sabine carried out his experiments using classical acoustics instruments. He used an organ pipe driven by a tank of compressed air as a sound generator and relied on his own hearing as a detector, along with a chronograph as a timekeeper. These investigation practices and Sabine's formulae reveal two characteristic aspects that had changed by the time Holtsmark started his investigations in the 1930s. First, Sabine's reverberation formula did not allow the reverberation time to go down to zero, even if the wall would be completely absorbent, represented by an absorption coefficient of one. Accordingly, an acoustically dead room was not allowed by the

250 The construction site could also sometimes prove to be a poor laboratory. See for example Holtsmark and Berg, 1934, *Målinger av lydisolasjon mot luftlyd i en del gulv- og veggkonstruksjoner utført i Handelsstandens Hus, Trondheim*, p. 154. The conditions in this "provisional laboratory" were unsuitable to the impact sound measurements that were planned to conduct.

251 See also this chapter, Section 2.

formula. Second, Sabine's investigations did not pay attention to the frequency dependence of reverberation time. They were in fact only conducted at one single frequency, 512 cycles per second.[252]

One might argue that zero reverberation time was only a theoretical value in 1898, when Sabine developed his empirical formula. There was no practical construction that would allow a room to have such an acoustical property. In 1930, the situation had changed completely mainly because of two reasons: the appearance of acoustically engineered materials and constructions designs, and the electroacoustical manipulation of sound. Acoustically engineered materials and constructions made the building of so called dead rooms possible. Electroacoustical devices produced or processed sound electrically. With advanced electrical modules and clever circuit design, reverberation time could be generated or manipulated artificially. Sabine's antiquated reverberation equation was modified by Carl Eyring in 1930. The physicist Eyring was employed at the Sound Motion Picture Studios of the Bell Telephone Laboratories, which again reflected the domination of the large corporate laboratories in acoustics research in the USA during the interwar period.[253]

Another shortcoming of the earlier reverberation measurements was the ignorance of frequency dependence of reverberation. The timbre of reverberation of a room could vary drastically, as Holtsmark noted. The earlier measurements, either summarised over the frequencies or, like Sabine's first investigations, obtained at only one single frequency, could give a very wrong picture about the real acoustical properties of a room, and its usefulness for certain events.[254] The use of acoustically engineered materials in order to lower the mean reverberation time of a room without considering the frequency dependence of absorption could surely give unwanted results. Consequently, all reverberation curves published and discussed by the Trondheim acousticians were frequency dependent.

From August 1931 to August 1934, Berg and Holtsmark measured reverberation in thirty-seven cinema theatres, concert halls, theatres and other public assembly rooms in Norwegian cities.[255] The main instrument in these investigations was Tandberg's suitcase - the transportable automatic

[252] The unit Hertz was first established in 1930 by the International Electrotechnical Commission.

[253] For Sabine, Eyring and the deconstruction of architectural acoustics, see Thompson, 1997.

[254] Holtsmark, 1968, *Noen erindringer fra akustikkens barndom i Norge*. Holtsmark mentioned Vern O. Knudsen, probably America's foremost authority in the field of architectural acoustics at the time. On a tour around Europe, Knudsen also visited Trondheim. Knudsen's measurements were summarised, a point that Holtsmark criticised. Unfortunately, Knudsen's visit at Trondheim is not dated or further documented.

[255] Berg and Holtsmark, 1935, *Akustiske målinger i en del forsamlingslokaler i Norge*.

reverberation measurement apparatus. Twenty-five of the studied premises were used as cinema theatres, thirteen as concert halls, eleven as theatres and six as lecture halls. Several of them were multi-purpose premises and a compromise had to be made in order to obtain satisfying reverberation characteristics for all types of arrangements. Whether the acoustical properties were satisfying also depended on the hearing habits of people. Characterisations of music halls, for example, could vary for both, musicians and listeners.[256] Regarding music halls, opinions about acoustics could be very divergent, whereas lecture halls mainly required intelligibility of speech.[257] Furniture had a large and usually positive influence on the timbre of reverberation and was discussed and investigated in great detail.[258] Besides reverberation, sound propagation through buildings, particularly through cement ceilings and different designs of sound insulation, was the major target of the investigation and consultation of the Trondheim acousticians.

We can witness Holtsmark's enthusiasm for novel electroacoustical devices in an interview in *Oslo Illustrerte* from 1934. When it came to the success of acoustical engineering in construction as opposed to traditional craftsmanship, Holtsmark appeared less thrilled. On several occasions, Holtsmark expressed his opinion about the superior acoustics of many buildings constructed before the age of architectural acoustics, particularly referring to the old *Leipziger Gewandhaus* and the Freemason's Loge at Oslo. Holtsmark accounted the long time experience the former architects had in constructing these kind of buildings, as opposed to the relatively short traditions of scientifically based architectural acoustics. For the construction of the large symphony studio of the new Oslo broadcasting house, Holtsmark recommended that NRK should copy elements of "the good old halls", like the gallery, padded chairs and pillars.[259]

[256] The change of hearing habits and consequently the change of valuation of acoustical properties of certain premises is also discussed in Thompson, 1992, particularly p. 330-331.

[257] Engl (1939) divided into premises depending on intelligibility of speech, like lecture halls, assembly halls and stages for speech, and premises for the performance of instrumental and vocal music, like concert halls, operas and churches. See Engl (1939) Chapter 11 and 12. The sound movie theatre was treated separately, see Engl, p. 345 ff.

[258] See, for example, Holtsmark and Berg, 1934, *Målinger av efterklang og lydabsorpsjon utført i Handelsstandens Hus, Trondheim*.

[259] See interview with Holtsmark, *Oslo Illustrerte*, also Holtsmark, 1936, *Einige akustische Probleme im Rundfunk*, particularly p. 20 ff., Holtsmark, 1968, *noen erindringer*, particularly for the mentioning of the *Leipziger Gewandhaus*, and *NeFAS' memorandum* of July 30, 1937.

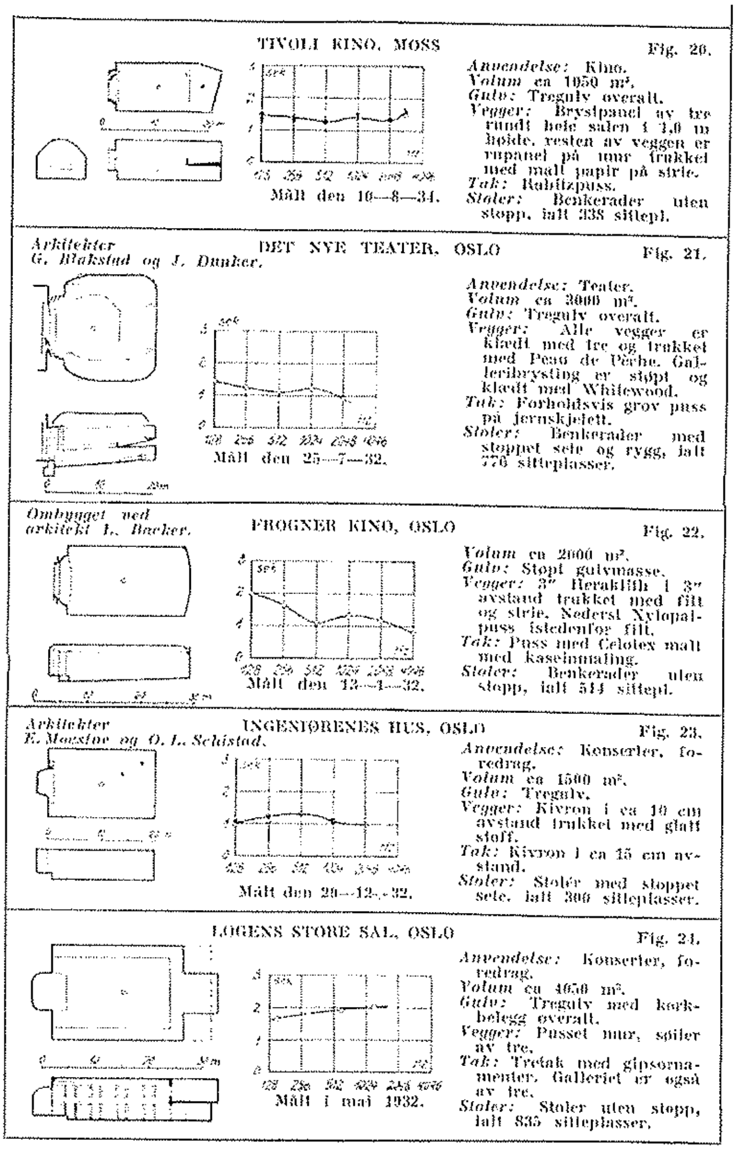


Fig. 4.9: Reverberation measurements in different public meeting premises. Altogether thirty-seven premises all over Norway had been analysed. The use of the premises varied between cinema theatre, lecture hall, theatre and concert hall. Many were multi-purpose premises (Berg and Holtsmark, 1935, *Akustiske målinger i en del forsamlingslokaler i Norge*).

4.5.2. Testing materials inside the laboratory

Scientism and the acoustical engineering of construction materials

The testing of all kinds of fabricated materials had been given a central position in the organisation of the Norwegian Institute of Technology right from its beginning in 1910. The Department of Testing Materials (*Materialprøvings-anstalten*) was arranged independently from the other departments of NTH. Its organiser and first director was Heinz Egerer, NTH's first Professor of Mechanics. But the German professor resigned from his position in 1912, only a few days after the first test had been carried out. The Department of Testing Materials served a double function.

Like other units of NTH, it served as a teaching institution to train engineers in the techniques of testing materials. The department also served as a public testing institution for private industry and the public sector. In the years after Egerer's resignation, the Department of Testing Materials was headed by engineers who carried out or delegated the tests, as well as lecturing in material sciences. In 1918 the Ministry of Church and Education approved the legal status of the department to serve as a public institution for testing materials. According to the regulations of 1918, only tests relating to mechanical properties of materials were carried out in the department's own laboratories, which were well equipped for this task. Other tests, for example regarding chemical or electrical properties of materials, were delegated to the NTH department that had both the expertise and the appropriate laboratories for such tasks. Accordingly, physical tests were to be carried out at NTH's physics department. In the first years there was very little co-operation between the physics department and the Department of Testing Materials. From a total of 5337 tests of different materials carried out between 1912 and 1927, only five tests were carried out by the physics department, compared to 1959 tests by the chemistry department, 178 tests by the electrical engineering department and one hundred tests by the geology department. 3068 tests were carried out by the mechanical laboratories of the Department of Testing Materials itself.[260]

With the testing of acoustical materials, the physics department got more involved in the business of testing materials. Several publications and other sources witness the extensive test series in the acoustical laboratories of the physics department. The tests included different construction materials, as well as different construction designs for walls and floorings. Construction designs and materials were often tested in combination. However, little of this business

[260] See, *Prøvingsanstalten gjennem 15 år (1912-1927)*, in *Norges Tekniske Høiskole- beretning for året 1925-1926* (1927), p. 73 ff.

seems to have been organised through the Department of Testing Materials. On the average only one test a year was mentioned in the annual reports of the 1930s. Avoiding the Department of Testing Materials may not be that much of a surprise. The department's testing procedures had a very formalised character resulting in a standardised test certificate. With official approval as a public testing institution, this document had a legal status that could be used as documentation, for example by a material's manufacturer. Most of the acoustical tests carried out by Holtsmark and Berg had very different character. The tests were usually commissioned by the user and not the producer of the materials. The test series were also usually of comparative nature. Different materials and construction designs were compared and optimised in certain combinations.[261]

Holtsmark and Berg's investigations did not only have a less formalised character than the tests of the Department of Testing Materials, they were also more scientific: in his consulting Holtsmark usually urged his client to investigate the problems at issue on scientific grounds. In the physics laboratory the problems were to be tackled in their principle physical origin. Holtsmark usually wanted the investigations to be more prolonged and theoretically oriented.[262] He generally argued that problems should be investigated in their profundity rather than treated superficially to serve temporary needs. In the long run the client would profit from such fundamental studies into the basics underlying the technology under investigation.[263]

Like architectural acoustics, the early history of acoustically engineered construction materials is also mainly attributed to Wallace Sabine. In 1911 Sabine, in co-operation with the ceramic-tile manufacturer Raphael Gustavino, developed the *Rumford tile*, a porous ceramic tile that absorbed about 26

[261] See for example Berg et al. *Lydisolasjonen mot bankelyd i gulvkonstruksjoner*, 1934. In the tests with 77 different combinations of materials a highlighting of certain materials as well as specification of companies was avoided. Holtsmark also repeatedly discouraged companies from having their construction materials tested acoustically. He argued that such tests would make little sense since it was not merely the material itself but the way it was used in construction that would determine its acoustical effect (See for ex. Holtsmark to *Materialprøvingsanstalten*, November 2, 1939, Statsarkivet i Trondheim - Arkiv *NTH-Materialprøvingsanstalten* NA: 75).

[262] See for example Holtsmark to *Telegrafstyret, søknad om bidrag*, April 5, 1939. Holtsmark contrasted practical trials to serve immediate needs with long term and more theoretically oriented tasks. The NTH should favour the latter.

[263] With advocating for fundamental studies in applied and industry related research Holtsmark was not alone in the interwar period. See Hagemeyer, 1979, p. 85 for fundamental research at the Bell Telephone Laboratories and Ramsauer, 1949, for the *AEG Forschungsinstitut* particularly p. 126.

percent of the incident sound energy.[264] In the following 20 years an endless number of acoustically engineered construction materials with promising properties appeared on the market. Many of these acoustical materials, often patented, would promise more than they would keep.[265] The increasing acoustical engineering of construction materials and designs did not happen in isolation but in the context of the growing engineering of construction materials in general. In the 19th century construction materials were to a large extent acquired, manufactured and installed locally and within a craft tradition. In the 20th century this situation had changed radically. Construction materials were increasingly mass-produced on an industrial scale. As a part of increasing standardisation they were also increasingly tested and constituted the vast majority of materials tested at NTH's Department of Testing Materials. Both the manufacturing of materials and the application of construction design and construction practices became increasingly dislocated. The realm of modern economic thinking with its categories of production and consumption started to dominate construction planning and execution. Ironically, as Holtsmark pointed out, there was a contradiction between economic thinking and progress: within the last generation construction materials were increasingly produced on the bases of modern engineering. But their quality, including their acoustical properties, had decreased considerably.[266]

The chronology of the development of sound laboratories at NTH's physics department cannot be re-constructed in complete detail. We can say though that during the 1930s, three rooms were finally converted to sound laboratories.[267] There were two constructions of fundamental difference, which were investigated at the physics department: first, wall constructions and second, flooring constructions. Measurements on wall constructions in the sound laboratory had started as early as 1931.[268] Wall constructions were either tested in test fields arranged in an opening between two laboratories, for measuring sound transmission, or within one laboratory, for measuring reflection and reverberation, respectively. The measurements were conducted over a range of audible frequencies using standardised gramophone records.[269] The instrument collection of the physics department contains an electroacoustic tone generator built at the department in the 1930s, suggesting that it was also used, together with a loudspeaker, as a sound source in measurements.

264 Thompson, 1997, p. 607-608.

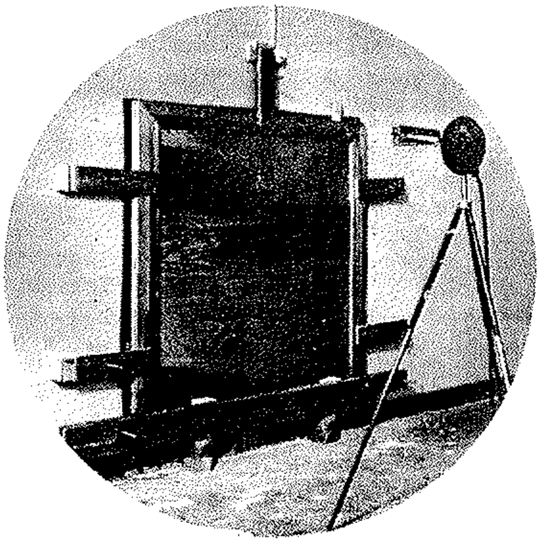
265 Holtsmark, Interview in *Oslo Illustrerte*, 1934, no. 5, p. 12.

266 Holtsmark, Interview in *Oslo Illustrerte*, 1934, no. 5, p. 12.

267 Krokstad, about 1965.

268 Berg and Holtsmark, 1931.

269 See, for example, Berg and Holtsmark, 1934, all four publications.



Mikrofonen står og lytter meget upartisk til de lyder som når frem gjennem de forskjellige veggkonstruksjoner.

Fig. 4.10: Test field for different wall constructions with microphone on tripod (*Forskning og fremskritt - Høittalere kan bygges helt fullkomne*, interview with Professor Holtsmark, *Oslo Illustrerte* no. 5, 1934).

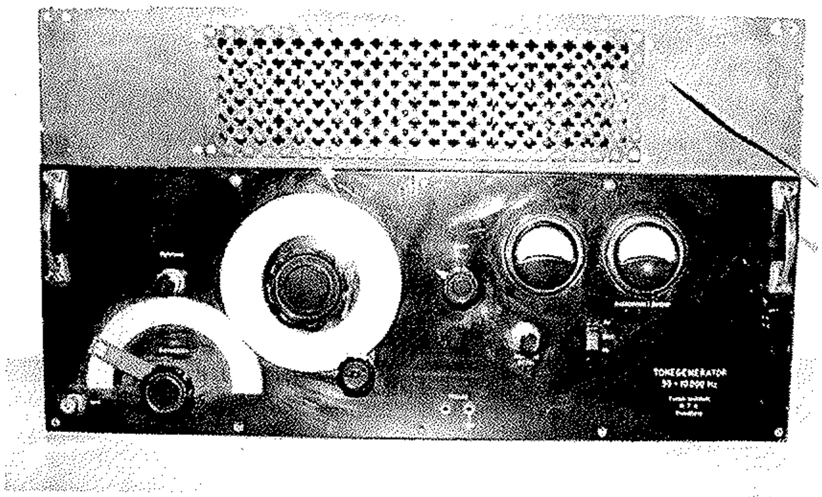


Fig. 4.11: Tone generator built at the physics department at Trondheim in the 1930s (Photo: Roland Wittje).

The testing of flooring constructions was again very different from the measurements on wall constructions. For flooring constructions the test field had to be in-between different floors. The measurements of the sound insulation or sound reflection qualities of wall constructions was always due to airborne sound, generated by means of test records or probably tone generators. The sound insulation qualities of floorings against airborne sound were, however, rather secondary. The researchers mainly investigated the insulation properties of the flooring against impact sounds, created by people walking on the floor above. In order to produce standardised impact sounds, the Trondheim acousticians developed a knocking apparatus (Fig. 4.12.). Regarding the impact sound, sound intensity was not measured over the single frequencies, like for wall insulations, but summarised over all frequencies. In order to account for the frequency sensibility of the ear, an ear filter (*ørefilter*) had to be applied. Fig. 4.13. shows the laboratory arrangement with the knocking apparatus and the measuring apparatus with amplifier, ear filter and sound intensity meter.

In 1931 the testing of the noise insulation of different flooring constructions against impact sounds started on the initiative of the municipal noise insulation committee of Oslo and with the support of 27 interested businesses. Beginning in the summer of 1932, Reno Berg tested different flooring constructions. The first laboratory was not set-up at NTH in Trondheim but in the unfinished building of the Norwegian School of Veterinary Science (*Veterinærhøiskolen*) at Oslo. The reason was most probably that the test field at the Trondheim physics department, requiring a square hole of two by two meters in the cement ceiling, was not established yet. Instead, Reno Berg was taking the laboratory instruments down to Oslo to the unfinished veterinary building. At least 77 flooring constructions were tested in the laboratory in the veterinary building and discussed in a 1934 publication.[270]

The test field at Trondheim was established at the latest by 1935.[271] For laboratory measurements the acoustical properties of the laboratory walls, ceiling and flooring had to be first considered. In 1937, Holtsmark and Berg started to investigate the interrelation between the insulation of wooden floorings regarding airborne sound insulation and impact sound insulation. For these measurements the airborne sound insulation of the laboratory ceiling

[270] Berg. R. R., Berner, F., Harboe, Edv. and Holtsmark, J.: *Lydisolasjon mot bankelyd i gulvkonstruksjoner*, *Byggekunst* 16, 1934, p. 132 - 140. The same article was also published in *Teknisk Ukeblad* 81, no. 33, 1934, p. 391 - 397. This article, together with Finn Berner, Professor of Architecture at NTH and the construction engineer Edvard Harboe was, however, Berg's and Holtsmark's only joint publication with architects and civil engineers.

[271] The test field is mentioned in a letter of Holtsmark to *Materialprøvingsanstalten*, September 25, 1935, Statsarkivet i Trondheim - Arkiv NTH-*Materialprøvingsanstalten* NA: 61.

around the test field proved to be insufficient. Building a sound insulating wooden box over the test field solved the problem.[272]

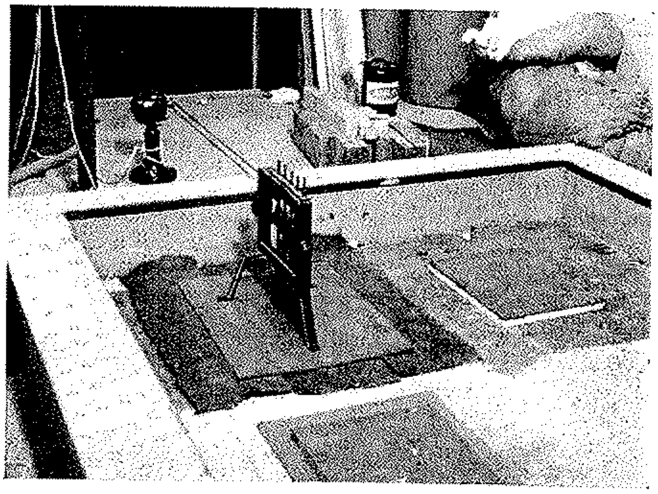


Fig. 2. Bankeapparatet anbragt på provegulvet i laboratoriet.

Fig. 4.12: Set-up of the knocking apparatus for generating impact sound on the flooring to be tested (Berg, Berner, Harboe and Holtsmark, *Teknisk Ukeblad,* August 17, 1934, p. 395).

[272] Berg and Holtsmark: *Die Schalldämmung von Holzdecken I + II*, 1937 and 1939.

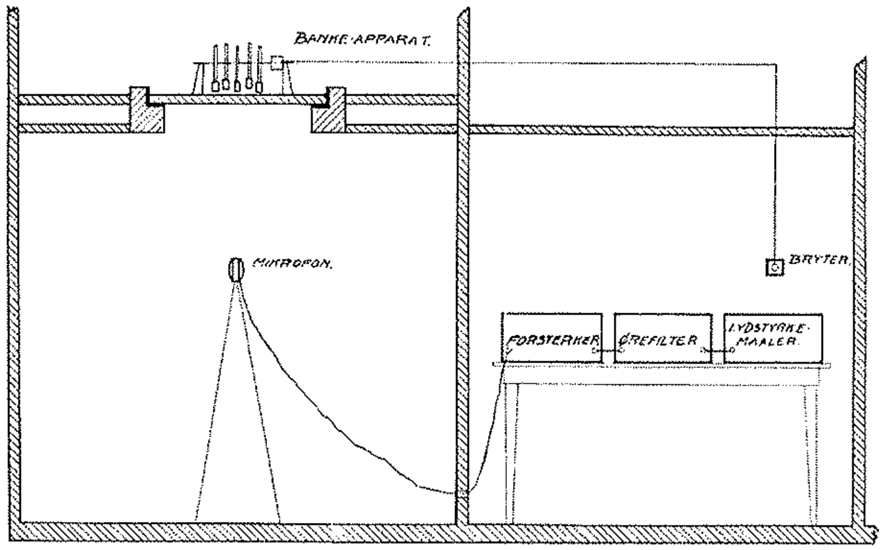


Fig. 4.13: Set-up of the laboratory for measurement of impact sound in flooring constructions (Berg, Berner, Harboe and Holtsmark, *Teknisk Ukeblad,* August 17, 1934, p. 395).

In several publications concerning sound insulation of wall constructions, Berg and Holtsmark made use of equivalent circuit diagrams in order to represent the wall as a mechanical oscillating system. These analogies were used in papers regarding theoretical as well as experimental investigations.[273] Equivalent circuit diagrams were frequently used for the representation of acoustical vibrations in scientific papers.[274] The use of equivalent circuit diagrams in publications by Holtsmark and Berg, together with Trumpy's lecture script (see this chapter, Section 4.1.), shows the wide presence of electrical analogies, not only in acoustics research instrumentation, but also in its representation and communication in teaching and research at NTH.

[273] See for example Berg and Holtsmark, *Die Schallabsorption einiger Wände und Decken,* 1931, and Holtsmark, *Zur Theorie der Schalldurchlässigkeit einer homogenen Wand,* 1930.

[274] In the publication *Die Schallisolation von Doppelwänden. I. Holz-Wände* (1935), for example, Holtsmark and Berg simply copied the equivalent circuit diagram from someone else's publication. Not all acousticians of the 1930s, however, used electrical analogies in acoustics representation. Engl, for example, limited the use of circuit diagrams in his *Bau- und Raumakustik* (1939) to the description of electrical measurement instruments.

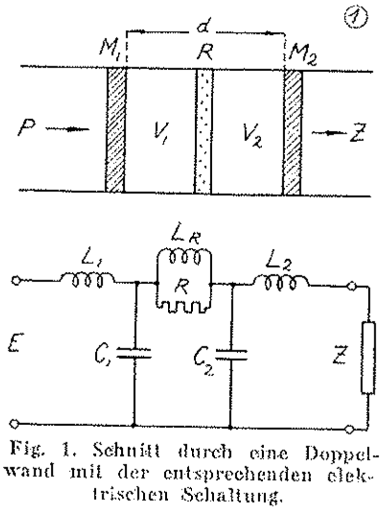


Fig. 4.14: Electrical equivalent circuit diagram of a double wall as a vibrating system with dampening (Holtsmark and Berg: *Die Schallisolation von Doppelwänden. I Holz-Wände*, 1935, p.75).

Berg's and Holtsmark's acoustical investigations were to a large extent connected with consulting assignments, such as to the construction of a soundproof telephone box for the Norwegian Telegraph Office (*Telegrafverket*).[275] Towards the end of the 1930s the Norwegian Broadcasting Corporation (NRK) became the largest customer for laboratory investigations of the NTH acoustics laboratories.

[275] Berg and Holtsmark, *Die Herstellung schalldichter Wände für Fernsprechzellen*, 1931.

4.5.3. Co-operation with the Norwegian Broadcasting Corporation

..."*« Give me a pack of students from N.T.H. and I will raise the earth »*"
[Erik Julsrud, 1950][276]

The co-operation between Holtsmark and the Norwegian Broadcasting Corporation (NRK) deserves special attention within the history of acoustics research at NTH during the late interwar period. From the mid-1930s NRK became Holtsmark's largest client for acoustics research and consulting. Around the outbreak of WWII, NRK gave comparatively large contributions to the acoustics laboratory at NTH's physics department which allowed Holtsmark to operate more freely than with fixed consulting assignments. The character of NRK as a public institution proved decisive for its co-operation with Holtsmark, and its practices of funding acoustics research at NTH. NRK's financing of research laboratories at NTH, which was a public institution organised under the same government department as NRK, lead to the debate about which institutions within the public sector should finance acoustics research, or more specifically, what part of the state budget should account for it. Norwegian physicists were heavily involved in the organisation and control of NRK with Sem Sæland as the chairman of the Broadcasting Program Commission and Olaf Devik as a member of NRK's board of directors.[277]

In 1934 Devik took the initiative to establish the Scientific Council of NRK (*Kringkastingens Videnskapelige Råd*). Among its members were four prominent Norwegian physicists, Sem Sæland and Lars Vegard from the University of Oslo, Olaf Devik from the Christian Michelsen Institute in Bergen and, as we expected, Johan Holtsmark from NTH at Trondheim. The other two members with academic background were NTH Professor of Telecommunication Engineering Ragnar Skancke and Jens Bache-Wiig, a former NTH Professor of Electrical Engineering. Bache-Wiig was now a director of the *International Standard Electric Corporation* in Berlin.[278] The

[276] Erik Julsrud, engineer in Norwegian Broadcasting Corporation, in *Vi fra N.T.H. - de neste ti kull 1920 - 1929*, (1950), p. 141, translated from the Norwegian original: « Gi meg en flokk studenter fra N.T.H. og jeg skal løfte jorden ».

[277] Devik was a member of NRK's board of directors from 1934 to 1936. See H. F. Dahl, 1999, p.367. According to Devik, Sæland also offered him the position of NRK's Program Director (*riksprogramsjef*) in 1933, but Devik declined the offer. See Devik, 1971, p. 134-135.

[278] Bache-Wiig's membership in the council was sharply criticised by the Norwegian trade journal *Farmand* (*Farmand - The Trade Journal of Norway*, Nr. 24 - 44. årgang, Oslo, June 16, 1934, p. 633). *Farmand* questioned Bache-Wiig's lack of bias as a representative of a

Scientific Council received its assignments directly from NRK's board of directors. NRK, in return, covered the Council's expenditure, including scientific investigations. The research agenda of NRK's Scientific Council concentrated on the propagation of radio waves through the atmosphere and especially their distortion by northern lights and did not include acoustical problems of radio broadcasting, as they were investigated in Holtsmark's laboratory at NTH. The Scientific Council thereby constituted mainly an institution to finance northern lights research of the Norwegian Institute of Cosmical Physics (*Det norske institutt for kosmisk fysikk*) under the directorship of Lars Vegard.[279]

It can be questioned why Holtsmark's acoustics research for NRK was not accounted for and organised through the Scientific Council. The answer might be that the acoustics research was more related to practical questions of radio broadcasting than northern lights research. As for most of Holtsmark's acoustics research, the research agendas financed by NRK were inextricably linked to Holtsmark's consulting activities. There was, however, one striking analogy between financing acoustics as well as northern lights research through NRK. In both cases it was the scientists who approached NRK and convinced its board of directors about the necessity of scientific research rather than NRK officials approaching the scientists and asking for advice. Facing the lack of other major public research funding, the community of Norwegian physicists had managed to utilise the public character of NRK and their own influence within its organisation, to mobilise funds from NRK for broadcasting-related research agendas such as technical acoustics and northern lights research.

NTH's position as the only Norwegian school for telecommunication engineers and Holtsmark's virtual monopoly on acoustics research resulted in a community of NTH graduates, usually former members of the Academic Radio Club and at some point affiliated with the physics department, who took a key position in the Norwegian radio industry as well as in the organisation and administration of broadcasting.[280] The appointment of the Trondheim amateur

major manufacturer of electrical equipment. The other members of the council defended Bache-Wiig's appointment by referring to his scientific and technical expertise and argued that it was important to have contact to the corporate laboratories of the industry. See correspondence between members of the council and NRK, NRK archive, 1934.

279 See correspondence between Scientific Council and NRK, NRK archive, 1934. Vegard received an annual contribution of about NOK 5,000 at least until 1939 for investigations about the propagation of radio waves. See draft by Chr. Vibe, *Bevilgninger til formål utenfor Norsk Rikskringkastings relære virksomhet*, January 7, 1941.

280 In *Kringkastingens tekniske historie*, Nils Mathisen describes the co-operation and consensus within this community of NTH-graduates as excellent and refers this to the common professional platform of everybody involved. See Mathisen in Andersen and Bernstein, 1999, p. 23.

radio veteran Erik Julsrud at the technical division of NRK in 1933, was characteristic for the links between the Academic Radio Club via Holtsmark's activities in acoustics at NTH and the NRK. After working as a private assistant for Holtsmark, Julsrud gained work experience with the *International Standard Electric Corporation* in London, Paris and Antwerp. In 1932, together with the NTH telecommunication engineer Frederik Møller, he founded the Oslo based consulting company *Akustikk A/S*. In 1933 Julsrud was appointed as an engineer at NRK where he later became chief engineer.[281]

Radio broadcasting in Norway, like other European countries, was from the beginning regulated and controlled by state authorities. In Oslo, public radio broadcasting started in 1925 with the formation of a joint-stock company, *Kringkastingsselskapet A/S,* with representatives of the Norwegian radio industry and mainly small stockholders, among these the Academic Radio Club with one share. The company was granted a concession by the Norwegian Telegraph Authority (*Telegrafstyret*). The Norwegian Telegraph Office held the technical responsibility for broadcasting. In 1933 the private broadcasting company was liquidated and broadcasting was taken over completely by the Norwegian state. This established the starting point for the Norwegian Broadcasting Corporation (*Norsk Rikskringkasting* or NRK).[282]

The take-over of broadcasting by the state and the foundation of NRK in 1933 also reflected on the 1930s as the consolidation phase of radio broadcasting in Norway and its breakthrough as a true mass medium. *Kringkastingsselskapet A/S* had rented its first studio in 1925 in a former factory for musical instruments, *Brødre Hals*, in Oslo. The walls and ceiling of the studio were covered with thick woollen carpets to deaden the sound, as it was common practice for broadcasting studios at the time. In the 1930s, the provisional studios that were used until then were not appropriate any more. With the consolidation and professionalisation of broadcasting and with innovations in radio technology, the demands on the technical and particularly acoustical qualities of the broadcasting program were increasing. With the formation of NRK in 1933, possibly even earlier, plans for an appropriate new building for the Oslo broadcasting studios, which included elaborate acoustical considerations, were developed.

[281] Julsrud transferred involuntary to the Norwegian Telegraph Office between 1936 and 1940. This referred to conflicts between the Telegraph Office and the Broadcasting Corporation about the technical responsibility for broadcasting. For Julsrud, see *Vi fra N.T.H. - de neste ti kull 1920 - 1929*, (1950), p. 141, and for the relationship between NRK and the Norwegian Telegraph Office, see Andersen and Bernstein, 1999, p. 117 ff.

[282] For the history of the private broadcasting company, its liquidation and the establishment of *Norsk Rikskringkasting,* see H. F. Dahl, 1999 and Andersen and Bernstein, 1999, p. 10-19.

The earliest documentation for Holtsmark's involvement in the planning of the new broadcasting house dates from December 1933 when Holtsmark, commissioned by NRK, drafted a memorandum about the necessity of a new broadcasting house. Holtsmark did not restrict his memorandum to the acoustical aspects of the planning but included considerations like space needed for certain arrangements, transport connections, real estate costs and even the availability of a restaurant for performing artists and visitors.[283] Also in later and more detailed proposals which Holtsmark drafted for NRK's new broadcasting house at Marienlyst, he placed the acoustical aspects of the broadcasting studios within a broader and partly non-technical context. Holtsmark's awareness of factors other than purely technical ones showed his understanding of broadcasting not merely as a technical but also as a social, cultural and economic system. Holtsmark made it clear in his proposals for the different studios that the acoustical properties were not static, abstract and merely technical values, but dynamic variables that had to be arranged in accordance with the architectural and economic considerations, and, most importantly, with respect to the different users of the studios.[284] Holtsmark's consulting for NRK did not only include the planning of the new Marienlyst studios but also the modification of existing studios in Oslo and else where.[285]

In 1936, Holtsmark together with NRK' chief engineer Christopher Vibe established NRK's *Committee for Acoustics Questions* (*Nevnden for akustiske spørsmål*, or NeFAS). It should not surprise us any more that Vibe was also an NTH-graduate from electrical engineering. He was some years older than Holtsmark and had graduated from NTH in 1915, long before the times of the Academic Radio Club and Holtsmark's appointment at NTH.[286] NeFAS was basically a planning and advisory committee but did not conduct investigations itself. In 1936, the same year NeFAS was founded, Holtsmark published the article *Einige akustische Probleme im Rundfunk* in NRK's lecture series (*Norsk Rikskringkastings Forelesninger*) where he summarised state-of-the-art acoustical planning of broadcasting studios and his own viewpoints. The

[283] Holtsmark to NRK, December 20, 1933, NRK-archive.

[284] At this point radio broadcasting clearly emerged as a seamless web of social, cultural political and economic considerations. Thomas Hughes *Technological System*-approach would probably be best suited to describe the technological development of radio broadcasting. It is, however, not my aim to write the technical history of broadcasting. See Bijker, Hughes and Pinch, *The Social Construction of Technological Systems* (1987), H. F. Dahl, 1999, *Innledning*, and Andersen and Bernstein, 1999, for the technical history of NRK.

[285] See for example Vibe to Holtsmark, November 8, 1933, NRK archive.

[286] Vibe had been, however, a member of the Trondheim Student Society's executive committee in 1914.

activities of NeFAS were centred around the acoustical planning of the new broadcasting house at Marienlyst, particularly the shape of the studios, their sound insulation against each other and the rest of the building, and the absorption materials to be used in order to adjust reverberation. In the reports, Holtsmark showed most interest in the planning of the large concert studio for the symphony orchestra, which reflected his personal interest for classical music and its performance. For the conduction of measurements and experiments and for the elaboration of detailed plans for the broadcasting house, the building committee contracted the consulting company *Akustikk A/S* that was headed by Frederik Møller after Julsrud's transfer to NRK.[287]

Holtsmark's consulting assignments with NRK and his activity for NeFAS, whose meetings were held at Oslo, did not involve other resources of NTH's physics department and were by Holtsmark rather treated as his private activity. But the co-operation between NRK and Holtsmark went further than Holtsmark's consulting and involved both the physics department's instrument maker shop and later also the acoustics laboratory. A number of measurement instruments were developed by telecommunication engineers and subsequently sold to NRK. The instruments were usually built in two copies of which one was sold to NRK and one was kept at NTH's acoustics laboratory. Through this strategy Holtsmark managed to build a number of measurement instruments for the research laboratory and let NRK pay for the development costs. The first measurement instrument sold to the broadcasting company, as documented in the archives, was the automatic reverberation measurement apparatus, built by Vebjørn Tandberg (See also Fig. 4.8.). Tandberg built the first apparatus for the physics department's acoustics laboratories in 1931, and a second copy in 1932, that was sold to *Kringkastingsselskapet A/S*. Together with the reverberation apparatus, Tandberg built a 6 W amplifier in 1932, which was also sold to the broadcasting company. According to Nils Mathisen, a second reverberation measurement apparatus was built at the NTH physics workshop for *Kringkastingsselskapet A/S* or NRK, which was based on a hydraulic principle and which had to be pumped up with a bicycle pump.[288] Several other devices made their way from their early development at the NTH physics department to NRK, via the private enterprises of the Tandberg Radio Factory and *Akustikk*

[287] See *Forslag til kontrakt mellem Byggekomiteen for Norsk Rikskringkastings nybygg og Akustikk A/S*, 1937, and Møller to NeFAS, February 16, 1937, both NRK-archive. For Møller at NTH, see this chapter, Section 3.1.

[288] Mathisen in Andersen and Bernstein, 1999, p. 23. For Tandberg's reverberation apparatus and the 6 W amplifier, see correspondence between Berg and Vibe in 1941, particularly Berg to Vibe, October 17, 1941, NRK archive. Berg also mentioned an amplifier built by Oddvar Johannesen for NRK in 1937, which otherwise is not documented.

A/S. This included condenser microphones and electrodynamic loudspeakers which were built for or in co-operation with NRK.[289]

The largest and best-documented assignment of building a measurement instrument for NRK was the construction of a fast registering decibelmeter between 1935 and 1937. In 1935, Holtsmark proposed to build such a decibelmeter in the physics' workshop. The Bell Telephone Laboratories and the Heinrich Hertz Institut in Berlin had built similar apparatus. Holtsmark argued that it would be cheaper to build such an apparatus at the workshop in Trondheim than to buy a similar one from America. He further argued that to build the instrument at NTH would help to acquire and maintain local (or we might call it national) expertise in the design of acoustics measurement apparatus. Holtsmark especially needed a new assignment for his assistant Eilif Bjørnstad, a skilled telecommunication engineer who had built scientific instrumentation in other research fields. Olaf Devik, consulted by NRK on whether the construction of the apparatus should be commissioned, supported Holtsmark by pointing out that it was of major importance for NRK to acquire and maintain instrument making expertise at NTH. The decision-making process within NRK to grant the NOK 5,000 estimated by Holtsmark for building the decibelmeter extended until August 1936. By then Bjørnstad had already started the construction based on a similar apparatus described in the *Journal of the Acoustical Society of America*. In the summer of 1936, Bjørnstad left the physics department and another telecommunication engineer, Oddvar Johannesen, continued with the construction of the decibelmeter. The instrument building also included a good deal of precision work on mechanical parts, which were mostly made by the instrument maker Toralf Nielsen at the workshop of the physics department. When the decibelmeter finally was finished in August 1937 it came out to be almost twice as expensive as estimated by Holtsmark in 1935. The Norwegian Telegraphy Authority, which had by then taken over the technical division of NRK, accepted that the apparatus exceeded the preliminary cost significantly and commented that the NTH apparatus was still cheaper than the comparable decibelmeter from the Bell Laboratories.[290]

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289 See Andersen and Bernstein, 1999, p. 54 and 55, Julsrud, 1980, 2nd vol. and Dahl and Svendsen, 1995, p. 77.

290 For Holtsmark's proposal to NRK, see Holtsmark to NRK, October 29, 1935. For Devik's recommendation, see Devik to NRK, June 22, 1936. For the higher price of the decibelmeter, see *Telegrafstyret* to NRK, September 2, 1937, all NRK archive. An article about the construction of the decibelmeter was published in *Fjernsyn & Radio*, August 21, 1937. See also Bjørnstad's publication in D.K.N.V.S. in 1936.

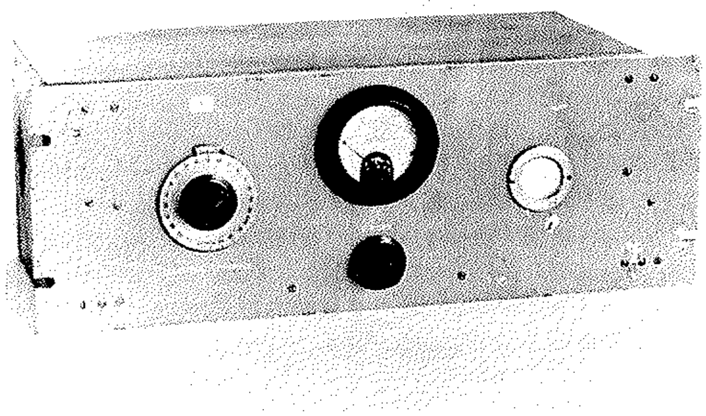

Fig. 4.15: Registering decibelmeter built for NRK by Eilif Bjørnstad and Oddvar Johannesen 1935-1937 (Photo: Erik Julsrud, Erik Julsrud's photo collection at the Norwegian Museum of Science and Technology).

In 1939 Holtsmark managed to get a general grant of NOK 15,000 for acoustics research from NRK which engaged the NTH acoustics laboratory more extensively in NRK-related research.[291] The largest single project to be financed by the grant was the model series of experiments by Helmut Ormestad for NRK's large orchestra studio. Ormestad, who was studying at the University of Oslo, was the first physics student involved in the acoustics research at NTH.[292] The grant of NOK 15,000, repeated in 1941, also employed a number of other assistants for shorter periods and procured more measurement instruments for the acoustics laboratory.[293] Holtsmark's most important contribution to the acoustics research for NRK during WWII was the development of slot resonators that were applied in the new studios.[294]

[291] To give an idea about this sum: The entire budget for the Department of Physics in the academic year of 1939/40 through NTH was, excluding salaries, NOK 18,000. A research scholarship given from NTH to graduated engineers amounted to NOK 3,600 in 1939. See *NTH-beretninger*.

[292] These model experiments were part of Ormestad's final thesis in 1940. See Ormestad, 1941, and Andersen and Bernstein, 1999, p. 23.

[293] See for example *Oversiktsregnskap* of Holtsmark, December 1940 and Holtsmark to NRK, February 6, 1941, both NRK archive.

[294] Berg and Holtsmark, 1943, and Andersen and Bernstein, 1999, p. 24.

Holtsmark's co-operation with NRK seems to have continued almost undisturbed through the first years of WWII and until Holtsmark moved the acoustics laboratory to the University of Oslo in 1942.[295]

Holtsmark's co-operation with the Norwegian Broadcasting Corporation constituted a link between NTH and Norwegian society outside the academic system. Other links were established by business ventures. Whereas most engineers who graduated from NTH chose to seek employment in the industry or the public sector, some chose to start their own business enterprise. One of them was Holtsmark's assistant Vebjørn Tandberg. In the next section we will look closer at the relationship between Tandberg's activities as Holtsmark's research assistant and the foundation of the Tandberg Radio Factory.

[295] In Oslo, Holtsmark continued his co-operation with NRK with the physics building at the *Blindern* campus being the direct neighbour of NRK's new broadcasting house. For the technical department of NRK during WWII, see Andersen and Bernstein, 1999, p. 103 ff.

4.6. Launching from the physics department for industry-building: The Tandberg Radio Factory

" *When I started at the Norwegian Institute of Technology I took along the doctrine of systematic troubleshooting, and that was of use both when I was a student in Trondheim and maybe even more when I became Professor Holtsmark's assistant for two years. He was an enormously inspiring boss. With him I dealt with everything between heaven and earth, I was allowed to build radio apparatus for him, I continued to construct loudspeakers, which had been my thesis, [and] I measured acoustics. All these were things I should find good use for when I once came so far that I could start my own factory. ...*"

[Vebjørn Tandberg, 1976][296]

"*... [The Tandberg Radio Factory] actually started in the basement of the Department of Physics, N.T.H., inasmuch as it was there I took up the beginnings of the fabrication of loudspeakers.*"

[Vebjørn Tandberg, 1950][297]

Vebjørn Tandberg is the most recognised and legendary personality in the history of the Norwegian radio industry. Tandberg's suicide after the bankruptcy of his company and the subsequent take-over by the Norwegian state in 1978 contributed to the legend and made Tandberg one of the most tragic figures in the Norwegian industrial landscape. Tandberg was known for living in a symbiotic relation with his company. Loosing his life after loosing control of his lifework, and seeing it collapse, is consistent with the picture of the hero of Norwegian radio, his triumph and his tragic fall.[298] The Tandberg Radio Factory was the largest commercial enterprise that was started by one of Holtsmark's assistants. Being an engineer and not an economist, Tandberg was known to not build budget-products, but only high quality instruments. Tandberg himself emphasised the close relationship between practices and products of scientific instrument building at NTH's physics department and the production of radio equipment at the Tandberg Radio Factory.[299]

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296 Vebjørn Tandberg, *Mennesket i bedriften*, 1976, p. 24, translated from Norwegian.

297 Vebjørn Tandberg about himself in *Vi fra N.T.H. - de neste ti kull 1920 - 1929*, (1950), p. 360, translated from Norwegian.

298 See Dahl and Svendsen, *Vebjørn Tandberg - Triumf og Tragedie*, 1995.

299 See, for example, quotes above.

Vebjørn Otto Tandberg was born in 1904 in Bodø, Northern Norway, as the son of a merchant. Like many boys and male teenagers of his generation, he developed a strong interest in amateur radio technology, which was supported by his uncle and engineer Reiert Tandberg. The enthusiasm for radio was also the motivation for Tandberg to start studying telecommunication engineering at NTH in the summer of 1926 in order to become a radio engineer. Ragnar Skancke had been appointed as Professor of Telecommunication Engineering in 1923, and 1926 was the first year the electrical engineering curriculum was divided into the disciplines of telecommunication engineering (*svakstrøm*) and electric power systems and machines (*sterkstrøm*). At NTH Tandberg continued to follow his interest for amateur radio and became an energetic chairman of the Academic Radio Club in 1929, the year the Student Society moved into its new building and the radio club into the radio attic. The club was dormant after Thorleif Dovland had graduated and left in 1927, and Tandberg brought it to new life with meetings and technical lectures.[300]

Tandberg unavoidably established contact with Johan Holtsmark through the radio club, if not before. For his diploma thesis in telecommunication engineering, he investigated loudspeaker design and built his own electrodynamic loudspeaker at the physics department with Holtsmark as his advisor. The thesis was graded with the best grade possible, 1.0. Between 1931 and 1933 Tandberg worked as Holtsmark's private assistant and built electroacoustical devices, such as loudspeakers, microphones, amplifiers and the reverberation measurement apparatus mentioned earlier (see Fig. 4.8.), which was the physics department's first electroacoustical precision measurement apparatus. Tandberg's most distinguished instruments remained to be his electrodynamic loudspeakers. He was known to be absorbed by problems related to reaching optimal sound quality for his loudspeakers. Together with Holtsmark, Tandberg sent a patent inquiry for his spherical loudspeaker design to the Norwegian Patent Office in 1932. The patent was refused in 1936. However, the loudspeakers constructed by Tandberg proved to be superior to others available on the radio market and gave the Tandberg Radio Factory a competitive edge. Tandberg continued his interest for sound propagation, sound measurement and the optimal loudspeaker throughout his life. In their Tandberg-biography, Helmer Dahl and Arnljot Strømme Svendsen expressed it like this: "*... In a way, the loudspeaker has come to be a close friend, a part of his [Tandberg's] inner life.*"[301]

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[300] Dahl and Svendsen, 1995, p. 61, citing *Norsk Radio*.

[301] Dahl and Svendsen, 1995, p. 44-45, citation on p. 45, translated from Norwegian. The circumstances around the rejection of the patent are not known. The superiority of a loudspeaker built at the physics department compared to commercially available loudspeakers was also discussed in an interview with Johan Holtsmark in *Oslo Illustrerte* in 1934 (*Høittalere kan nu bygges helt fulkomne*, *Oslo Illustrerte* no. 5, 1934). Even though

Fig. 4.16: Vebjørn Tandberg as private assistant of Professor Johan Holtsmark from 1931-1933 (H. Dahl and Svendsen, 1995, p. 40).

Tandberg himself claimed that the launching of his factory derived from the manufacturing of loudspeakers at the physics department's workshop.[302] Tandberg originally wanted to locate his company in Trondheim in order to maintain his close contacts with Holtsmark and the NTH environment. But he needed his father's financial support, who wanted him to start in Oslo, where he perceived the customers were located.[303] Due to his father's requirements Tandberg established his radio factory as a registered company in Oslo in January 1933. Tandberg hired also other telecommunication engineers from NTH who had worked as assistants at the physics department. Olav Slotnæs had

not mentioned in the interview, it is most probable than this loudspeaker was built or at least designed by Tandberg.

[302] See quote above and Fig. 4.17. One of these loudspeakers, labelled "*Vebjørn Tandberg, Elektroingeniør*" is found in the collection of the *forsterkergjengen* at the Trondheim Student Society.

[303] Dahl and Svendsen, 1995, p. 42.

graduated from both the telecommunication and the power current division of the Department of Electrical Engineering and was Holtsmark's private assistant for six month in 1933 before Tandberg employed him as his production manager.[304] Matz Jenssen worked at the Tandberg Radio Factory from 1940 to 1943 and 1946 and 1947, before he became Professor of Radio Techniques at NTH in 1950.[305]

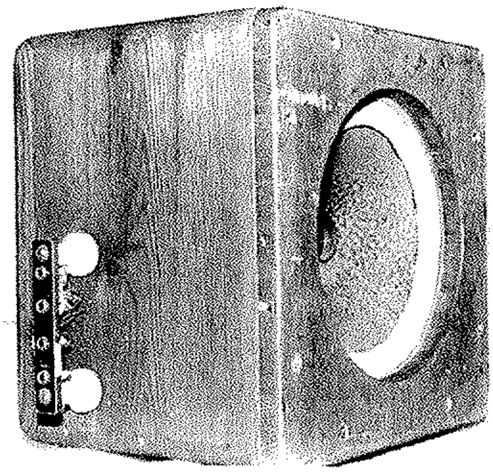

Fig. 4.17: Electrodynamic loudspeakers made by Vebjørn Tandberg at NTH's physics department in the early 1930s (Photo: Roland Wittje).

From Tandberg's biographies it has to be concluded that apart from his interest in sound propagation and loudspeaker design he had no strong scientific ambitions. Throughout his studies and his assistantship with Holtsmark, Tandberg followed his intentions to establish his own radio manufacturing company. Tandberg nevertheless saw his involvement into the construction of scientific instrumentation and the scientific investigation of sound as helpful if not a necessary base for his industrial enterprise. He fully agreed on the viewpoint that it was important in modern production life to be familiar with

304 Dahl and Svendsen, 1995, p. 71, and *Vi fra N.T.H*, p. 405. Slotnæs designed and built a tone generator and a five-tube radio receiver for Holtsmark. See Holtsmark, *Attest*, December 5, 1933, Archive *NTH-Fysisk institutt*.

305 See also this chapter, Section 3.2.

the scientific background of the products developed.[306] In the example of the Tandberg Radio Factory we can follow the transition of scientific practices into practices of radio design and production, the transition of scientific devices into radio technology as home equipment, and the transition of scientists and scientific instrument makers into radio manufacturers. Whether the Tandberg loudspeaker, for example, was applied as a piece of scientific instrumentation within acoustics investigations or as a piece of home radio equipment, was determined by the context of the use of the artefact rather than the design of the artefact itself. There is a striking parallelism between these transitions and the transformation of amateur radio practices into scientific practices and the transition of amateurs into scientists and builders of scientific instrumentation. Tandberg has lived through both transitions: from being an enthusiastic radio amateur and chairman of the Academic Radio Club, he turned into a maker of precision measurement instruments in the scientific context and finally into a producer of commercial radio equipment.

The founders of the other two important Norwegian radio manufacturers of the 1930s were electrical engineers as well. Jan Wessel, founder of *Radionette* and Salve Staubo, founder of *Høvding,* both studied in Germany and had some background from the USA.[307] Several other engineers from NTH were working in the Norwegian radio industry. *Edda Radiofabrikk,* the only Trondheim based radio manufacturer, was established in 1939 by the NTH telecommunication engineer Sverre Lund.[308] None of these radio manufacturers, however, had managed to acquire the same legendary status for themselves and their products as Tandberg and his Radio Factory.

[306] Dahl and Svendsen, 1995, p. 69. In an article in *Teknisk Ukeblad* in 1935, Holtsmark argued in a similar way for the necessity to be able to think and work scientifically in modern production life. See quote of Holtsmark in Chapter 5, Section 4.

[307] Dahl and Svendsen, 1995, p. 84.

[308] Lund was apparently not affiliated with the physics department but was an assistant in telecommunication engineering at the Department of Electrical Engineering.

4.7. Concluding remarks

During the 1930s acoustics became Johan Holtsmark's main research interest. What was his motivation to engage in technical acoustics and electroacoustics and build up a research laboratory at NTH?

In his autobiographical lecture script *Noen erindringer fra akustikkens barndom i Norge,* Holtsmark mentioned a visit to Leipzig in 1913 as his first encounter with the discipline, where he experienced the much discussed acoustics of the world-famous concert hall *Leipziger Gewandhaus.* He also quoted Sem Sæland's talk in 1920, about his study tour to the United States. Sæland had mentioned the acoustical investigations of Wallace Sabine in Boston's Memorial Hall. Technical acoustics as a research and teaching subject at NTH made sense because of its potential for co-operation with other departments as well as a field of activity for technical physicists in the industry. There was little or no competition in architectural acoustics in Norway. Holtsmark was the only specialist in this field and had a monopoly on consulting and authority in architectural acoustics.

However, the engagement in acoustics at the Physics Department of NTH was really triggered by the presence of the Academic Radio Club in the physics building. It was the telecommunication-engineering students who started to build equipment, such as the provisional broadcasting station in 1926, as well as loudspeakers and amplifiers. Holtsmark both supported this activity and involved himself. He declared that the initiative to establish a lecture course in acoustics came from the students themselves. It seems like Holtsmark became motivated to engage in electroacoustics through the enthusiasm of the radio amateurs. In the early years of ARK, Holtsmark was not much older than the rest of the crowd. Like many advisors of graduate students Holtsmark let students work with what they were interested in themselves. Consequently, it was the students and their interests that determined to a large degree the acoustics research activities at the physics department.

The atmosphere of dynamism in acoustics applied not only to Holtsmark and his students, the whole field was in motion. New technologies like radio, sound motion picture and other technologies of electrical amplification of sound and music challenged established acoustics in its traditional measurement instrumentation and experimental practices, but also in its representation in journal articles and textbooks. It was both a scientific discipline, and a piece of social, cultural and political reality that was re-shaped. Architectural acoustics did not stay in the laboratory but moved out in the field, travelled around in Norway, measured properties of concert halls, motion picture theatres and hospitals. It defined the timbre of broadcasting studios and thereby the sound in the living rooms of the Norwegian families. The way Vebjørn Tandberg learned to measure sound at NTH affected the characteristics of generations of Tandberg audio products.

Other research activities of Holtsmark, like electron scattering and nuclear physics, were mainly directed towards international research communities. By establishing these research agendas, Holtsmark introduced new research practices and bodies of knowledge in Norway. These activities were, however, rather removed from everyday Norwegian life. Technical acoustics, in contrast, intervened directly with everyday life. In this sense, acoustics was an important agenda within the modernisation of Norway. But architectural acoustics and the technical realisation of media, such as sound motion picture and radio broadcasting was only one way in which technical acoustics could aid in the modernisation of Norway. Olaf Devik had very different ideas about how technical acoustics could be applied within Norwegian society. When he left his lecturing position at the physics department of NTH to become a fellow of the Christian Michelsen Institute in Bergen, he proposed the idea of developing an acoustical system for navigation aid in bad weather. Air sound transmitters had long been used for sending fog signals on ships. The NTH telecommunication engineer and senior member of the Academic Radio Club Helmer Dahl was Devik's assistant in these observations. He later recalled the following about their experiences with carrying out acoustical measurements over the open Norwegian Sea:

> " *Through longer time periods, the measurements were carried out at the lighthouses, it was especially the Marstein and Geitungen lighthouses that were the workplaces. Devik chose to do little in the laboratory and go directly out in the field. With his ability to awake interest and to establish contacts, he obtained the best co-operation with the lighthouse-crew and the fishermen. We measured on the lighthouses and out on the sea. It has to be said that a fishing boat is not a good laboratory, particularly during bad weather, and one should have good sea legs. But it was in bad weather that we had to measure, and so it was done. For those who should arrange coastal navigation it was no bad school to live for some time in a lighthouse and to sail with the small boats.*"
>
> [Helmer Dahl, 1979][309]

Helmer Dahl's description illustrates that Holtsmark's going out in the field to measure architectural acoustics in concert halls differed essentially from Devik's approach. Both Devik's and Holtsmark's approach to acoustics were not a mere academic exercise, but aimed at changing Norwegian reality within a

[309] Helmer Dahl in *Fra solatmosfære til havdyp*, 1979, p. 208, translated from Norwegian. Parts of Devik and Dahl's work was published in 1935 in the *Journal of the Acoustical Society of America*.

framework of modernity. Holtsmark's research and consulting in acoustics contributed to the humanist project in a very different way than Devik's. Devik's goal was to save the lives of Norwegian fishermen and sailors. Holtsmark's acoustics ideal was rather directed towards the sensation of hearing and the fine arts: the delight to listen to the Oslo symphony orchestra in your living room as if you would be sitting in the concert hall. Holtsmark's approach to acoustics was an urban activity with urban cultural values. In contrast, Devik's acoustics stayed with the fishermen, one of Norway's most traditional ways of living with deep roots in the rural coastal communities.

From the local and national perspective we should come back to the global picture. Modernisation through acoustics affected local communities in different ways. But the impulses for change and the electroacoustic technology were global. The media and telecommunication industries made the world smaller in the way that they established mass communication and brought sounds and images from all over the world to the local motion picture theatre and even into people's private homes. The USA was the leading power in this development. The German electrical industry and academic environment, which was traditionally Norway's main influence, maintained a strong position of autonomy and integrity against American practices. Were activities in acoustics at NTH oriented more towards the USA, Great Britain or Germany? From where did Holtsmark and his students borrow their ideas and practices? A majority of the impulses came from America. Germany as well as the rest of Europe had a difficult time to keep up. Research activities in America's huge corporate laboratories like Bell and other American electrical companies had little to be compared with in the Old World. The amateur radio movement was strongest in the USA. Amateur radio was a hobby for young boys, which went well with American culture, American identity and American values of personal freedom, unlimited communication and mass culture and mass technology. Most of the amateur radio literature came from the USA. In Germany amateur radio was much more restricted by the broadcasting monopoly of the state. With Adolf Hitler and the Nazi regime, the broadcasting system was transformed into part of the propaganda apparatus, all amateur radio activity was declared illegal and the amateur clubs were liquidated. The *fiddling radio amateur physicist* was more an American than a German phenomenon. An exception for Germany in this instance was Manfred von Ardenne, the self taught Baron with his private research and development laboratory, who contributed to technological developments like radio tubes, the cathode ray oscilloscope, television and the raster electron microscope. But how seriously was von Ardenne taken by the German academic environment, when he called himself a physicist without possessing a diploma?[310]

[310] von Ardenne, 1987.

Germany's electrical industry was, even though struggling to keep up with the USA, Europe's strongest. In 1928 the *Heinrich Hertz Institut für Schwingungsforschung* was founded in Berlin in close contact with the *Technische Hochschule Berlin-Charlottenburg.* The *Heinrich Hertz Institut* was Germany's strongest research environment of technical acoustics and electroacoustics combined with communication technology. Holtsmark had contacts to the *Heinrich Hertz Institut,* particularly to Erwin Meyer. Holtsmark was more connected to Germany and had not travelled to the USA during the interwar period. But he became a member of the Acoustical Society of America in 1931. He reviewed articles of the *Journal of the Acoustical Society of America* for the German *Physikalische Berichte,* and thereby took the role as a mediator between the American and the German scene.

4.8. Beyond electroacoustics

The impact of the electrical engineer on scientific instrumentation

So far we have looked at the transfer of knowledge and practices from amateur radio and informal student networks to acoustics research in academic laboratories and further to the radio industry. However, the emergence of a novel kind of research instrumentation based on applying components and practices from radio technology did not stop with acoustics. The advance of radio technology based instrumentation can be observed in all fields of physics research during the 1930s. Electrical sensors were developed in order to detect sound, light, temperature, radioactive radiation, vibration and other observables, and to transfer their values into electrical signals. These electrical signals were then amplified with the help of radio-tube based circuits and could be observed and registered by cathode ray oscilloscopes or counters, or plotted out. The measurement data could also be refined or manipulated with the help of filters, oscillators, and other electric circuits based on radio tubes. As we have seen in the case of acoustics, signals were not only detected but also created electrically by means of signal generators. Moreover, electrical circuits were being introduced in order to control increasingly complex research installations like particle accelerators. Electrical technology of the 1930s was mainly analogue technology, translating a variable into an analogue electrical signal. The amplitude and time variation of the electrical signal was then equivalent to the value and the time variation of the observable.[311]

[311] There was, however, also a development of digital electrical systems and calculating machines during the 1930s. See Ceruzzi, 1983.

The use of equivalent circuit diagrams in the representation of acoustical systems has been discussed in the previous sections of this chapter. The thinking in terms of analogue equivalent circuit diagrams opened the way to the development of analogue electrical calculating machines: if a mathematical problem could be represented by an electrical circuit, this electrical circuit could be built as an electrical machine. The electrical analogue calculating machines of the 1930s were adding to the mechanical, optical and hydraulic analogue calculating machines developed at the time. The best known among these was Vannevar Bush's differential analyser at the Massachusetts Institute of Technology (MIT).[312]

At the small Trondheim physics department, Johan Holtsmark pursued several advanced research agendas simultaneously. A strategy to establish and maintain these different research agendas was to find intersections that would tie these agendas together and reinforce them. Such intersections between different research agendas could be found in different spheres. In scientific instrument making, they were represented by sharing practices of instrument design and making, as well as workshop facilities. In the experimental sphere, the intersections were represented by sharing experimental practices and techniques, instruments, research installations and laboratory space. In the sphere of theoretical investigation, the intersections were represented by sharing theoretical methods and models. The example of the analogue circuit diagram and the analogue electrical calculating machine shows that the levels of theory, experiment and instrument making were not necessarily separated. The intersections that tied together the different research fields included material objects as the scientific instrument and the workshops and laboratories as the premises to house the activities. But they also included the people working in these premises, the researchers and the instrument makers and their knowledge, skills and work capacity.[313]

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[312] There is a large amount of literature on the history of computing, including analogue calculating machines. See, for example, Allan G. Bromley: *Analog computer devices*, Chapter Five in Aspray, 1990, Croarken, 1990, Hartmut Pezold: *Wilhelm Cauer and his mathematical device*, in Finn, 2000, p. 45 ff. and Hartree, 1950.

[313] Peter Galison has described what I call *intersections* as *trading zones*. Like my intersections, Galison's trading zones include practitioners, devices, techniques, theoretical entities and other. See Galison 1997, especially Chapter 9. However, considering the small size of the Trondheim physics department I find it more appropriate to describe the overlaps that tie the different research agendas together as intersections. I do not want to construct a strong theoretical model through the idea of the intersection like Galison with his trading zones. I mainly want to make an argument about how different research fields are tied together by sharing different entities such as personnel, various forms of knowledge, space and technical devices. To make the argument complete for a teaching institution like NTH's physics department, aspects of teaching would have to be included, which I have left out in order to keep the picture more simple at this point.

At the physics department of NTH, most of the research agendas were administrated by Holtsmark and carried out by him and his research assistants. Because of the lack of institutional borders, research practices and practices of scientific instrument making could easily be shared between different research fields.[314] The instrument workshop was organised under the firm hand of the sovereign senior instrument maker, Reed. The emergence of radio-technology based research instrumentation did not seem to have led to major conflicts between the traditional instrument makers and the electrical engineers who assembled the new radio technology.

In the mid-1930s Holtsmark, his assistants and the workshop staff had built up a tradition in constructing electroacoustic instrumentation, first in the amateur radio context, and since around 1929 in the acoustics research context. With the construction of radio-technology based instrumentation and with practices of applying and controlling this novel research instrumentation, research fields that seemed to be very distant from each other, suddenly had something in common. Links through instrumentation allowed scientists and engineers to enter a research field that otherwise was not seen as their domain.[315] From the mid-1930s telecommunication engineers with a background in amateur radio began to build radio-technology based research instrumentation at NTH for research fields other than acoustics. In doing so, some of these engineers crossed several research fields. Eilif Bjørnstad, for example, was involved in the construction of a registering decibelmeter for acoustics, the design of an analogue electrical calculating machine for electron scattering and the building of an automatic cloud chamber and an electric counter arrangement for the Van de Graaff accelerator laboratory. Roald Tangen started with an assignment on radio technology and continued being appointed to the Van de Graaff accelerator project. With the Van de Graaff accelerator Tangen also crossed the lines from being an instrument maker to become an instrument user and subsequently one of Norway's first nuclear physicists.[316]

314 The picture changes when we look at the comparatively scarce co-operations across departmental or disciplinary borders within NTH. But students and research assistants from chemical and electrical engineering could penetrate relatively easy into the physics department under Holtsmark relatively easy. See Chapter 3, especially Section 4.4. Also within the physics department the sharing of research practices and resources was not always unproblematic. The lecturer Olaf Devik, for example, organised and followed his research agendas independently from Holtsmark. Devik's claim for independence from Holtsmark and its consequences for the construction of a particle accelerator at NTH are discussed in Chapter 5, Section 3.

315 Again, see Galison, 1997, for his concept of the *trading zone*.

316 On Tangen and the Van de Graaff accelerator, see Chapter 5, Section 7.4. and 8.

The importance for the transfer of radio technology and practices, and the appointment of personnel with amateur radio background for the Van de Graaff accelerator project at NTH will be dealt with in the intermezzo following this chapter, as well as in the next chapter. In the next section we will look closer at yet another research agenda at NTH's physics department where the transfer of personnel and practices from amateur radio and electroacoustics research played a significant role: electron scattering.

4.8.1. Analogue computing and electron scattering

The electrical calculation of scattering curves

Electron scattering was a research field taken up by Holtsmark during a research stay at the Institute of Theoretical Physics at Copenhagen in July 1927. In the early 1920s the German physicist Carl Ramsauer had observed that slow electrons penetrated argon and other noble gasses in a way that could not be explained by classical particle scattering. At very low velocities of only a few volts, the free path length of the electrons increased considerably with decreasing velocity. Other physicists made similar observations. The puzzling non-classical effect became established around 1923 as the Ramsauer effect, before quantum mechanics was fully formulated.[317] In 1926 Max Born opened a new way to a theoretical explanation of the Ramsauer effect by applying wave mechanics to the collision process. However, the first quantum mechanical calculations of the collision of slow electrons with the atomic shell did not agree well with the experimental data of Ramsauer and others.[318]

Together with the Swedish physicist Hilding Faxén, who visited the Copenhagen Institute at the same time, Holtsmark derived in the summer of 1927 the first satisfying quantum mechanical theory of the scattering of slow electrons by atoms of noble gases that provided good agreement with experimental data.[319] Holtsmark and Faxén derived their scattering equation by applying Schrödinger wave mechanics and by making use of analogies from classical acoustical wave scattering, explicitly citing from Lord Rayleigh's *Theory of Sound*. The calculation of the wave function of the scattered electron

[317] See Soon Im, 1995. The abnormality of slow electron penetrability for certain gases was also observed by Nils Åkesson, Franz Mayer and John Sealy Edward Townsend. The effect is also known as the Ramsauer-Townsend effect.

[318] Soon Im, 1995, p. 294-295.

[319] Faxén and Holtsmark, *Beitrag zur Theorie des Durchgangs langsamer Elektronen durch Gase*, 1927.

required numerical methods, even for the simple case of hydrogen, which did not show the Ramsauer effect. Whereas Faxén seemed to have left the field of electron scattering after the co-operation at Copenhagen, Holtsmark continued during the following years to calculate the effective cross-section of a number of gases by using Douglas Hartree's simplified method of the self-consistent field.[320] Together with his earlier work on the Stark effect and the width of spectral lines, which was carried out around 1919 and through the early 1920s, the Holtsmark- Faxén equation and his application of a modified Hartree field became Holtsmark's internationally most recognised contributions to physics.[321]

Holtsmark's investigations were of purely theoretical character to begin with. Around 1930, Holtsmark and one of his assistants, Wilhelm Holst, also turned to experimental investigations in electron scattering. Holst graduated from chemical engineering in 1931, and worked for one and a half years as Holtsmark's assistant. Holst and Holtsmark copied the experimental methods from the Ramsauer scholar Ernst Brüche at the *AEG Forschungsinstitut* in Berlin. The NTH physicists were able to borrow most of Brüche's set-up, including the collision chamber, of AEG. The collision chamber was sent to Trondheim in November 1930, and other parts of the set-up, including the arrangement for the electrometer and the coils for bending the electron beam, followed in February of 1931, after Holtsmark visited the AEG researchers in Berlin.[322] In 1933 Holst left Trondheim for *Stockholms Högskola* where he worked under Erik Hulthén on spectroscopic investigations. He defended his *dr.techn.*-thesis on *Spektroskopische Untersuchungen über einige Aluminium-verbindungen* at NTH in 1936.[323]

Holtsmark continued his theoretical investigations, which increasingly included elaborate numerical calculations. Already in 1928, Holtsmark had appointed assistants to carry out the numerical calculations, mostly women who were office personnel of NTH. The chemical engineer Arne Schulerud and the student Fridtjov Grøntoft carried out the calculations for *Zur Theorie der Streuung von langsamen Elektronen*, published in 1928. Julie Thaulow, Holtsmark's office worker at the physics department, carried out the

[320] See Soon Im, 1995, p. 295 and Holtsmark, for example *Elastic Electron Scattering in Argon*, 1933.

[321] See for example Mott and Massey, 1965 p. 25 and p. 774 ff. and Max Born in his Nobel Lecture, 1954 (Nobel Lectures - Physics, 1964, p. 263). For Holtsmark's work on the Stark effect, see Born, 1933, § 88.

[322] See Holst and Holtsmark, 1931, the letter from Holtsmark to the President of NTH, November 24, 1931, Eb:1 and the correspondence between Holtsmark and AEG in 1934 about the return of the apparatus, Ea:4. All archive *NTH-Fysisk institutt*, Statsarkivet I Trondheim

[323] *NTH beretning for året 1935-36*, p. 51.

calculations for the publication *Der Wirkungsquerschnitt des Kryptons für langsame Elektronen* in 1930. For *A Calculation of the Atomic Fields of Neon by Means of Screening-Constants* in 1933, Schulerud again carried out the numerical calculations. For *Elastic Electron Scattering in Argon. Computation of the Phase Differences from Experimental Results* in 1933, Gunhild Pleym-Hansen, again one of Holtsmark's women office workers, carried out the numerical calculations. For *Some Numerical Data to the Method of Gauss for the Calculation of Definite Integrals of Polynomials to the 25th Degree* in 1934, Guro Nordahl-Olsen, who was a female telephone operator at NTH, carried out the numerical calculations. The calculations were most probably carried out with the help of the physics department's desk calculators, which included a half-automatic Mercedes-Euklid calculator and a Brunswiga mechanical crank-handle calculating machine.

The numerical calculations for electron scattering were the only occasions where women became visible in physics research at NTH. Until 1929 only seven women had graduated from chemical engineering at NTH and none of these worked as assistants at the physics department. There was no woman among NTH's academic staff and the only women were found among NTH's office personnel.[324] Office assistants and telephone operators were, besides undergraduate students, the cheapest labour at NTH. Thaulow and Pleym-Hansen's official title was *kontordame* (woman office worker), not secretary. NTH had only one official secretary, a representative position that was held by a man. Office personnel like office workers and telephone operators were listed at the end of NTH's list of officials and employees topped with the professors and carefully arranged in a ranking order.[325] The employment of women as computers, as they were titled, for numeric calculations was widespread in the international scientific community. Most known among them are the women computers of the Los Alamos nuclear weapons work during World War II. Cheap labour was one reason why it was predominantly women who were employed as computers. Women were also generally seen as better qualified for work that demanded concentration and accuracy.[326]

Holtsmark had given over his earlier research field, the Stark effect and the width of spectral lines, to his assistant Bjørn Trumpy, who delivered his *dr.techn.*-dissertation on this subject in 1927. Also in the case of the research field of electron scattering, Holtsmark gradually engaged assistants in the

[324] See *NTH-beretninger*. The annual reports, however, left out cleaning personnel, among whom more women might be found.

[325] See *NTH beretninger, personalet*.

[326] For women as computers as well as scanners for particle traces, see Galison, 1997, p. 199, 375 and 718. However, I have not found any comment by Holtsmark on the issue of women as computers.

investigations and in the mid-1930s abandoned the field himself. After Holst had left electron scattering in 1933 it was Sverre Westin who took over. Westin graduated as a chemical engineer in 1933. He had carried out the experimental work for his diploma thesis in the physics department's X-ray laboratory under Haakon Brækken. From 1933 onwards, Westin worked on experimental as well as theoretical investigations in electron scattering. These investigations became his *dr.techn.*-thesis which he defended in 1949. The circumstances leading to the long delay of the thesis were rather complex. From 1934 to 1936, Westin worked, together with Wilhelm Ramm, on the construction of the physics department's Van de Graaff generator, where Westin headed the development of the vacuum technology. The vacuum pumps were also needed for Westin's electron scattering experiments in order to evacuate the collision chamber. Vacuum technology constituted an intersection on the level of research instrumentation that brought together the different research agendas *nuclear physics* and *electron scattering*. However, Westin's involvement in the Van de Graaff accelerator project seems to have been more extensive than it would have been necessary only for the development of vacuum pumps.[327] Westin also had a number of teaching obligations. In the academic year of 1935/36, he was substitute lecturer for the physics department's lecturer position, vacant after Trumpy had left to become professor in Bergen.

From at least 1935 onwards, Westin was disabled from working in the laboratory because of chronic mercury intoxication. In 1937, he left NTH for a position at the Swedish lamp manufacturer *Luma*, which he had to abandon already in 1938 because of his hypersensitivity to mercury.[328] In 1939, Westin came back to Norway and received a research scholarship from NTH (*høgskolestipendiat).* With the scholarship he went to the Institute of Theoretical Astrophysics (*Astrofysisk institutt*) at the University of Oslo where he carried out numerical calculations at the department's differential analyser. In 1940, Westin left academia for a second time to become the head of the chemistry department at *Statens Teknologiske Institutt* in Oslo. In his spare time Westin continued his research at the physics department of the University of Oslo. In 1942, Holtsmark was also appointed Professor at the University of Oslo. In November 1943, however, the closing of the University of Oslo by the German occupants and Quisling's regime imposed a forced break for all

[327] For a more detailed account on Westin's engagement in the Van de Graaff accelerator project and the development of the vacuum system as a research technology for various research agendas at NTH's physics department, see Chapter 5, Section 7, particularly 7.2.

[328] See Archive *NTH-Fysisk institutt*, box Da: 9, 1-14 *Kvikksølvsaken*, Statsarkivet i Trondheim, and Chapter 5, Section 7.4.

experimental activities until liberation in May 1945.[329] Westin delivered his dissertation titled *Investigations on the Elastic Scattering of Slow Electrons in Helium, Neon and Argon* at NTH in May of 1946. A committee was set up in July of the same year and the dissertation was approved for defending a year later, but it took more than two years before Westin could finally defend his thesis.

After this extensive excursion into the research field of electron scattering and Westin's biography we will now come back to the main issue of this section: the transformation of research instrumentation in physics during the interwar period through electrical devices and telecommunication engineers. This novel kind of research instrumentation entered Westin's research in two separated domains: as a part of the experimental set-up of the collision chamber and in the shape of an analogue calculating machine for the calculation of scattering curves. A close look at the experimental set-up of the collision chamber reveals the extensive wiring for the control of the experimental conditions as well as the measurement of the current of the scattered electron beam. In Westin's thesis, these electrical arrangements were represented by altogether four wiring diagrams.[330]

The most distinctive electrical device developed by Westin for his research in electron scattering was, however, the electrical analogue calculating machine. As we have seen above, Holtsmark's theoretical investigations had involved laborious numerical computation for the calculation of scattering curves. The idea to apply a more effective computation device than the mechanic or half-mechanic desk calculators suggested itself. Holtsmark and Westin were not the first physicists engaged in electron scattering, who applied analogue calculating machines. A number of British physicists carried out investigations similar to Holtsmark and Westin's and turned to various kinds of analogue calculating machines in order to solve their calculation problems. Douglas R. Hartree, since 1929 Professor of Applied Mathematics at Manchester University, carried out theoretical investigations on the distribution of electron density in atoms and in electron scattering. His method of the self-consistent field was successfully applied by Holtsmark (see above) and Hartree and Holtsmark were in close correspondence on issues concerning electron

[329] For the University of Oslo during the German occupation between 1940 and 1945 see, for example, Collett, 1999, Chapter 5.

[330] Westin 1946, Fig. 13a. *Wiring diagram for accessories of the collision chamber*, Fig. 13b. *Electrometer tube circuit*, Fig. 14. *Measurement of high resistance*, Fig. 15. *Diagram for the hot wire gauge*. Parts of the original arrangement, like the collision chamber, one of the deflecting coils and some of the measurement instruments are preserved in the historical collection of the physics department. The whole set-up, however, has been rebuilt.

scattering.[331] In 1933, Hartree visited Vannevar Bush at the MIT in Boston to use Bush's differential analyser for his work on the approximation of the atomic field of mercury. Hartree subsequently arranged for the construction of a four-integrator differential analyser at Manchester by the Metropolitan Vickers Electrical Company.[332] Bush and Hartree's differential analysers were purely mechanical analogue calculating machines. Edward Crisp Bullard and Philip Burton Moon constructed an electrical analogue calculating machine at the University of Cambridge between 1931 and 1932 that was apparently similar to the one later built at the NTH physics department. Bullard and Moon were at the time involved in geophysical research.[333] But at the same time, Bullard and another British physicist, Harrie Stewart Wilson Massey, conducted investigations in electron scattering similar to Holtsmark and Westin's.[334] Massey later built a four-integrator model differential analyser at the Queen's University in Belfast.[335]

In August of 1935, Holtsmark and Westin published the proposal for *An Electrical Calculating Machine for the Calculation of Electron Scattering Curves* in the proceedings of the Royal Norwegian Society of Science and Letters in Trondheim[336]. Considering the close contact between Holtsmark and the British physicists he was well aware of the development of the British calculating machines. In his journey to Cambridge in September or October 1934, Holtsmark visited among others the physicist Nevil Mott, another close co-operator of Massey and Bullard.[337] Westin and the telecommunication engineer Wilhelm Ramm visited both Manchester and Cambridge University in June 1935, two month before Holtsmark and Westin submitted the publication about their design of a calculating machine. According to the correspondence with Holtsmark, Westin found something interesting in Cambridge that made him stay for some more time than he had planned.[338] Unfortunately I do not

[331] See, for example, Holtsmark to Hartree, January 24, 1930, Archive *NTH-Fysisk institutt.*

[332] Croarken, 1990, p. 51 ff.

[333] Croarken, 1990, p. 48.

[334] Holtsmark reviewed, for example, one of Bullard and Massey's theoretical articles in the German *Physikalische Berichte* of 1931. See also Westin 1946, p. 98, 108 and 118.

[335] Croarken, 1990, p. 58-59.

[336] Holtsmark and Westin, 1935.

[337] In 1933, Massey and Mott wrote the first edition of the well-known textbook *Theory of atomic collision.* For the Cambridge visit, see Holtsmark to Mott, August 27, 1934, Archive *NTH-Fysisk institutt*, Ea: 5.

[338] See introductionary letters, Holtsmark to Rutherford and Holtsmark to W. L. Bragg, both May 7, 1935. In both letters Holtsmark mentions Westin's interest in electron scattering. I do not have any correspondence with Hartree regarding Westin's visit at Manchester. It is

have documentation about what was so interesting in Cambridge that made Westin stay for more time. It might have been the electrical analogue calculating machine of Rawlyn Richard Maconchy Mallock at the Cambridge University Engineering Laboratories, which attracted Westin's attention. Holtsmark and Westin described their own calculating machine design in their proposal as "*somewhat similar to the Mallock machine*".[339]

Westin and Holtsmark's idea of the electrical calculating machine was to transfer the formula describing the scattering of a beam of electrons by an atomic field into an equation of an electric circuit, which had the same mathematical form. In electroacoustics research, equivalent circuit diagrams were used to represent acoustic vibrations as electric oscillating circuits. The idea of the electrical calculating machine was similar: to translate the electron scattering problem into an equivalent circuit diagram. The equivalent circuit diagram could then be built as a real electrical machine. The machine under operation then carried out the calculation and the scattering curve was printed out.

The scattering of a beam of electrons by an atomic field was given by the equation:

$$f(\theta) = \frac{1}{2ik}\sum_{n=0}^{\infty}(2n+1)[\exp(2i\delta_n)-1]P_n(\cos\theta) \qquad (1)$$

where $f(\theta)$ is the angular distribution of the scattered wave, $|f(\theta)|$ its amplitude and $k = \frac{2\pi}{\lambda}$,

δ_n is the phase shift of the $n-th$ spherical harmonic of the incoming wave in passing through the atom, and P_n is the $n-th$ Legendre function.[340]

however most likely that he visited Hartree and the Manchester differential analyser that was in operation since March that year.

339 Holtsmark and Westin, 1935, p. 50. See also *The Mallock Electrical Calculating Machine*, Engineering, 1934 and Mallock, 1933. For the history of the Mallock machine see Croarken, 1990, p. 49 f. and Hartmut Pezold in Finn, 2000, p. 64-69.

340 Holtsmark and Westin, 1935, p. 87.

Observations could only give the absolute values of $|f(\theta)|$. The chief problem of electron scattering was, according to Holtsmark and Westin, to evaluate the phase shifts δ_n from a measured scattering curve. In general cases a scattering curve had to be calculated from an arbitrarily chosen set of phase shifts δ_n. The principle idea of the electrical analogue calculator was to place two coils in a uniformly rotating magnetic field (Fig. 4.18.). One of the coils could be turned, the other was fixed. When the magnetic field rotated an alternating electromotive and an alternating electromotive force was induced in the coils, which value is given by:

$$[\exp(2i\delta_n) - 1]\; e^{i\omega t} \qquad (2)$$

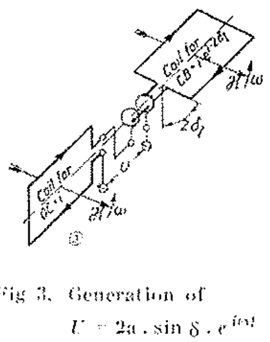

Fig. 4.18: Principle drawing of electrical analogy to scattered electron wave. ***H*** is a uniformly rotating magnetic field, in which are placed two coils ***A*** and ***B*** with identical winding areas. The coils are mounted in the middle of the field with their axes parallel to the plane in which the magnetic vector rotates. One of the coils can be turned in relation to the other one, which is fixed in the magnetic field (Holtsmark and Westin, 1935, p. 87).

Through a system of such generator coils and the use of transformers in series, the output voltage of the circuit would give the value of $f(\theta)$ with the phase given by the angle of the coils in the generator (see Fig. 4.18. and 4.19.). By turning the coils, which indicated changing phase shifts, the calculated curve could be fit to the experimentally measured curve. The positions of the coils in the generator then indicated the phase shifts δ_n of the waves scattered in different directions. The method was still laborious because the right positions of the coils had to be found, but much less laborious than the approximate numerical calculation of the phases.

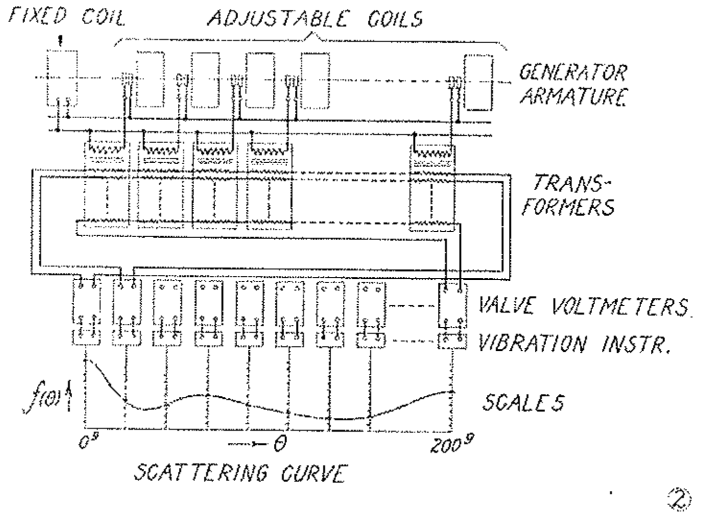

Fig. 2.

Fig. 4.19: Principle drawing of the calculating machine with generator coils, transformers, valve voltmeters and vibration instruments for writing the electron scattering curve (Holtsmark and Westin, 1935, p. 88).

Already in the planning stage of the calculating machine Westin and Holtsmark had received "*invaluable assistance*" by the telecommunication engineer Eilif Bjørnstad, "*especially as regards the practical electrical aspects of the problem*".[341] Westin and Bjørnstad began the construction of the calculation machine presumably already in 1935.[342] After Bjørnstad left the physics department in 1936, Oddvar Johannesen, another telecommunication engineer, assisted Westin.[343] Holtsmark's letter of reference for Westin from April 7,

[341] Holtsmark and Westin, 1935, p. 90.

[342] See Holtsmark's letter of reference for Bjørnstad, June 26, 1936.

[343] After Bjørnstad left the physics department, he lectured at the Department of Electrical Engineering for one year and became laboratory engineer at *A/S Elektrisk Bureau* in 1937. Johannesen also took over other work assignments of Bjørnstad. See Holtsmark's letter of reference for Johannesen, May 11, 1937.

1938 suggests that the calculating machine then was working successfully and giving valuable results that would be published soon. Westin, however, did not publish anything about the machine until his thesis in 1946.

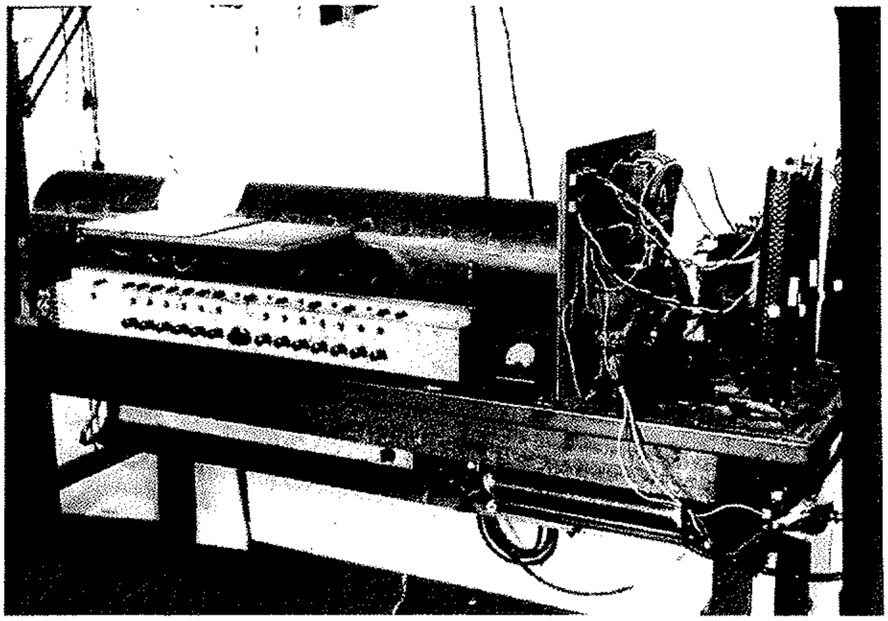

Fig. 4.20: Calculating machine for electron scattering curves at Trondheim in the1930s (Photo: Statsarkivet i Trondheim).

By the time Westin published his thesis he had already carried out calculations with another type of analogue calculating machine used by physicists in the research field of electron scattering: the differential analyser. In 1939 Westin received a research scholarship from NTH to carry out calculations with the new differential analyser of the Institute of Theoretical Astrophysics at the University of Oslo. The Institute of Theoretical Astrophysics under the leadership of Svein Rosseland was built in 1934 with a large grant from the Rockefeller Foundation. The donation from the Rockefeller Foundation included explicitly a sum of $ 15,000 for research instrumentation that made it possible to build the world's largest differential analyser. Rosseland had studied Vannevar Bush's machine at MIT in 1933. Bush's machine had six integrators and the Manchester and Cambridge machines had eight integrators each, whereas Rosseland's analyser had twelve integrating units. It was built by the Oslo instrument maker and optician *Gundersen & Løkken A/S* and mounted in the basement of the Department of Astrophysics in 1938 covering around 15 square meters and was in close connection to the instrument maker's shop.[344] When Westin came to use the differential analyser in 1939, it was still a new machine and represented one of the largest, if not the largest computing capacity of the world. With the differential analyser Westin calculated, or more precise mechanically integrated wave functions and phase shifts for electron scattering similar to the calculations with his own electrical machine. He published these results, however, separately from his thesis in 1947.[345]

Returning to the electrical analogue calculation machine at Trondheim, Westin reported in his thesis that the device, which he now called an electrical phase analyser, had been further elaborated with several technical improvements and developments. In 1946 it was "*in its present finished state*" where "*the device is quick and perfectly reliable in operation*", indicating that the original device did not function properly or reliably.[346] This may imply some difficulties with the original design. Westin's electrical analogue calculating machine was probably not a big success. Instead of giving a detailed report about the design and operation of his electrical phase analyser, in his thesis Westin referred to a forthcoming separate publication about the device. To the best of my knowledge, Westin never wrote this publication. This is not surprising. In 1949, when Westin's thesis was finally published, the design was more than ten years old and clearly outdated. In its original design of the 1930s, however, the device reveals a number of characteristic aspects of analogue calculation machines of the time. The Holtsmark, Westin and Bjørnstad machine shows some characteristics that make it similar to the Bullard and Moon analogue calculating machine mentioned earlier. The British historian of computing Mary Croarken describes the Bullard and Moon machine as typical for British analogue computation devices in the late 1920s and early 1930s.[347] Croarken gives four characteristics that fit for both the Bullard and Moon machine, and the Holtsmark, Westin and Bjørnstad device: first, the machine

[344] Jensen, 1994, and Holst, 1996. Knut Strøm Gundersen, the son of the instrument maker and founder of *Gundersen & Løkken*, Trond Gundersen, represents a link between the physics department at NTH and the construction of the differential analyser at Oslo. Knut Strøm Gundersen graduated from NTH as the first technical physicist in 1932. In 1933 Gundersen became technical director of *Gundersen & Løkken*, and played a part in the construction of the differential analyser. See *Vi fra N.T.H.*, 1950, p. 425.

[345] Westin, 1947. Interestingly, Westin did not make any cross-references in the publications between the calculations with the different types of analogue calculating machines.

[346] See Westin, 1946, p. 35.

[347] Croarken, 1990, p. 48 ff.

was designed and built by individuals rather than commercially manufactured by an instrument company. Second, the development of mathematical instruments or computing machines was not the main interest of the inventors. The machine was an attempt to solve a certain type (and only one!) of computing difficulty. Third, the machine was the only one of its kind to be built. Fourth, the machine had no influence on future computing machine development.

These characteristics reveal a number of general differences between the Holtsmark, Westin and Bjørnstad machine, the Mallock calculation machine and the Bush differential analyser. Both the Mallock machine and the Bush differential analyser were built as calculating devices to solve mathematical problems for different applications. Copies of the Bush analyser were built at a number of other institutions in various countries and the machine had a serious impact on the development of computing.[348] The Mallock machine was a widely publicised device built by the Cambridge Instrument Company, which tried unsuccessfully to market it.[349] The analysis of Croarken indicates that Holtsmark and Westin proposed this design of an analogue calculating machine relatively late compared to the British development, which headed towards multipurpose devices and commercial production. Holtsmark and Westin were clearly not interested in the problem of computing itself. They had a well-defined computing problem, which they sought to solve with the means available at the small Trondheim physics department. The design and construction of an electrical analogue calculating machine seemed to be an obvious answer to this problem because of the experience of representing non-electrical systems in analogue circuit diagrams in electroacoustics research, and the experience of constructing electrical research instrumentation by telecommunication engineers at the workshop of NTH's physics department. Croarken's fourth characteristic of early analogue calculating machines leads the story of Holtsmark, Westin and Bjørnstad's electrical analogue calculating machine to a bitter ending: the machine had no influence whatsoever on future computing machine development. It remains, however, as a relic of early computing machine development at NTH as well as a representative of a tradition of scientific instrument making at the physics department.

[348] See, for example, Hagmeyer, 1979, Chapter 5, *Die Wissenschaftliche Laufbahn Claude Shannons*, Section 1, *Das Differential Analyzer Program* (p. 489): "*Das erste technische Entwicklungsprogramm, das von großem Einfluß auf Shannons weitere Entwicklung war, war der Differentialanalysator von Vannevar Bush. ...*"

[349] See Croarken, 1990, p. 94 ff.

Intermezzo

How to build a particle accelerator

Electrical engineers and the construction of the Van de Graaff generator

How are research fields, apparently so different from each other as nuclear physics and technical acoustics, connected? Technical acoustics and nuclear physics constituted the largest research agendas at the small physics department at NTH during the 1930s. The effective co-existence of these two very different research agendas was related to the significance of electrical engineering and radio technology based research instrumentation in both disciplines. To enter the research fields of technical acoustics as well as accelerator-based nuclear physics, the Trondheim physicists and engineers had to learn how to build and control electrical devices based on radio technology. In both technical acoustics and nuclear physics the research instrumentation was usually not bought ready-made but assembled in the physics department's instrument shop. In both technical acoustics and nuclear physics telecommunication engineers with a background from amateur radio entered the field of scientific instrument making with new practices and altered the relationship between the traditional instrument makers in the shop and the scientists in the laboratory.

The importance of electrical engineers with a background in amateur radio for accelerator building was not specific for Trondheim. In several histories on pre WWII particle accelerator laboratories, the importance of the transfer of knowledge and practices from amateur radio technology to accelerator building has been acknowledged. John Heilbron and Robert Seidel identified the reliance on radio technology as the distinctive feature of the Berkley Radiation Laboratory's approach to particle accelerators. Not only Ernest Lawrence but also many of the laboratory's earliest workers had been radio hams. According to Heilbron and Seidel, "*The Laboratory was so filled with radio waves that its members could light a standard electric bulb merely by touching it to any metallic surface in the building. Many cyclotron laboratories were to eke out* *their resources by cannibalizing old radio parts.*"[350] Not only the cyclotron accelerator laboratories, also the groups working with linear high-voltage accelerator designs relied largely on radio technology and practices from amateur radio. Merle Tuve's biographer Thomas David Cornell has stressed the importance of what he calls "*The Radio Pattern of Learning*" in Tuve's professional development.[351] Cornell described the early years of Tuve and his boyhood friend Lawrence as radio amateurs and the importance of these early experiences with wireless for Tuve and Lawrence's later careers. Tuve had engaged in using radio waves to study the conducting layer of the atmosphere before he turned towards nuclear physics and accelerator building.[352] Also Odd Dahl, the Norwegian instrument builder and co-worker of Tuve in the Washington Van de Graaff accelerator project was a former radio amateur. In the festschrift in the occasion of his 70th birthday, we find a picture of Dahl as a Boy Scout with his self-made field telegraph.[353]

Jeff Hughes has elaborated the link between radio technology and the development of instrumentation in nuclear physics at the Cavendish Laboratory during the interwar period.[354] Hughes has disproved the myth that experimental physics before World War II relied on sealing wax and string, still bearing the odor of small science and the physicist relying on simple facilities. He has shown the strong connection of the Cavendish Laboratory to industry, especially the electrical industry, and that modern and industrially made highly elaborate products like radio valves had already entered scientific instrumentation. The radio amateurs and research students Eryl Wynn-Williams, F.A.B. Ward and W. B. Lewis were commissioned by Ernest Rutherford and James Chadwick to construct an amplifier for Geiger-Müller counters. According to Hughes, for Rutherford and Chadwick "*... familiarity with the latest developments in circuit and electronic hardware now [the early 1930s] became one of the most valuable resources that a young physicist could bring to experimental nuclear physics.*"[355]

What was needed to build up a particle accelerator and a nuclear physics laboratory were students who could build these kinds of electrical devices. At

350 Heilbron and Seidel, 1989, p. 127.

351 Cornell, 1986, p. 13 ff.

352 Cornell, 1986, p. 151 ff.

353 See *Festskrift til Odd Dahl i anledning av hans fylte 70 år 3. november 1968 / fra venner og kolleger*, 1968, opposite to p. 24. Dahl also operated the Marconi radio station during Roald Amundsen's last polar expedition from 1922-1925. See Odd Dahl, 1988, p. 52 ff.

354 Hughes, in Gaudillière and Löwy, 1998, p. 58 ff. and Hughes, 1993, Chapter 4.

355 Hughes, in Gaudillière and Löwy, 1998, p. 58 ff.

NTH in Trondheim these students were found among the members of the Academic Radio Club.

Fig. I: The "guys" in the Radio Attic, 1933. From left: Birger Evensen, Ralph Eide, Oddvar Johannesen, Eilif Bjørnstad and Anders Gohn. 80% pipe smoking and 20% cigarette smoking. Some years later three of the radio amateurs, Johannesen, Bjørnstad and Gohn, were recruited as assistants by Johan Holtsmark and involved in the building of the Van de Graaff accelerator. Bjørnstad and Johannesen also worked on the registering decibelmeter for NRK and Sverre Westin's calculating machine (Photo: Akademisk Radioklubb).

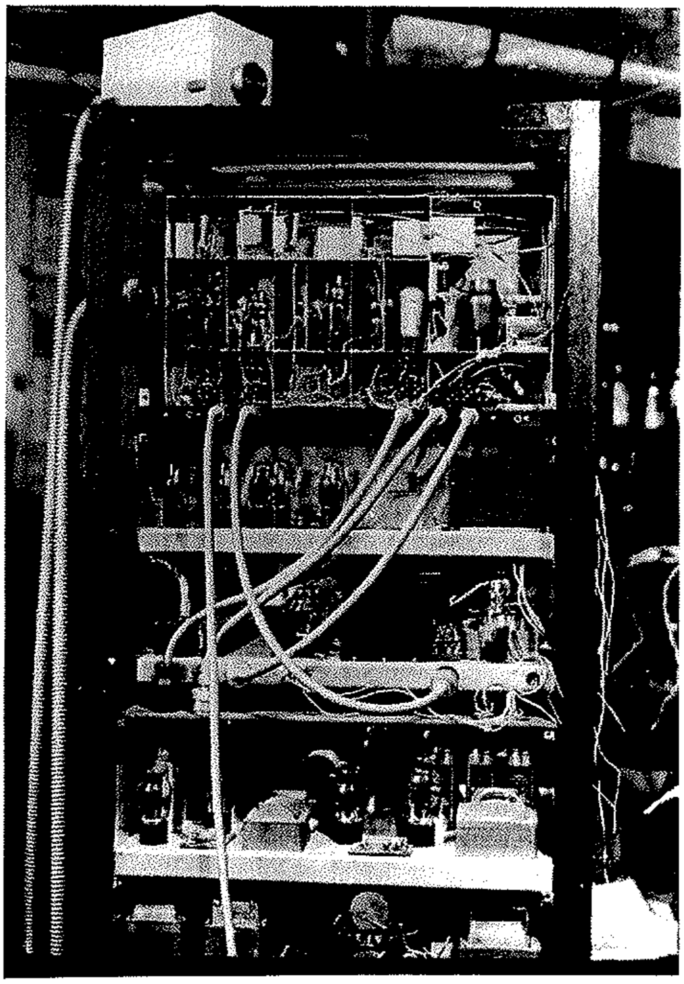

Fig. II: Circuits based on radio technology in the instrument rack of the Van de Graaff generator, about 1937 (Photo: Statsarkivet i Trondheim).

5. On the beginnings of nuclear physics in Norway

The Van de Graaff proton accelerator in the 1930s

5.1. Nuclear physics in the periphery of Europe's scientific community

On May 11, 1936, Johan Holtsmark gave a lecture in nuclear physics at the Royal Norwegian Society of Science and Letters in Trondheim with a subsequent demonstration of the physics department's newly finished Van de Graaff generator. The lecture and demonstration attracted quite a bit of publicity and was covered by all daily newspapers in Trondheim on the following day. While *Adresseavisen* and *Arbeider-Avisen* printed rather sober articles, *Nidaros* printed a first-page story with the headline "*Atom smashing is disappointing the highly- learned gentlemen of the Society of Science and Letters*". The reporter's observations during the demonstrations may well be quoted here:

> " *The members of the Society of Science and Letters, and a number of other auditors of the Society's meeting at the Institute of Technology's physics department yesterday, got the opportunity to peek into Professor Holtsmark's most holy - the atom splitting laboratory. A motor went around at a high speed and produced an enormous noise. Here and there large sparks shot out of the apparatus which was standing in a «darkroom» while the distinguished audience had the opportunity to study the very process in a peeking closet in a neighbouring room.*
>
> *If we wish to explain this peeking closet better, we have to compare it to a photographic camera of the old fashion type where the photographer is adjusting on a focusing screen, and on this focusing screen the curious audience saw a small bright blue spot. However, this was all the non-expert audience*

could get out of the atom splitting, the result of the million volts that the large, and surely enough also expensive, and at any rate very much discussed apparatus put into activity.

But out of this here you don't really get wise, said one of the disappointed observers to the Professor.

No, but that's rather not its purpose, answered the Professor with his imperturbable smile.

..."[356]

The Van de Graaff generator was a type of linear particle accelerator used to accelerate protons for nuclear reactions. Electrical and chemical engineers at the physics department of the Norwegian Institute of Technology built the generator in Trondheim between 1934 and 1937. Demonstrations like the one at the Royal Norwegian Society of Science and Letters could not be done in many places at that time, even though many auditors attending the meeting did not seem to be aware of the exceptionality of what they were witnessing. The Van de Graaff technology, based on using an electrostatic belt generator to accelerate particles, was first developed and applied in the USA. Professor Holtsmark stated, in 1937, that at the time this generator had only one working equivalent in Europe, the Van de Graaff accelerator of Bothe and Gentner at the division of physics at the Kaiser Wilhelm Institute of Medical Research in Heidelberg in Germany.[357] Why was Scandinavia's first Van de Graaff generator built in Trondheim, far north of its metropolitan centres?

In this chapter I want to give an account of the history of accelerator based nuclear physics research at the Trondheim physics department during the interwar period. The story at Trondheim started in 1923 with the appointment of Olaf Devik to Trondheim and his failed attempt to develop a successful discharge tube driven by a Tesla coil. In 1932, the same year Devik left Trondheim, the first nuclear disintegration produced with an accelerator was observed at the Cavendish Laboratory at Cambridge. In 1933 Professor Holtsmark established contact with Odd Dahl at the Carnegie Institution of Washington where Dahl and his collaborators had managed to use a Van de Graaff generator successfully as a particle accelerator. Holtsmark decided to build a Van de Graaff generator at Trondheim as well. To construct the various parts of the accelerator he employed a number of assistants, most of them electrical engineers and veteran members of the Academic Radio Club. Dahl came to Trondheim twice in order to advice the Trondheim group. Holtsmark

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[356] *Nidaros,* May 12, 1936. p. 1 and 8. Translated from Norwegian.

[357] In *Norges tekniske høiskoles fond, Årsberetning,* 1937, NTH-fond, Trondheim, 1938, p. 12.

and his assistants visited the Cavendish Laboratory and other European laboratories to study high voltage- and nuclear technology and experimentation. Like with other accelerators, the Trondheim generator was to a large extent financed by organisations that were attracted by the potential accelerator technology had for cancer treatment and research. In summer of 1937 the Van de Graaff accelerator produced the first successful experimental results. The Trondheim Van de Graaff generator was by the time it was finished too small to compete in the large accelerator laboratories' race for higher and higher energies, but it became a successful device as a precision machine for carefully measuring nuclear resonances where others had rushed over. The subsequent research history of the accelerator continued at Trondheim until 1942, when Holtsmark was appointed professor at Oslo and took the generator as well as his assistant Roald Tangen with him. At Oslo, the Van de Graaff generator was in use until 1962 when it was decommissioned and given to the Norwegian Museum of Science and Technology where it rests today.

The various activities in acoustics at NTH's physics department, which were discussed in the last chapter, had a rather local and national character. They had much of their origin in the local Academic Radio Club and involved local and national developments like the establishment of sound film, radio broadcasting and the emergence of a Norwegian radio manufacturing industry.[358] The Van de Graaff accelerator project bore little of such local reference but was oriented towards the international community of physics. Developments in electroacoustics could be experienced by everyone simply by going to the cinema, listening to radio or being exposed to acoustic irradiation of an electromagnetic loudspeaker in the public sphere. Developments in accelerator based nuclear physics were not meant to be understood or be experienced by everyone.[359]

The international character of accelerator based nuclear physics also meant that the project's success could only partially be established locally. Holtsmark's goal was the local establishment of international, to a large extent American, research technology and research practices. What a successful establishment

[358] These technical and cultural developments had mainly happened on an international scale and are not to understand without the international picture. Nevertheless, they were established locally and affected the local community substantially.

[359] Tangen stated in his interview in 1990 that in the early 1930s no one in Trondheim besides Holtsmark understood the importance of accelerator development. This is surely an overstatement that would underestimate other academics at NTH in the 1930s. The article in *Nidaros* nevertheless shows that it was difficult to obtain an understanding even in the Trondheim academic scene. The situation of public interest and public involvement in nuclear physics changed drastically with the atomic bombs over Hiroshima and Nagasaki and the following cold war, when nuclear physics moved heavily into the public sphere. Again, see interview with Roald Tangen, 1990.

meant had to be negotiated with other laboratories. This became especially clear when the Trondheim group was looking for a research program appropriate to their machine.

The research practice of accelerator based nuclear physics was established internationally. Research funding for the accelerator was in comparison established locally. Holtsmark argued for the possible application of his Van de Graaff generator for cancer treatment and lobbied for funding from cancer related institutions. The rhetoric of cancer was again borrowed from other accelerator laboratories. Holtsmark did not seem to have a deep interest in the problem of cancer and the Van de Graaff generator was never seriously used in this context. To base the funding for the accelerator laboratory locally or nationally was, however, not a self-evident choice. Niels Bohr, for example, financed the re-direction of the Copenhagen Institute of Theoretical Physics towards accelerator based nuclear physics mainly through contributions of the Rockefeller Foundation.[360] Other research institutions in Norway, like Svein Rosseland's Institute of Theoretical Astrophysics and the Norwegian Institute of Cosmical Physics (*Norsk Institutt for Kosmisk Fysikk*) in Tromsø, were founded with Rockefeller money. Anyway, the involvement of international funding in the establishment of the NTH accelerator laboratory, if realistic, would have required a severe re-direction of the research profile at the Trondheim physics department. There is no indication that Holtsmark was ever interested in such a severe re-direction. Holtsmark wanted to continue the Trondheim physics department as an institution with several co-existing research activities. In this manner the Trondheim Van de Graaff accelerator laboratory of the 1930s remains an example of small science involvement in a growing environment of big scale accelerator facilities.

5.2. The beginnings of accelerator based nuclear physics

In this section I want to give a short introduction to the international research activities in nuclear physics and accelerator technology as they had developed until the 1930s. The field of accelerator based nuclear physics was established by the merging of very different research fields, research traditions and technologies. In the accelerator community, scientists and technologists from various backgrounds would meet, like radio-chemists, physicists and technologists from X-ray and cathode ray research, theoreticians with background in quantum mechanics, high-voltage electrical engineers and

[360] See Aaserud, 1990.

telecommunication engineers with experience from amateur radio building. As we will see in the Trondheim example, there is no sharp line that can be drawn between, for example, cathode ray and X-ray research and the construction of accelerators. I will briefly introduce some of these communities and their approaches to nuclear physics and accelerator technology.

Early work in radioactivity research was mainly organised under the field of radiochemistry and Nobel Prizes were given both in physics and chemistry. Antoine Henri Becquerel discovered spontaneous radioactivity in 1896 when he investigated the phosphorescence of uranium salts and found that the emitted rays could fog a photographic plate covered with opaque paper. These rays also caused gases to ionise as well as they could be deflected by electric or magnetic fields. Marie and Pierre Curie announced the discovery of polonium and radium by fractionation of pitchblende in 1898. One of the students at the Curie Institute at the Sorbonne in Paris from 1907 to 1912 was the Norwegian chemist Ellen Gleditsch. In 1916 Gleditsch was appointed lecturer in radiochemistry and in 1929 Professor of Chemistry at the University of Oslo. Radiochemistry had thereby made its way to the Norwegian scientific community.

A central figure of early radioactivity research was Ernest Rutherford, who developed a model of radioactive disintegration that regarded radioactive phenomena as atomic - not molecular - processes. Rutherford's appointment to the Cavendish Laboratory at Cambridge in 1919 made the Cavendish the internationally leading laboratory for radioactivity research. Also in 1919, the year of his appointment, Rutherford managed to disintegrate nuclei of certain light elements, such as nitrogen, by the impact of energetic alpha particles originating from some radioactive source. During this process fast protons were emitted. Rutherford's disintegration experiments opened up for the emergence of the accelerator idea: to accelerate particles *artificially* by means of high voltage in discharge tubes to energies similar as Rutherford's alpha particles. Rutherford himself promoted the development of million-volt accelerators in a famous speech at the Royal Society of London in 1927.[361] Already some years before the speech, several scientists and engineers had set out to smash the atom with help of an accelerated particle beam.

The technology for early radioactivity research in radiochemistry was quite different from later accelerator laboratories. Naturally radioactive elements such as radium were used as radiation sources. Early detectors for the radiation emitted were electrometers and the spinthariscope developed by William Crookes in 1903. At the Cavendish Laboratory the scintillation counting method was developed into a standard method for detecting particles, using fluorescing screens and special microscopes. Several controversies in the late

[361] Heilbron and Seidel, 1989, p. 49.

1920s about experimental results obtained with the scintillation counting method put doubt about the reliability of the method. Most famous of the disputes was the controversy between the Cavendish Laboratory and the Vienna Radium Institute.[362] An alternative detector, the cloud chamber developed by Charles T. R. Wilson at the Cavendish Laboratory, was commercially available from 1913.[363] Investigations with the cloud chamber were, however, demanding and time consuming. A comparatively reliable and easy to handle detector for radioactive radiation was found in the development of electric counter arrangements. The Rutherford-Geiger counter was developed in 1908 and Hans Geiger developed an improved *Spitzenzähler* around 1913. Both showed some unpredictable behaviour due to unwanted discharges. It was Walter Maria Max Müller's systematic improvement of the counter design in 1928 that made the Geiger-Müller counter an attractive and reliable instrument.[364] All in all radiochemistry research had the character of rather small scale research, very different from the large and complex accelerator laboratories that would emerge in the 1930s.

Rutherford's disintegration experiments of 1919 and the idea of the disintegration of atoms by means of accelerated beams of particles connected new fields of research and technology to radioactivity research previously alien to the radiochemistry and radio-physics laboratory: high voltage, high vacuum and the merge of it, the discharge tube.

The development of high voltage technology and study of high voltage phenomena was promoted during the 1920s especially by the development of long distance high-voltage current transmission lines. High voltage power transmission was an almost inevitable technology for efficient long distance transport of electricity due to the general decrease of energy loss by the increase of the voltage used under transmission. Consequently electrical power supply companies as well as the electrical industry established high voltage research laboratories.[365]

In the late 1920s not only experimental physicists and chemists but also theoretical physicists moved further into the core of the atom. The application of the laws of quantum mechanics to new theories about the atomic nucleus proved to have a major impact on the design and interpretation of accelerator experiments. In the 1920s, quantum mechanics had concentrated on the electron shell, spectroscopy experiments and the electron field of atoms. Around 1930 the theoreticians started to direct their attention towards the nucleus. The first

[362] See Jeff Hughes, 1992, especially Chapter 2.

[363] Galison, 1997, p. 118.

[364] Galison, 1997, p. 438 ff. and Jeff Hughes, 1992, Chapter 4.

[365] See Thomas Hughes, 1983, p. 377 ff.

serious theory of the nucleus based on quantum mechanics was developed by George Gamow about 1930.[366] The first quantum mechanical theories of the atomic nucleus had a large uncertainty because of the lack of sufficient experimental data available. Accelerator builders needed theories in order to estimate energies needed to smash atoms. Theoreticians, on the other hand, were in need for experimental data from the nucleus in order to settle their theories on experimental grounds.[367]

As mentioned earlier, there is no sharp line to be drawn between cathode-ray tube, X-ray tube and accelerator discharge tube development. All of these tubes accelerated charged particles, or rays, towards different kinds of targets. With the introduction of the wave-particle dualism and the concept of complementarity in quantum mechanics it became two sides of the same coin whether to consider the accelerated entities either as particles or as rays. This continuity from X-ray to accelerator development became clearest in radiation treatment technology for cancer therapy. For the radiologist, the move towards accelerators as radiation source basically meant *harder X-rays*. What in the view of the physicist made the discharge tube an accelerator was its intended use in splitting the atom. The million volts of acceleration that were apparently required for the atom smashing represented an enormous energy jump compared to the creation of conventional X-rays.

All the imagined principles to reach these energies involved advanced high voltage technology or electromagnetic principles. It therefore does not surprise that mainly electrical engineers involved in developing accelerator principles. One of them was Rolf Widerøe, a young Norwegian electrical engineering student at Aachen in Germany. In 1927, he developed a ray transformer, a linear accelerator design, later known as the *linac*. With the help of high frequency, the charged particles were accelerated by means of the same high voltage source several times. A similar device, published by Gustav Ising in 1924, inspired Widerøe. Already in 1923 Widerøe had sketched the idea of a circular accelerator, later known as a *betatron*, which was not developed before WWII. For his doctoral dissertation in 1928, Widerøe built a working model of the ray transformer, but he did not develop it into an accelerator used in nuclear disintegration.[368] Ernest Lawrence at Berkley took up Widerøe's ray transformer and developed it into another circular accelerator design, the

366 Aaserud, 1990, p. 39 ff., for Gamow p. 45 ff.

367 Jeff Hughes concludes, regarding Gamow's engagement in the Cavendish Laboratory's accelerator experiments, that "*A culture of theory had transformed a culture of experiment, and in so had transformed itself*". Hughes, 1998, p. 360. See also Heilbron and Seidel, 1989, especially p. 67 and Cornell, 1986, especially for Gregory Breit's role and engagement in the Washington accelerator project.

368 Waloschek, 1994, p. 21 ff. and p. 27 ff.

cyclotron. In the cyclotron the particle beam was bent into a circular trajectory by a huge electromagnet. The cyclotron became one of the most successful accelerator designs of the 1930s.[369]

Most other accelerator principles developed and tried out in the 1920s relied on the production of extraordinarily high voltages, preferably several million volts, and their discharge through a linear tube. Most spectacular and most tragic was Arno Brasch, Fritz Lange and Curt Urban's attempt to use atmospheric electricity in the Italian Alps. Curt Urban was killed during a thunderstorm in 1928. Brasch and Lange returned to the AEG research laboratory (*AEG Forschungsinstitut*) at Berlin and continued their experiments using an impulse generator for high-voltage.[370] A very successful high voltage generator design, mainly because of its simplicity and high voltage stability, was the Van de Graaff generator: Robert J. Van de Graaff at Princeton developed an electrostatic belt generator based on the ancient and well known influence machine. The Van de Graaff principle was later used by the Trondheim group and we will come back to it in the following sections.[371]

The first group to manage the disintegration of the nucleus by artificially accelerated particles were John D. Cockcroft and Ernest T. S. Walton at Rutherford's Cavendish Laboratory in 1932. Cockcroft and Walton used a rather conventional 600 kV step-up high-voltage transformer produced by an electrical manufacturer. Beforehand Cockcroft had confirmed with Gamow that this voltage would be sufficient to split atoms of light elements. Before applying the step-up transformer, the Cavendish scientists had unsuccessfully tried to develop an accelerator design based on the Tesla coil as a high-voltage source. Several research groups had tried their luck with the spectacular but unpredictable Tesla coil.[372] Among these were Gregory Breit, Merle Tuve, Lawrence Hafstad and Odd Dahl at the Carnegie's Department of Terrestrial Magnetism in Washington and a little known Norwegian physicist, Olaf Devik, at Trondheim. Our local history therefore starts with Devik and his attempt to develop an accelerator design based on an evacuated Tesla coil.

369 Heilbron and Seidel, 1989.

370 See Heilbron and Seidel, 1989, p. 50 ff. and Weiss, 1999.

371 For a more general history of the Van de Graaff generator, see Brenni, 1999.

372 See Hartcup and Allibone, 1984, on Cockcroft, Jeff Hughes, 1998, *Modernist with a Vengeance,* on Gamow and Cockcroft, and Heilbron and Seidel, 1989, p. 45 ff. for an overview.

5.3. Early attempts at NTH:
Olaf Devik and the Tesla coil

After Sem Sæland was appointed Professor of Physics at the University of Kristiania (Oslo) the vacant chair at Trondheim was fought about by the two candidates taken into consideration: Olaf Devik and Johan Peter Holtsmark.

The young Holtsmark at the age of 29 could show a long list of publications and had among other places worked as Peter Debye's assistant at Göttingen. He was internationally known for his work on the Stark effect and held a *dr.philos.* degree from the University of Kristiania. Holtsmark had lost the competition with Sæland for the chair at Kristiania, but only because Kristiania University decided to abstain from calling in a commission to evaluate the candidates on scientific grounds. Kristiania appointed Sæland not for his arguably limited qualifications as a scientist but for his abilities as an administrator and planner and his experience in politics in order to raise the new university complex at Blindern.

In 1923, the 37 years old Devik was already a veteran in the Norwegian physics scene. Like Sæland, he did not hold a doctorate degree. Like Sæland, Devik had been student and assistant of Kristian Birkeland during Birkeland's cathode ray discharge experiments to simulate northern lights in the laboratory. And again like Sæland, Devik also went to Heidelberg where he worked on cathode ray experiments in Philip Lenard's laboratories. WWI set a sudden end to Devik's studies in Germany and he returned to Norway. Back home he soon joined Ole Kroghness at the Haldde Aurora Borealis observatory. Devik had worked as Vilhem Bjerknes assistant from 1908 to 1911 during Bjerknes' pioneering work on *Dynamic meteorology and hydrography.*[373] From 1915 - 1922 he was put in charge to organise weather forecast in Northern Norway.

When Devik applied for the vacant chair at Trondheim he included a number of documents outlining research projects he proposed to work on in case he would be appointed. One of these proposed projects was the construction of a discharge tube for exceptionally high voltages. The proposal, a document of three typewritten pages and signed by Devik on May 31, 1923, is the earliest document which witnesses Devik's plans to construct what can be called a particle accelerator based on a Tesla coil as a high voltage generator.[374] Devik's description was written in the tradition of cathode ray experiments and seemed to be inspired by his earlier work on cathode rays as well as Rutherford's disintegration experiments with alpha particles, or alpha rays as

[373] Bjerknes et. al., 1910/1911.

[374] Olaf Devik Privatarkiv, Riksarkivet i Oslo.

Devik wrote. To prevent corona discharges and discharges through the coil's insulation, the coil's secondary winding, or alternatively the whole coil, should simply be arranged within the highly evacuated discharge tube itself. The accelerated entities should be, in Devik's words, cathode rays emitted from a glow cathode. Devik's understanding of the entities to be produced and accelerated in his discharge tube was in the cathode ray research tradition the understanding of rays rather than particles. Devik's proposed device might therefore be described more properly as a "ray accelerator" rather than a "particle accelerator". Devik proposed to follow three main goals with his discharge tube:

1. To create cathode rays with a velocity close to the velocity of light and to study these rays.

2. To create cathode rays with a kinetic energy close to those of alpha-rays, and to study these, among other properties in regards to their abilities to split atoms. Even though Devik did not call his device a particle or ray accelerator, it becomes clear that he had in mind to use the discharged energy for nuclear disintegration.

3. To create X-rays with a hardness that comes close to gamma-rays. These hard X-rays would, according to Devik, open new areas of use for X-ray technology in the industry.

To reach cathode ray energies in order to carry out the proposed investigations, Devik estimated that he had to bring the voltages produced by the Tesla transformer up to about four million volts and that his discharge tube had to withstand these potentials.

It was Holtsmark, not Devik, who was appointed Professor of Physics at Trondheim. But Devik was offered the lecturer position at NTH to cover the teaching obligations at the newly established Norwegian Teacher College (*Norges Lærerhøiskole*) at Trondheim. In the competition between Holtsmark and Devik for the professorship it was made clear that this lecturer position would be offered to the loser. Devik had announced that he could not accept the lecturer position if it was subordinated Holtsmark's position as the professor.[375] Accordingly, his lecturer position was organised independently from Holtsmark's and with the basic professor's salary. There are no indications for any quarrels or larger disagreements between Devik and Holtsmark. Devik later recalled Holtsmark as a "good friend" in regards to the situation at NTH.[376] But

[375] Olaf Devik Privatarkiv, Riksarkivet i Oslo, private letter to Richard Birkeland, president of NTH, June 6, 1922.

[376] Devik, 1971, p. 120.

Devik's claim for independence also hindered any co-operation between Devik's and Holtsmark's research projects. When Devik defended his doctoral thesis on ice-formation in Norwegian water bodies in 1931 he did so at the University of Oslo and not at NTH at Trondheim. Devik's lecturer position was not equivalent to a professor's position, neither in its endowment nor in its academic reputation. Devik did not dispose of any assistants to carry out research for him and he lacked the prestige to raise sufficient funding.

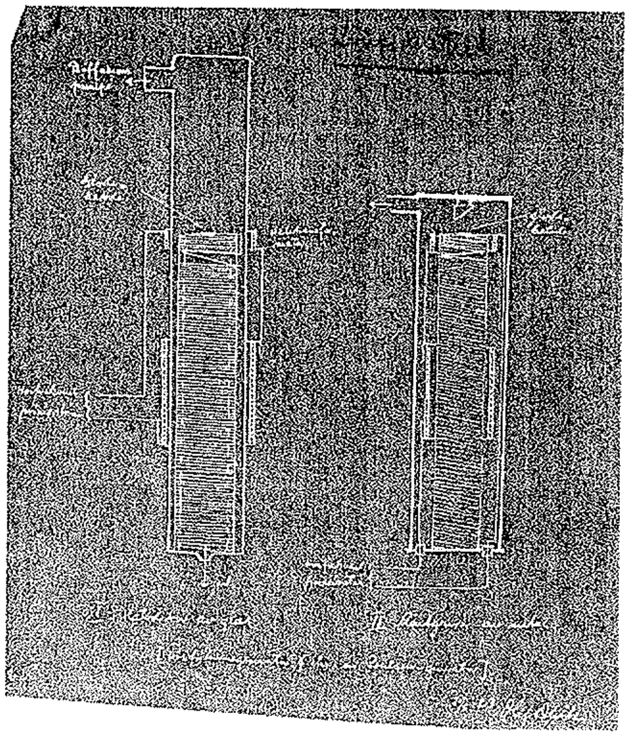

Fig. 5.1: Drawing of the proposed discharge tube with Tesla transformer of 1923 (Olaf Devik Privatarkiv, Riksarkivet i Oslo).

Given the limitations of laboratory space in the old combined building of physics and electrical engineering, the infrastructure to start a research project like the discharge tube was not available before the new physics building was taken into use in 1925. From 1925 onwards Devik started, very energetically, his project to build the discharge apparatus. The ambitious project included the construction of a glass blowing lathe to handle the discharge tube made of glass. For treating the glass tube Devik had to develop novel skills in glass blowing. Holtsmark mentioned that Devik's enterprise was funded by a research foundation.[377] However, no references to the funding of Devik's discharge-tube project are found in NTH's annual reports. Devik never published any work connected to his discharge tube but applied for a patent at the Norwegian Patent Office (*Styret for det Industrielle Retsvern*) on September 18, 1926. The patent was published on June 25, 1928 under the title "*Procedure for the generation of very high voltages*" and with the patent number 44504.[378] The patent was ready to be granted already in September 1927 but its release was postponed to July 1928 by Devik's patent attorney Alf Bryn. Bryn gave intended patent applications in other countries, especially the USA, and negotiations with a larger company as reason for the postponement. I do not have information on whether Devik applied for patents in other countries. Neither do I know the name of the larger company Devik had negotiated with. The patent specifications concentrated on possible technical and medical applications of the device and did not specify any research applications, like its possible use for disintegrating atoms.

To take out a patent for a device like Devik's discharge tube was quite untypical for a physicist of the interwar period. Patenting was more common among engineers. The Norwegian electrical engineer and accelerator builder Rolf Widerøe, who was mainly working in Germany, also patented several accelerator designs. Widerøe's patents had, in the historical retrospective, little importance because physicists did simply not take notice of them. As pointed out by Pedro Waloschek in 1994, referring to Widerøe, patents do not generally feature in scientist's required reading lists.[379] It was Widerøe's published dissertation and not his patents which was taken notice of and which inspired Ernest Lawrence's cyclotron design at Berkley.[380] It was, however, quite typical for Devik to take out patents for devices and design principles developed by him, rather than publishing them. Devik took patents for a procedure for artificial drying of fish, for the extraction of grease out of greasy materials, for an apparatus for the direction reference of sound waves, and for procedures to measure wind speed and the flow velocity in water.[381] As for Widerøe, there is no indication that the scientific community took notice of Devik's patents.

[377] Holtsmark, FFV, 1946, p. 197.

[378] Norsk Patent Nr. 44504, klasse 21g, *Fremgangsmaate til frembringelse av meget høie spændinger*.

[379] Waloschek, 1994, p. 4.

[380] See Waloschek, 1994, p. 39 and Widerøe, 1929.

[381] All Norwegian patents, patent numbers 32584, Kl. 53c, 1918, nr. 29064, 1917, nr. 37724, Kl. 74d, 1918, nr. 29530, 1918, and nr. 32050, Kl. 42K, 1918.

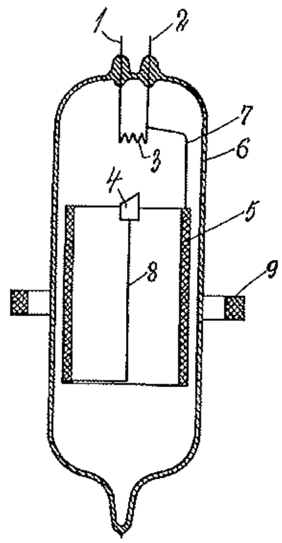

Fig. 5.2: Drawing of the patented device, Norsk Patent Nr. 44504 Klasse 21 g, June 25, 1928. (1) and (2) are the voltage supply to the (3) glow cathode. (4) is the anticathode, (5) the secondary coil, (6) the evacuated glass tube. (7) is a connection between glow cathode and secondary coil and (8) a connection between anticathode and the other terminus of the secondary coil. The primary coil (9) is mounted outside the evacuated tube.

There is no line of similarity, or personal contact, that can be drawn between the engineer Widerøe and the physicist Devik other than they both patented their accelerator designs. Devik seems to have inherited the habit of patenting ideas and devices from his mentor Kristian Birkeland, one of Norway's most renowned physicists. Birkeland had taken patents for a number of inventions. Most famous among these were his electrical cannon and the patents in connection with the Birkeland-Eyde process for the fixation of nitrogen by passing air through an electric arc. Birkeland's electric cannon failed to become a success. The Birkeland-Eyde process, in contrast, laid the technical foundation for one of Norway's largest industrial enterprises, the *Norsk Hydroelektrisk Kvælstof-Aktieselskap* (Norsk Hydro). The Birkeland-Eyde process became the most powerful symbol of Norwegian based, rather than imported technology and the importance of scientific research for industrial development. For Birkeland probably more important than fame, royalties from the patents made him a rich man and allowed him to pursue more freely his Aurora Borealis research.[382] Devik, in contrast, never seem to have earned considerable royalties from his patents. I only know of one of Devik's devices, a registering anemometer, which was built commercially.[383] The patenting of the Tesla coil drive discharge tube and "negotiations with a larger company" indicate that Devik imagined a considerable commercial market for the device. By 1928, when the patent was granted, however, a number of research groups were working on accelerator designs applying Tesla coils and it seems doubtful that Devik could have successfully claimed priority.

Devik's work on the high voltage device was well known at NTH and referred to.[384] Also in the international research community, Devik's device did not remain unnoticed, despite the fact that it was not published about. In summer of 1930 Lawrence Hafstad, a physicist from the Carnegie Institution of Washington, Department of Terrestrial Magnetism visited Devik. Like Devik, Hafstad was working with his Washington co-workers Merle Tuve and Odd Dahl on the development of a Tesla coil driven discharge tube for nuclear disintegration. Their development of a Tesla coil-driven discharge tube at Washington had started with Merle Tuve and Gregory Breit in 1926.[385] In 1929 Breit left the Department of Terrestrial Magnetism and the team was subsequently lead by the electrical engineer and physicist Merle Tuve.[386] Odd Dahl became the instrument designer and builder of the team. Hafstad was not exactly on alien soil when he visited Devik at NTH in Trondheim, one of the northernmost outpost of Europe's scientific and engineering culture. Both Tuve and Hafstad were American citizens of Norwegian ancestry and grew up in Norwegian-American communities with strong roots in Norwegian traditions. Hafstad's father was originally shoemaker in the little town of Steinkjer, just north of Trondheim, who immigrated to the USA before his son was born.[387] Dahl was a true Norwegian. He came to Washington in 1926 by

[382] For Birkeland and the Birkeland-Eyde process see Andersen and Yttri, 1997, p. 9 ff., and Friedman in Collett, 1995, p. 5 ff.

[383] The registering anemometer was built by R. Fuess in Berlin, see R. Fuess, Druckschrift A 40a, not dated, p. 9 ff. *Anemograph nach Prof. Devik*, Olaf Devik Privatarkiv, Riksarkivet i Oslo. Devik lively describes Birkeland's activities as an inventor in his autobiography. One of Devik's patents for a procedure for artificial drying of fish (1918) originated directly from an idea expressed by Birkeland. See Devik, 1971, p. 83 f.

[384] For example in Georg Brochmann's popular presentation of 1927, *Hvor Norges fremtid bygges*, p. 78.

[385] Cornell, 1986, p. 178 ff.

[386] Cornell p. 209.

[387] Odd Dahl, 1981, p. 136.

recommendation from the Norwegian geophysicist Harald Ulrik Sverdrup. Dahl had participated in famed arctic explorer Roald Amundsen's last polar expedition as a pilot and had no formal education in science or engineering. Dahl claimed to have learned everything he knew about physics from the two years when they were trapped in the polar ice where he was building and repairing geophysical measurement devices for Sverdrup. In 1936 Dahl was hired back to his home country in order to benefit from his talent regarding the design and building of research technology for Norwegian research activities. The common Norwegian background of the members of the Washington group made them good friends and contributed to their working dynamics.

Also Tuve, Hafstad and Dahl did experience discharge by corona and heavy sparking of their Tesla coil when they moved up in high voltages. They did not try to overcome the insulation problem of the Tesla coil by evacuating its surrounding, as Devik did, but immersed the coil into a pressurised container of oil. Measuring the voltage with the little accurate method of a spark gap they claimed in 1929 to have reached 5.2 million volts.[388] As the discharge tube they built a cascade tube based on a modified Coolidge design. The tube was subdivided into sections to divide the voltage over several electrodes. This way the Washington group claimed to have discharged successfully 1.4 million volts through the whole tube.[389] Devik and the Washington group were not the only ones who were trying to develop an accelerator design based on a Tesla coil as the high voltage source. Also Thomas Edward Allibone, Cockcroft and Walton at the Cavendish Laboratory were experimenting from 1926 to 1930 with a Tesla transformer immersed under oil.[390]

In July and August 1930 Hafstad made a trip to Europe to study contemporary high-voltage research and to expand the Washington researchers' contact net. For his trip Hafstad received detailed instructions by the acting director of the Department of Terrestrial Magnetism, John Adam Fleming, especially about whom to visit:

"...

2. Among the investigators whose work is of interest are Brasch and Lange, and Bothe in Berlin, Busch and Wolf at Jena, Wolfke at Warsaw, Siegbahn at Upsala, Devik at Trondhjem, Petterson, Kirsch, and Stetter at Vienna, and Rutherford and his collaborators at Cambridge. ... If at all possible you should not fail to visit the following, whose investigations are of perhaps greatest

388 Breit et al, Phys. Rev., 1930, p. 51-65.

389 Breit et al Phys. Rev., 1930, p. 66-71, see also Cornell, 1986, pp. 185.

390 Hartcup and Allibone, 1984, p. 37-46.

interest: Prof. Devik at Trondhjem, Norway, regarding his use of a Tesla coil in vacuum instead of oil; ..."

[John Adam Fleming, 1930][391]

It remains unknown how the scientists at the Department of Terrestrial Magnetism noticed Devik's work. It is clear, however, that Devik was taken seriously by the Washington researchers and seen among Europe's leading scientists in the field, especially since both Devik and the Washington group worked with Tesla coils. After returning from Europe, Hafstad wrote a 15 pages long typewritten report for Fleming. An impressive 1 ½ pages of these were devoted to Hafstad's observations at Trondheim, giving a detailed account for Devik's activities and especially his practices of instrument making:

"...

In Trondhjem I had a long visit with O. Devik at the Techniske Hoiskole. Devik has been working for about the past five years on the general problem of producing high-speed particles by using the high voltages readily attainable by means of Tesla coils. To overcome the voltage-limitations due to corona in air Devik has worked with Tesla coils using spaced bare-wire turns in vacuum, thus taking advantage of the very good insulating properties of high vacua. The work is still in an incomplete state, however, the technical difficulties making progress very slow, and hence no reports on this work have as yet been published.

Various shapes of tubes were tried, but the general type of tube finally used was approximately as follows: A tube of about 3 inches in diameter and 30 inches long was provided with a filament at one end and a target at the other and means provided for exhausting the space between these electrodes. On the outside of this cylindrical tube the secondary of the Tesla was wound with spaced turns. This whole tube was then sealed coaxially into a larger one and the space between the two tubes exhausted to as high a degree as possible, thus attaining the desired condition of vacuum-insulation for the secondary.

Devik hoped to detect hard X-rays produced by this arrangement photographically but found no effect. After a considerable time spent in making such tubes in modified forms, never attaining any really high voltages, he turned his attention to the Tesla voltage wave-form and has since been working on cathode-ray oscillograph studies in this line. The tubes were all of hard glass and made by Devik himself, the technique required for handling the large tubing being acquired only after long practice. The large tubing was worked on a lathe and electric heaters of special form were resorted to in order to give uniform heating of the glass. With these heaters the work was kept uniformly hot and the

[391] Fleming to Hafstad, June 21, 1930, M.A. Tuve papers.

actual seal could be made using a hand torch playing on the edges. Devik emphasized the fact that it was possible for him to repair cracked tubes of large diameters, which is practically impossible using ordinary methods.

The first Tesla coils were made on straight tubes using bare molybdenum wire spaced by means of glass beads. This provided unsatisfactory, so Devik resorted to forming a spiral groove in the glass tubing and winding the wire in this. His method of making these grooves was to heat the tube in the lathe with the above -mentioned heaters to the softening point and then pressing against it a loop of electrically heated nichrome wire of a diameter giving the desired size of groove. This loop was mounted on the tool-holder and was carried along the work mechanically just as in cutting threads on metal. This process gave a very neat and rugged coil but has the objection of not giving enough turns since it was only possible to get about 20 turns to the inch.

In Devik's tests the limiting condition was the gaseous glow between turns and along the winding of the secondary. No good method of measuring the voltages was available, but Devik estimates this to be several hundred thousand. He hopes to carry on these experiments if means permit and has in mind ultimate atomic disintegration experiments.

..."

[Lawrence Hafstad, 1930][392]

Hafstad's report confirms the suspicion that Devik's device never worked satisfactorily and that he did not overcome the initial problems of instrument design to get to using his device for discharge or disintegration experiments. Nevertheless, Hafstad's account acknowledged the skills in instrument making Devik had developed, especially in treating large glass tubes. The account did not mention any kind of help Devik might have received, either from assistants or from the department's workshop. Hafstad's detailed listing of practices acquired by Devik indicates that he did absolutely everything himself, from the most basic mechanical and glass blowing work to the assembly of the device, its testing and experiments. According to Hafstad, Devik had spent most time in making and trying out different types of discharge tubes and Tesla-coil arrangements. Devik had not managed to attain "*any really high voltages*" or to detect hard X-rays produced by his device. Also Tuve Hafstad and Dahl experienced ongoing problems with their device especially in regard to using it as a proton accelerator, and were looking for alternative high voltage sources.[393] But by the time Hafstad visited Devik the Washington group had managed to discharge more than a million volts through their tube. At New Year 1931 they

[392] Hafstad to Fleming, October 1, 1930, copy in M.A. Tuve papers.

[393] Cornell, 1986, p. 244 ff.

were awarded a $ 1,000 prize given by the American Association for the Advancement of Science (AAAS) for the best paper at its annual meeting.[394]

Devik does not seem to have followed up his investigations with the discharge tube after he left Trondheim for an appointment as a research fellow at the newly established Christian Michelsen Institute at Bergen in 1932. For his appointment at Bergen, Devik used another of his patented ideas, the apparatus for the direction reference of sound waves to propose the development of an acoustically based navigation system for ships during bad weather and low visibility. 1932 was also the year Tuve, Hafstad and Dahl scrapped their Tesla transformer in favour for the Van de Graaff generator as the high voltage source for their discharge tube. 1932 was as well the magical year the first nuclear disintegration by artificially accelerated particles was carried out by John D. Cockcroft and Ernest T. Walton in Rutherford's Cavendish Laboratory at Cambridge using step-up transformers.[395] The idea of the Van de Graaff generator radiated back over the Atlantic from Washington to Trondheim, as we will see, and already in 1934 another member of the Washington group, Odd Dahl, visited Trondheim, this time to give advice for the construction of a Trondheim Van de Graaff.

In his autobiography Devik left out his work with the discharge tube, as well as he did not mention other failed undertakings, like his struggle in vain to be appointed as a professor in Norway. There are only scarce reminiscences left that document Devik's endeavour with the high voltage discharge tube: Devik's proposal from 1923, the documents of the patent application from 1926 to 1928 and Hafstad's report to Fleming in 1931. Holtsmark included Devik's work with the Tesla discharge tube in his memoir written on the occasion of Devik's 60th Birthday in 1946. There do not seem to be any material relicts of a discharge tube or a Tesla coil left by Devik. The Tesla coil driven discharge tube had failed to develop into a successful device. But in retrospective it seems strange that Devik wanted to forget about the Tesla accelerator. In the history of science and technology we have seen better known and respected devices which did not work either. Certainly, Hafstad was impressed by Devik's abilities when visiting in 1931. Tuve, Hafstad and Dahl's Tesla transformer failed to work as a particle accelerator. Nevertheless it was very successful in earning them a prize from the American Association for the Advancement of Science in 1931.

In the case that Devik's design of a high voltage discharge tube driven by a Tesla transformer would have been a possible design for a particle accelerator there are several reasons to question whether Devik would have been able to develop it as a successful device for nuclear disintegration. Devik lacked the

[394] Cornell, 1986, p. 246.

[395] The Tesla transformer was abandoned by the Cavendish group already between 1930 and 1931, see Hartcup and Allibone, 1984, p. 46-47.

academic position, the political influence and the contacts to raise the funding appropriate to his research. Devik also lacked a sufficient understanding and internalisation of modern theoretical physics, especially quantum mechanics, in order to understand the physical properties of his "cathode rays" and to use his *accelerator* as an atom smasher. Like much of Devik's other research projects and research practices, his cathode rays experiments have to be seen in the tradition of the gas discharge experiments of his mentor Kristian Birkeland. Being an apprentice of Birkeland and student of Lenard, Devik belonged to the older generation of physicists who in the interwar period still not believed the dispute about the ether as settled.[396] In contrast to Lenard, who fought fiercely against quantum mechanics and the theory of relativity, Devik never seem to have expressed any doubts about the great theories of 20th century physics. Like other Norwegian physicists of the older generation, as Sæland and Bjerknes, Devik simply did not engage with the new physics. Accelerator design and nuclear disintegration experiments were, however, not detached from the new physics. At the Cavendish Laboratory it was precisely the close contact to the theoretician and Bohr co-worker Gamow, and the use of quantum mechanics, that enabled Cockcroft and Walton to surpass the American laboratories and to detect the first accelerator-generated nuclear disintegration.[397]

A third reason to doubt that Devik would have possibly succeeded in the accelerator project was his known habit to be involved in too many disconnected activities at the same time. Bjerknes already pointed this out in a letter to Devik in October 1923 when Bjerknes tried to advise Devik and to explain why he did not succeed in the competition with Holtsmark. Also during the ten years at Trondheim Devik did not follow Bjerknes' advice to "*do only one thing at a time*" and involved himself in the study of ice formation, which had no connection at all with the discharge tube project.

In 1934 Devik made one more attempt to be appointed to a Norwegian professor's position when the Chair of Terrestrial Magnetism and Cosmic Radiation became vacant at Bergen's Geophysical Institute. According to the official published report Devik withdrew his application before the appointed committee evaluated his qualification. But among Devik's papers in his private archive a manuscript of an earlier evaluation of the candidates including Devik's evaluation can be found. It appears that the original version of the evaluation was leaked to Devik by the committee members and he was given

[396] See Devik, *Litt om æteren*, Norsk Radio, 1925.

[397] See for ex. Jeff Hughes, 1998. See for the Washington group's knowledge of Gamow's theory Cornell, 1986, p. 207. See also Heilbron and Seidel, 1989, p. 67 and 139. Lawrence, however, knew about Gamow's theory and the possibilities it contained. According to Heilbron and Seidel, "*the main reason that the Berkley group did not succeed in splitting the atoms before Cambridge is that they did not try*" (Heilbron and Seidel p. 139).

the option to withdraw in order to avoid to have published was has to been seen as a negative evaluation of his qualifications. After crediting Devik's abilities as an experimenter and instrument designer the commission concluded that his contributions to pure physics were few and that they did not indicate significant research initiatives. Neither did they lead to significant results. The commission nevertheless concluded that Devik was qualified for the position he applied for.[398] Again it was a younger candidate and good friend, this time Bjørn Trumpy, Devik's successor to the lecturer's position in Trondheim, who was appointed at Bergen. Devik's attempt to develop a Tesla-coil driven discharge tube for nuclear disintegration secures him a place among other accelerator pioneers. But at least in 1934, it seems that the Norwegian scientific community had lost its faith in Olaf Devik as one of its leading scientists.

5.4. International research in nuclear physics in the early 1930s seen from Holtsmark's perspective at Trondheim

In the beginning of the 1930s, the study of the nucleus became arguably more and more the most interesting and most important frontier in science internationally. An increasing number of laboratories entered the competition of building the first successful accelerator to disintegrate atoms. The year of 1932 was referred to as the *annus mirabilis,* or the miraculous year of nuclear physics.[399] In 1932, two additional particles were discovered, the positron and the neutron. In the same year John D. Cockcroft and Ernest T. S. Walton, at Cambridge, managed to disintegrate lithium and boron by bombardment of accelerated protons. This marked the beginning of accelerator based nuclear physics and opened the race to higher and higher energies of the accelerated particles in order to disintegrate heavier and heavier nuclei. Before 1932, Devik represented the field of high voltage and nuclear disintegration research at NTH's physics department. It seems doubtful that Johan Holtsmark could have entered this field without creating tensions, as long as the senior Devik was still at Trondheim. But Devik's departure to Bergen opened the possibility for Holtsmark to move into high voltage and nuclear physics research.

In contrast with Devik, who had few international contacts, Holtsmark was both well known and well informed about the newest developments, especially in the German speaking community, but also in Great Britain and the USA.

[398] Both versions of the committee's declaration can be found in Olaf Devik's Privatarkiv, Riksarkivet i Oslo.

[399] See for example Aaserud, 1990, p. 51.

Holtsmark's strongest contacts were with the Institute for Theoretical Physics at Copenhagen University under the leadership of Niels Bohr. The Institute at Copenhagen was frequently visited by Holtsmark as well as by his close assistant Bjørn Trumpy. It was at Copenhagen Holtsmark wrote the important paper on the scattering of electrons, together with the Swedish visiting scientist Hilding Faxén.[400] Bohr, who had close contact to the ruling figures of the Norwegian physics community, especially Vilhelm Bjerknes and Sem Sæland, was a strong supporter of Nordic scientific co-operation.[401] The annual informal conferences at Copenhagen were well visited by the younger generation of Norwegian physicists. The beginnings of the 1930s were also heralding the turn for Niels Bohr and the Copenhagen Institute away from the quantum mechanics of the atomic shell and towards the nucleus.[402] At the annual conference on theoretical physics at Copenhagen in mid-September 1933, nuclear physics was one of the main subjects. Three Norwegian physicists, Johan Holtsmark and Bjørn Trumpy from NTH and Egil A. Hylleraas from the Christian Michelsen Institute in Bergen were present. According to the preliminary program no one of these Norwegian physicists was presenting any work. But they were surely listening well to the many presentations concerning nuclear physics, radioactivity research and cosmic radiation. The accelerator laboratories did not seem to be represented by associated scientists but they were nevertheless discussed.[403]

[400] Faxén and Holtsmark, 1927. See also Chapter 4, Section 8.1.

[401] See Vaagen, 1985, p. 64 ff.

[402] See Aaserud, 1990, p. 39 ff.

[403] See archive of the Niels Bohr Archive, Copenhagen, informal conference, 1933, *Vorläufiges Programm.* Montag [Evan James] Williams: *Experimentelle Ergebnisse über Kernzertrümmerung und Masseneffekte*. Also Heisenberg: *Kernaufbau.*

Fig. 5.3: Copenhagen conference, September 1933. In the first row from left: Niels Bohr, Paul Dirac, Werner Heisenberg, Paul Ehrenfest, Max Delbrück, and Lise Meitner. Johan Holtsmark first left in second last row, Egil A. Hylleraas and Bjørn Trumpy last row, fourth and fifth from left (Photo: Niels Bohr Archive Picture Collection K007).

The Copenhagen conference was also the subject of an interview with Bjørn Trumpy by the Norwegian magazine *Oslo Illustrerte.* Enthusiasm and rumours about the rapid developments in nuclear physics had not passed unnoticed in the popular press and Trumpy was asked about it:

"...

- Did you talk about the disintegration of the nucleus and the freeing of atomic energy?

- Yes, the fourth day this was on the agenda. It is possible to disintegrate nuclei, as it was shown by experiments in Cambridge, but not on a large scale, so it will not be a solution to the energy problem. Would it be possible to free the

atomic energy, the chance must have been there, and the earth would have exploded long ago.

- Yes, if it has to be understood like this, we should rather give up on it."

[Unknown interviewer and Bjørn Trumpy, 1933][404]

That much about the perspectives of nuclear power as they were judged in 1933. Holtsmark was, not least through the contact to Bohr and the Institute in Copenhagen, well aware about international developments and novelties in the physics community. In 1935, when the Trondheim Van de Graaff generator was under construction but not yet finished, Holtsmark wrote:

"...

The modern production system is at the moment in radical alteration from inexact and empirical methods to more exact and theoretically grounded ones. Proper measurements are, constantly to a greater extent, introduced into technology, and people are needed to carry out these measurements. These people must learn to think and work scientifically. But one cannot learn this without being occupied with pure, not applied research. It is up to NTH to meet the right conditions for that. Once it has been recognised that there is no way around pure research, and the question is what research field should be chosen, it is self-evident to take up what is the focus of concern.

It has been asserted that technology is able to continue after people have finished understanding the principles which underlie the culture and which have shaped the technology. There are on the other side also the ones who think that technology cannot live isolated without support in pure research. If research is cut off, technology will continue for some time due to its inertia, but it will stop inevitably in the course of few years. I believe that the last conception is the right one. Technology in the way we have it now, cannot be imagined without connection to pure research, and a country that cannot keep up research will not be able to assert itself, and it will be doomed to being an outdated and insignificant country.

..."

[Johan Holtsmark, 1935][405]

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404 Trumpy, 1933. *Fysikerne intime*, interview in *Oslo Illustrerte* no. 50. Translated from Norwegian.

405 Holtsmark, 1935. *Kunstig radioaktivitet*. In *Teknisk Ukeblad* 82, no. 4, p. 30. Translated from Norwegian.

To begin with experimental nuclear physics was, according to Holtsmark, motivated by the wish to establish in Trondheim new and exciting research fields that were "*in the focus of concern*". Holtsmark personally did not seem to be more interested in nuclear physics itself than about other research fields in physics and he never became a nuclear physicist himself. Holtsmark's motivation to start an accelerator project was more driven by the fact that accelerator based nuclear physics internationally had approached the status of being the most fashionable, we might say the *hottest* research field of the time. Like other contemporary scientists in Norway, Holtsmark made the nation's ability to compete in international research to a question of cultural development and cultural ascent to a level of other nations.[406] Holtsmark felt certainly challenged to bring this internationally *hottest* research field to Norway. However, accelerator based experiments in nuclear physics were carried out with rather expensive equipment, which seemed to be out of reach, considering the economic limitations of scientific research in Norway. High voltage generators of different types were used, or at least tried to be used to accelerate protons in evacuated linear tubes. The nuclear reaction achieved was crucially dependent on high voltage output and stability, and on the current capacity of the high voltage generator used. Even more advanced, more costly and more difficult to construct and handle was Lawrence's cyclotron where the particle beam had to be kept on a circular trajectory by means of a magnetic field. A feasible design for Holtsmark at Trondheim turned out to be the Van de Graaff generator. The Van de Graaff electrostatic generator was, at that time, a rather new device developed by the electrical engineer Robert J Van de Graaff in the United States and little known to the European physics community.

Van de Graaff used two arguments for applying an electrostatic belt generator as a high voltage source for experiments in nuclear physics. First, it supplied a direct steady potential, and second, it was comparatively simple and cheap to build.[407] Robert J. Van de Graaff did not manage to use his own accelerator in experiments in nuclear physics in the 1930s, but the idea of his apparatus was used with great success by Tuve, Hafstad and Dahl at Washington. As we have seen in this chapter, Section 3, on Devik's attempts with the Tesla coil, contacts between the group at the Carnegie's Department of Terrestrial Magnetism at Washington and the physics department at Trondheim had already been established in 1930 when Hafstad had visited Devik in order to study Devik's work on the Tesla transformer. In 1933, it was Holtsmark's turn to re-animate contact with the American-Norwegian group at Washington.

406 At this place I would like to refer to the discussion of the underlying concept of culture in Chapter 2, Section 2, as well as Chapter 3, Section 2.

407 Van de Graaff, 1931.

5.5. Norwegian adaptation to an American technology: Further contacts to Odd Dahl and the Carnegie Institution

Around 1930 several research groups had tried to develop a linear particle accelerator based on a Tesla coil as the high voltage source. Devik at Trondheim had given up the high voltage transformer when he transferred position to Bergen. Also two other groups we know of who tried to use Tesla coils, the Cavendish group under Cockcroft and the group at the Carnegie's Department of Terrestrial Magnetism, experienced ongoing problems regarding the uncontrollable behaviour of their devices. As a result both groups were looking for more stable and controllable high voltage generators.

The Cavendish group with their strong contacts to the British electrotechnical industry, especially to Metropolitan Vickers, turned to a more conventional commercially produced step-up generator.[408] Such a commercially produced high voltage transformer was relatively expensive and, as far as Holtsmark could imagine, way out of his reach.[409]

Tuve, Hafstad and Dahl, who, like Holtsmark, did not possess strong contacts to the electrical manufacturing industry, managed to find a cheaper solution for their high voltage problem. From the late 1920s an electrical engineer and fellow at Princeton University, Robert J. Van de Graaff, developed an electrostatic belt generator as high voltage source for an electrostatic accelerator. Tuve came in contact with Van de Graaff prior to Van de Graaff's famous demonstration at the meeting of the American Physical Society in September 1931. On his move from Princeton to MIT in Boston shortly after the September meeting of the Physical Society, Van de Graaff visited Tuve and the Washington group with his belt generator. They tried out the Washington discharge tube developed for the Tesla coil together with the novel high voltage generator. After these preliminary experiments, Tuve, Hafstad and Dahl decided to build a Van de Graaff accelerator.[410] Soon after, Odd Dahl started to design a large Van de Graaff generator. Dahl was the one most closely associated with the construction of the generator and Tuve later remarked that Dahl had built the machine "*with his own hands*".[411] Already by

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[408] See Hartcup and Allibone, 1984, p. 46 ff.

[409] Holtsmark to Dahl, September 29, 1933. Also Dahl and Trumpy experienced in 1938 that commercially produced high voltage transformers were out of reach under Norwegian funding conditions. See Odd Dahl, 1981 p. 155 and this chapter, Section 6.

[410] See Cornell, 1986, p. 276 ff.

[411] Cornell, 1986, p. 304-305.

the end of May 1932 the device was operational and its voltage potential estimated to two million volts. The only problems resulted from the fact that it was set up out-doors, because the previously used laboratory was too small and still occupied by the useless Tesla device. The group reacted to this problem in two ways: first, they requested for a new building from the Department of Terrestrial Magnetism, a hall to house the large Van de Graaff generator with a room below for observations. Second, they scrapped the Tesla device and built a smaller Van de Graaff generator with a one-meter sphere in their existing laboratory. In early 1933, the Washington group was able to do nuclear disintegration experiments with their small one meter Van de Graaff generator delivering a maximum of approximately 600 kV. Tuve, Hafstad and Dahl had thereby managed to develop their Van de Graaff generator into a successful particle accelerator. The larger two-meter Van de Graaff generator was installed in the new hall during the summer of 1933 and its maximum voltage finally measured to 1.2 million volts. The first disintegration experiments could be carried out in November 1933.[412]

The first letter from Johan Holtsmark to Odd Dahl asking for assistance to build a Van de Graaff accelerator at Trondheim dates from September 29, 1933. That was shortly before the Washington group got their large Van de Graaff accelerator working and only a few days after Holtsmark had returned from the Copenhagen conference. Holtsmark's eagerness to start an accelerator laboratory at Trondheim might have well been triggered by the Copenhagen news. However, Holtsmark received first hand detailed information on the Van de Graaff accelerator of the Washington Group from a very different source. It was the NTH Professor of Geology Thoralf Vogt who had visited the Washington Department of Terrestrial Magnetism in summer of 1933 and subsequently told Holtsmark about the Van de Graaff generator as well as other constructions Dahl had carried out. There was a long tradition of contacts and co-operation between Norwegian geoscientists and the Carnegie Institution of Washington's Department of Terrestrial Magnetism that, strangely enough, had now started to engage in nuclear physics. Vilhelm Bjerknes' groundbreaking meteorological work had been supported by the Carnegie Institution, which also published Bjerknes' *Dynamic meteorology and hydrography* in 1910 and 1911.[413] As we remember from earlier this chapter, Section 3, it was the Norwegian oceanographer and former assistant of Bjerknes, Harald Ulrik Sverdrup, who brought Odd Dahl to the Department of Terrestrial Magnetism after the Amundsen expedition. During and after the Amundsen expedition Sverdrup had close contact to the scientists at the Carnegie Institution and in

[412] Cornell, 1986, p. 377 ff.

[413] See Friedman, 1989, p. 72 ff.

1930 he was offered a position at the Department of Terrestrial Magnetism. Sverdrup, by then Professor of Meteorology at the Geophysical Institute at Bergen, declined the offer.

In the letter of September 1933, Holtsmark informed Dahl about his plans to build a Van de Graaff generator and asked for information, and if possible, drawings of the Washington apparatus. Holtsmark mentioned the generally limited financial means at Trondheim, but with blueprints from Washington and the expertise of Odd Dahl, he realised that he should be able to start an accelerator laboratory at NTH.[414] Odd Dahl as well as the acting director of the Department of Terrestrial Magnetism, John A. Fleming, were happy to help. Already in November 1933, plans and photographs were sent to Trondheim. In the following years, a number of letters were sent between Washington and Trondheim concerning the construction of the generator. Fleming and Dahl also helped to procure materials and instruments from the USA when they proved to be difficult or impossible to find in Europe. In summer of 1934, during a work stay in Norway, Dahl himself came to Trondheim to advise about the planning and construction of the generator.

The Van de Graaff high voltage generator was at that time still a technology used only by a few research groups in the Northeast of the United States. In 1934, Holtsmark also corresponded with L. C. Van Atta who was working together with Robert J. Van de Graaff at the MIT, mainly about technical aspects of the high voltage generator.[415] Another MIT scientist who had built a working Van de Graaff generator, though not as an accelerator, was Ervin H. Bramhall.[416] Holtsmark and his assistants copied some of the Bramhall design. Two letters from Holtsmark to Bramhall, however, seem to have not been answered.[417]

As we will see later, Holtsmark and his assistants also developed strong contacts to European accelerator laboratories. The contacts with the Americans and especially with Odd Dahl were nevertheless necessary in order to start with the relatively inexpensive Van de Graaff technology. It was more typical for the British Cavendish Laboratory and also for most of the early German accelerator

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414 Holtsmark to Dahl, September 29, 1933, archive *NTH - Fysisk institutt*, box Ea: 3, Statsarkivet i Trondheim.

415 Holtsmark to Van Atta, April 30, 1934, Van Atta to Holtsmark, May 19, 1934. archive *NTH - Fysisk institutt*, box Ca: 3, Ea: 4 and Ea: 5, Statsarkivet i Trondheim. The large generator of Van de Graaff and Van Atta at Round Hill, sighting at a 7 million volts, never developed into a successful accelerator and the engineering problems tended to overshadow scientific concerns. See Cornell, 1986, p. 352.

416 Bramhall, 1933.

417 Holtsmark to Bramhall, February 1 and April 30, 1934 archive *NTH - Fysisk institutt*, box Ca: 3, Ea: 4 and Ea: 5, Statsarkivet i Trondheim.

groups to commission at least large amounts of their equipment ready-made from electrical manufacturers. The Trondheim group, much like the Washington group at the Department of Terrestrial Magnetism, had to build almost everything themselves. In a later visit in 1936, Dahl confirmed that the group at Trondheim had dynamics and a work style typical for a comparable American group. Interestingly, at that time Holtsmark and his assistants had travelled over much of Europe to study performances at other accelerator and high voltage laboratories but none of them had so far visited the USA.

5.6. Financing big research technology: Artificial radio isotopes and the rhetoric of cancer treatment

After Holtsmark had decided to build a Van de Graaff accelerator at Trondheim and had secured support from Washington, several questions still remained open about starting the project at Trondheim. A crew of motivated assistants had to be assigned and Holtsmark had to decide what size of generator the project should aim at. Ideally the generator should be as big as possible, but the modest prospects for local funding limited the project's perspective. Holtsmark decided to build the generator within the existing physics building, thereby avoiding the costs of a new edifice, which would have endangered the financial feasibility of the project right at the beginning.

In 1934, Holtsmark made some moves towards collecting money from different institutions for buying components for the generator's construction as well as for the financing of the various assistants and technicians involved. In February 1934, he received a grant of NOK 1,200 from NTH's research fund (*Norges tekniske høiskoles fond*) which financed all kinds of research activities at NTH and had given contributions to most of the physics department's other fields of research. The contributions by NTH's research fund to the accelerator project were then repeated every year until 1942, rising to NOK 1,500 in 1935 and topping NOK 4,100 in 1939. In September 1934, Holtsmark applied for an extraordinary contribution from NTH's budget of NOK 10,000 and for the same sum from the Norwegian Life Insurance Company's Association (*De Norske Livsforsikringsselskapers forening*). In November Holtsmark applied for a contribution from Director Johan Throne Holst of the *Freia* chocolate company, Professor Helland-Hansen, head of the Geophysical Institute (*Geofysisk Institutt*) at the Bergen Museum and Director Severin A. Heyerdahl at the recently established Norwegian Radium Clinic (*Radiumhospitalet*, which opened in 1932) at Oslo. Especially in the applications to the Radium Clinic and the Life Insurance Company's Association, Holtsmark stressed the potential use of the high voltage apparatus for cancer treatment. He also proposed co-operation to the Radium Clinic. Holtsmark proposed to produce artificial radioactive substances in the accelerator. These substances could be used to substitute extremely expensive radium in cancer treatment.[418] Holtsmark pointed out his contacts to the Washington group and estimated that the apparatus at Trondheim could be built for approximately NOK 20,000, only half the cost of the apparatus at Washington. The annual ordinary budget of NTH's physics department amounted to, in comparison, NOK 12,000 in 1935, not including salaries. An NTH graduate research scholarship (*høgskolestipendiat*) was endowed with NOK 3,000 a year.

None of these applications yielded success. In 1934 Holtsmark had to start the accelerator project with the NOK 1,200 from NTH's research fund and with the ordinary budget and means of the physics department. Only a donation of glass plates asked for by Bjørn Trumpy and Holtsmark at Drammen Glass Works (*Drammens Glassverk*) to build a condenser was granted.[419] In December 1934 finally, another Norwegian research fund, *Norsk Varekrigsfond*, contributed NOK 5,000, still way too little to continue the construction of the generator. Facing a possible bankruptcy of his project Holtsmark started a public relation campaign including a lecture at the Polytechnic Association (*Polyteknisk forening*) in January 1935, titled *Artificial Radioactivity*. The lecture was subsequently published in *Teknisk Ukeblad*. In March, an enthusiastic article titled *Norway self-sufficient with radium?* appeared in *Aftenposten*, one of Norway's largest and most recognised newspapers.[420] Both articles focused very much on the vision of producing artificial radioactive substances in order to substitute radium for cancer treatment.

To his lecture at the Polytechnic Association in January, Holtsmark had asked to have members of all life insurance companies organised in the Life Insurance Company's Association invited, but only two were eventually noticed. The association funded a variety of initiatives on the improvement of

[418] This possibility arose after the discovery of induced artificial radioactivity by Jean Frédéric Joliot and Irene Joliot-Curie earlier in 1934 and its successful replication in accelerator laboratories. The production of artificial radio-isotopes was soon much discussed internationally and a frequent argument in grant applications towards cancer related foundations. See for ex. Heilbron and Seidel, 1989, p. 177 ff.

[419] Ragnar Andreas Tandberg, technical director of the Drammen plant, had graduated from electrical engineering at NTH in 1923 and was a good friend of Trumpy. See letter Trumpy to Tandberg, November 13, 1934.

[420] *Norge selvhjulpent med radium? Aftenposten,* March 6, 1935. The article carried a strong propagandistic character, stating that it would be "in principle" possible to make literally gold, the old alchemist' dream, and that with this machine in hand the radioactivist would come a step closer to the biblical process of creation.

public health, though medical research was unusual for their philanthropy.[421] During the interwar period the problem of deaths caused by cancer came more and more into the concern of life insurance companies. For the American company *Metropolitan Life* the claim payments caused by cancer rose from 6% in 1911 to over 14% in 1943, more than $ 25 million a year![422] In other words, cancer grew to a serious death factor among Western middle class society, who were the typical customers of life insurance companies. To have cancer reduced or eliminated as cause of death was an important economic concern for the life insurance companies.

Another important aspect was, however, that Holtsmark was also through his family related to the life insurance business. His father, Gabriel Holtsmark, a physics doctorate himself, had worked as an actuary for the Norwegian life insurance company *Fram* from 1910 to 1920 and had participated in the association's study on the death statistics in Norwegian life insurance companies regarding annuity assurances.[423] Gabriel Holtsmark lobbied for his son's repeated application to the Life Insurance Company's Association by writing a personal letter to the director of the association, H. A. Sommerfeldt.[424] Odd Stubb, a senior physician in Trondheim, also sent a letter of unrestricted support for Holtsmark's research generator. Stubb nevertheless pointed out the research character of the plant and that one should not expect the production of larger amounts of radioactive substances. He further stressed the importance of co-operation with, for example, the Norwegian Radium Clinic and of scientifically trained medical personnel in order to study the properties and effects of the radioactive substances being produced.[425]

[421] About the association's donations to initiatives of public utility, see Christensen, 1965, p. 266 ff. Between 1915 and 1965 altogether NOK 4 ½ million were donated to various projects. During the interwar period contributions to medical research did not seem to have been typical. However, in 1953 and 1956 the medical-statistical department at the *Ullevål* clinic and the University Department for Thrombosis Research were supported.

[422] Dublin, 1943, p. 449.

[423] J. Holtsmark about his father in *Aschenhougs Konvesasjons Leksikon*, 1954-1962, and Christensen, 1965, p. 49 ff.

[424] *De Norske Livsforsikringsselskapers forening arkiv*, letter dated March 1, 1934. Gabriel Holtsmark used a personal style when writing about his son to Sommerfeldt and pointed out that Norway should not loose its international position in research. He also mentioned Valentin Fürst, senior physician at the *Diakonissehuset* clinic and experienced in medical research, who was supposedly very interested.

[425] Letter from Stubb, March 24, 1935. I do not have any reference showing that any kind of co-operation between Holtsmark and Stubb or any other physician has actually taken place later.

In May 1935, ten life insurance companies organised in the association decided to support Holtsmark's high voltage accelerator collectively with NOK 15,000. Exactly this sum Holtsmark had mentioned in the *Aftenposten* article:

> "... *We are lacking, in short, 15,000 crowns today, procure us these and we won't let a day go unused. Here there are excellent conditions at the Department of Physics for this plant, good house and good rooms and more like that. What we need here in this country now is just this one last assistance* (denne ene siste håndsrekning) *to be among the first out in the world.*"
>
> [Johan Holtsmark, 1935][426]

Holtsmark also alleged that it was only the construction of the generator itself that would cost significant amounts of money, not the later experimentation, carefully avoiding mentioning the annual salaries of the two assistants he planned to employ at the accelerator laboratory. In June, Holtsmark was pressing on paying out the contribution of the insurance companies for balancing a number of unpaid bills. By the end of 1935 it became clear that the estimation of an additional NOK 15,000 to complete the accelerator, as mentioned in the *Aftenposten* propaganda article, was too low. Even with the contribution of the *Varekrigsfondet* of NOK 3,000 in autumn of 1935, the budget was not sufficient to finish the generator.[427]

In spring of 1936, a contribution of NOK 10,000 made by the Norsk Hydro Company saved Holtsmark's balance. Little is found in the Norsk Hydro Archive about the origins of the contribution and nothing in the NTH archive.[428] In all likelihood the deal was arranged through Professor Leif Tronstad and accounted for as part of Hydro's involvement in heavy water research. The Norsk Hydro company was at the time the world's sole producer of heavy water on a significant scale and had a research co-operation with Tronstad at NTH's chemistry department.[429] Tronstad was Professor of Inorganic Chemical Engineering and had a close contact with the physics department where a number of chemical engineers worked as assistants. In order to investigate properties and possible applications of heavy water, a novel and unique product, but yet without a significant market, Hydro financed two

426 Holtsmark in *Aftenposten,* March 6, 1935, translated from Norwegian.

427 Holtsmark, December 12, 1935.

428 I am much obliged to Kari Kaalstadt at the archive of the Hydro company. There are only two letters confirming the allowance, the receipt of NTH and a short letter of acknowledgement by Holtsmark.

429 Andersen and Yttri, 1997, p. 127 f.

research assistants from 1936 onwards. A strong demand for heavy water first arose after Otto Hahn's experiments on the fission of uranium, and Lise Meitner and Otto Frisch's interpretation of the results in 1939, when it became clear that heavy water could be used as a moderator for controlled nuclear reaction.[430] Going back to 1936: one of the imagined applications of heavy water was, again, cancer research.[431] Beams of positive deuterium ions were also used in accelerator laboratories in Great Britain and the USA, and Rutherford's Cavendish Laboratory was directly supplied by the Hydro Company.[432]

Another possible concern of the Hydro Company would have been the development of high voltage technology for long distance transmission of electricity. The Norsk Hydro Company was in possession of some of Europe's largest hydroelectric power plants and had Europe's cheapest electricity at their disposal. This factor made Hydro a producer of heavy water to begin with.[433] In the 1920s, high voltage laboratories set up by electricity supply companies and electrical manufacturers flourished in may countries like Germany, the USA and also Norway's Big Brother Sweden.[434] The Norsk Hydro company, however, did not involve in long distance high voltage transmission, but built their power intensive industry in direct connection to the hydropower plants.[435]

Hydro's contribution in 1936 was the last donation made by private companies or associations to the Trondheim Van de Graaff project that can be traced. The building of different parts of the apparatus was basically completed by then. The financing of the two assistants commissioned by Holtsmark to run the accelerator and to carry out the experiments was covered by research scholarships of NTH (*høgskolestipendiat*) and other contributions of the NTH-

[430] See especially Per F. Dahl, 1999, but also Andersen and Yttri, 1997, p. 141 ff. and Brun, 1985.

[431] Andersen and Yttri, 1997, p. 127 and personal communication with Andersen.

[432] Andersen and Yttri, 1997, p. 128. On the use of deuteron beams, see Heilbron and Seidel, 1989, p. 153 ff.

[433] Andersen and Yttri, 1997, p. 127.

[434] See Thomas Hughes, 1983, p. 377 ff. and Heilbron and Seidel, 1989, p. 6, f. For Sweden, see Norinder's report on the Uppsala Institute for High Voltage Research (*Institutet för Högspänningsforskning*), especially his reference to the The Royal Waterfall Management (*Kungl Vattenfallssyrelsen*) and their long-term investigations in high-voltage phenomena, Norinder, 1939, p. 5. See also Kaiserfeld, 1997, p. 107 ff. Also Californian hydropower companies involved in high voltage research for long distance transmission.

[435] Andersen and Yttri 1997, p. 42. The involvement of Hydro in long distance transmission was taken into consideration but the company decided that they could not work on all research and development fronts at the same time and concentrated on chemical process technology.

fund, *Det vitenskapelige forskningsfond av 1919* and *Det Vitenskapelige Forskningsfond 1938*.

The Norwegian life insurance companies repeatedly asked for a final report regarding the high voltage plant and its production of artificial radioisotopes for cancer treatment. This report did not come before April 1939, two years after the completion of the apparatus and the beginning of experiments. Holtsmark pointed out that the apparatus worked satisfactorily. He included a number of scientific publications about experimental results in nuclear physics achieved with the accelerator, and highlighted the attention received from the scientific community. Regarding the production of artificial radioisotopes, the results were less impressive. Holtsmark's report makes it clear that these trials had not overcome initial stages. Even though several artificial radioactive substances were made in small amounts, significant quantities of radioactive substances, thought to be used in animal experiments, had never been produced. Like other pioneers of accelerator building, it seems Holtsmark depended on the research money of the cancer people but he was himself never really interested in cancer research.[436]

In his 1939 report, Holtsmark could already point towards a second Norwegian Van de Graaff generator designed for cancer treatment under construction at the *Haukeland* clinic in Bergen. The Bergen Van de Graaff was built mainly by Odd Dahl and in co-operation with the senior physician Sigvald N. Bakke, the Christian Michelsen Institute and the Geophysical Institute of the Bergen Museum. Two events coincided with the building of the generator. One event was the beginning of a fund-raising campaign for work against cancer by the Norwegian Red Cross in 1935, and the decision of the Bergen district to relate the funding with the X-ray and radium department of the *Haukeland* clinic. The other event was the return of Odd Dahl to Norway in 1936. Bjørn Helland-Hansen, director of the Geophysical Institute at Bergen managed to poach Dahl from his position at the Department of Terrestrial Magnetism, Carnegie Institution of Washington, to a joint position at the Geophysical Institute and the Christian Michelsen Institute. The Christian Michelsen Institute for Science and Intellectual Freedom, an independent research institute established as a foundation in Bergen in 1930, with a distinctive department for

[436] Holtsmark was not alone with claiming to use his accelerator for cancer treatment in order to raise funding. Lawrence was, according to Seidel (in Galison, 1992, p. 27 - 29) promoting his cyclotron as an effective X-ray machine to save radium but privately confessing that there was no point in using X-rays as hard as he would produce. See also Hartcup and Allibone, 1984, p. 59 on the subsidy of Cockcroft's journey to the USA in 1933 by the Rockefeller Foundation and medical research organisations in London. There is no indication that the Trondheim Van de Graaff generator was ever used in direct relation to cancer research or treatment after 1939 either.

science and technology, was the closest Dahl could get to as a Carnegie-Institution-like in Norway.

At Bergen, Dahl co-operated with other scientists already mentioned: Olaf Devik, who had worked on the Tesla coil accelerator at NTH at Trondheim, and Bjørn Trumpy, Holtsmark's former assistant and lecturer at NTH who had been appointed as Professor of Terrestrial Magnetism and Cosmic Radiation at the Geophysical Institute in 1935. Harald Ulrik Sverdrup, Dahl's companion during the Amundsen polar expedition and the person who brought Dahl to the Carnegie Institution in the first place, left Bergen in the same year of Dahl's appointment for the directorship of the Scripps Institution of Oceanography in La Jolla, California. The institutions at Bergen could now profit from Dahl's exceptional talent as a designer and builder of research technology in order to push Norway towards the forefront of international scientific research. From the very outset of his appointment, Dahl had planned to construct a Van de Graaff generator at Bergen, if possible in a pressure tank.[437]

The original idea of the fund-raising campaign conducted by the Norwegian Red Cross, to procure as much radium for cancer treatment as possible, was soon abandoned in favour for a high voltage plant for so called supervoltage radiation. In contrast with the Trondheim accelerator, the Bergen generator would not be used to produce artificial radioisotopes but to treat patients directly with the accelerator beam for deep treatment. A few similar installations were already in use in the USA and in Europe. The original plan of the Bergen group was to buy a high voltage generator made by an electrical manufacturer rather than building a Van de Graaff generator themselves. In 1938, Dahl and Trumpy tried to buy a high voltage installation delivering 500 kV from the Phillips Company at Eindhoven. The NOK 150,000 from the money collective, however, was not sufficient and the do-it-yourself Van de Graaff turned out to be the solution again.[438] The construction of the Van de Graaff generator at the *Haukeland* clinic started in 1939 and was finished in March 1942 without exceeding the budget. The plant, producing high voltages up to 1.7 MV was in use for deep cancer radiation treatment until 1968.[439] Apart from cancer treatment, Trumpy and Dahl also used the *Haukeland* Van

[437] Dahl to Tuve, June 5, 1936, *Merle A. Tuve papers*, box 4, Library of Congress, Washington DC.

[438] Odd Dahl, 1981, p. 155. Dahl told the story at Eindhoven in this way: "... *We told them what result the fund-raising had given and the Phillips guys, who we knew from before, looked at each other and said: -Oh, you have 150,000 Crowns! That was indeed pretty. Now we pay you a decent dinner, and then you go home and build the plant yourselves for that money.* " (translated from Norwegian).

[439] The history of the Van de Graaff generator at the *Haukeland* Clinic is treated in Janssen et al., 2001.

de Graaff for experiments in nuclear physics until 1950, when a second Van de Graaff was finished at the Geophysical Institute.[440]

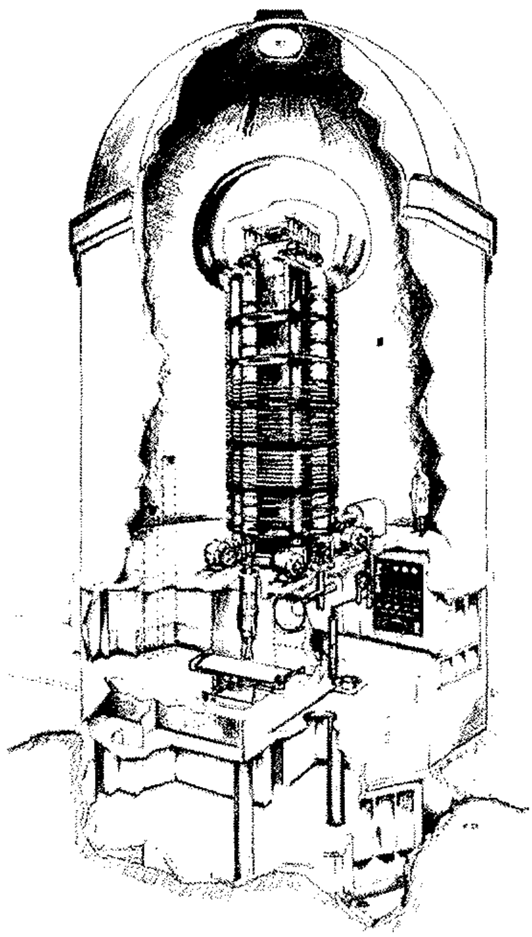

Fig. 5.4: Finn Devik's drawing of the *Haukeland* Van de Graaff generator. At left accelerator tube for supervoltage radiation, at right accelerator tube for positive ions for nuclear physics experiments (Janssen et al., 2001, p. 210).

440 See for example Dahl and Trumpy, 1942, and Trumpy, 1943 and 1945. The second Bergen Van de Graaff accelerator is still in operation. See also Chapter 2, Section 3.

Whereas the Trondheim Van de Graaff generator was never used in cancer related research or treatment, the Van de Graaff generator of the *Haukeland* clinic was a successful machine for cancer treatment. The starting points of both machines were, however, very different. Johan Holtsmark was basically interested in building a high voltage accelerator, as big as possible as a means to enter the field of experimental nuclear physics, a field he saw as being a central concern in international science development. When Holtsmark developed his plans in 1933, no one else was active in the field of accelerator based nuclear physics in Norway. In 1937, he had managed to complete Scandinavia's first successful working accelerator. Like for his other research projects, Holtsmark managed to obtain contributions from Norway's existing research funds for the accelerator project, above all the NTH-fund. However, research funding for pure science in Norway was not arranged to allow the construction of what was seen at the time as big research technology. The typical contributions of the research funds only allowed to buy or build smaller apparatus and maybe to pay one research assistant. It was only after WWII, the Hiroshima and Nagasaki bombs and the beginning of the Cold War, that the Norwegian state acknowledged the importance of nuclear physics and started funding the research activities on a larger scale.[441] In order to succeed in building the Van de Graaff generator, Holtsmark was forced to procure money from other sources. Cancer related institutions were usually willing and able to pay large amounts of money for research. Holtsmark could copy the rhetoric from other leading accelerator laboratories in order to tap this source. Other research fields, like the rapidly developing molecular biology and genetics, as well as their appertaining research technologies being developed, also depended to a large extent on cancer-money. Many of the scientists involved were using the cancer-research rhetoric. Often they were not more interested in cancer itself than Holtsmark was. It was a common strategy to argue like Holtsmark that, whether nuclear physics or molecular biology, basic research had to come first. A contribution to the solution of the cancer problem might evolve later.

In comparison, the situation at the *Haukeland* Clinic differed drastically. The plant was built as a hospital facility within an existing department for radiation treatment and not as a research installation at a physics department. Experiments in nuclear physics became consequently, even though conducted, a minor matter. The financial situation of the *Haukeland* Van de Graaff was also very different. Even though the collected NOK 150,000 were not sufficient to buy an industrially-made high voltage generator, the budget of the *Haukeland* Van de Graaff exceeded Holtsmark's budget about five times and allowed, among other things, to construct a separate accelerator building. To be forced to build the accelerator in an existing laboratory had been the main cause for the

[441] See interview with Roald Tangen, April 2, 1990.

voltage limitation of Holtsmark's accelerator. Consequently, the *Haukeland* accelerator became a more powerful machine.

5.7. Building the Van de Graaff accelerator at Trondheim

In summer of 1934, Holtsmark proceeded well in the planning and preparation of the Van de Graaff project. With the help of the Americans and especially Odd Dahl, the design of the high voltage apparatus was laid out. Holtsmark had delegated most of the planning, design and construction work to private assistants. The accelerator was decided to be set up in two laboratories in the third floor of the physics department. The space was originally built as part of a meteorological station of Trondheim that was never established. The rooms had been used as X-ray laboratories before the accelerator group moved in. One room was reserved for the high voltage generator. The other room would house control instrumentation and the observation platform, with the beam of the accelerator tube going through a hole in the wall between the laboratories. The size of the generator room, 3.45 x 4.5 m with a height of 3.5 m, limited the maximum voltage of the Van de Graaff generator considerably. This was the compromise Holtsmark had to go in for, in order to fit the apparatus in the existing building without limiting the other research and teaching activities. The localisation of the observation room besides, rather than beneath the generator room, as it was in Washington, meant that the accelerator tube had to be arranged horizontally rather than vertically. This was a clear disadvantage for the tube's design and stability.

At the same time, Holtsmark and his team had also started to inquire about parts and materials, and to place orders. Everything that was available locally was ordered locally, like the aluminium sphere and the original paper belt, which was later exchanged for a Goodyear rubber belt. Many parts, however, had to be bought of specialised manufacturers. The Bakelite support was ordered from *Emil Haefley & Cie*, Basel and the tube of lead glass, which broke, was bought from *Jena Glass Works*. Other special parts, like bellows, some special amplifier tubes and vacuum lacquer were ordered from the USA. After Holtsmark had secured enough funding, the construction of the generator could start more seriously. In December 1935, the Van de Graaff high voltage generator with the 20 kV rectifier set was finished and tried out. The high voltage limit before discharge was not measured exactly but estimated to a million volts, most probably by a spark gap. Also the vacuum pump system was finished and tried out. The ion source was under construction. The tube of lead glass was procured but the assembly of the accelerator tube had not started. The construction of the deflecting magnet had not started either. A Wilson chamber was already built, together with a mercury lamp for lightning. A remote control for the camera to take pictures of the particle tracks was under consideration. This is the last time we get to hear about the Wilson chamber in regards to the Trondheim accelerator project. Holtsmark seems to have demonstrated a Wilson chamber in his lectures at NTH, but in the experiments with the Van de Graaff generator, the Wilson chamber, if used at all, did not get a place as a detector prominent enough to be mentioned in any publication.[442] This is probably due to the proton capturing experiments the Trondheim group concentrated on. The Wilson chamber was mainly a detector for alpha particles whereas gamma rays did not produce a visible track. Also Cockcroft at the Cavendish Laboratory, which was visited by Ramm and Westin in 1935, had moved from the scintillation screen to counters for quantitative measurements.[443] In the end of 1935 Eilif Bjørnstad, who was in charge of the Wilson chamber, had already bought parts to build Geiger-Müller counters at Trondheim.

One might get the impression that the construction of the Van de Graaff at Trondheim progressed at a slow pace compared to other accelerator laboratories. Holtsmark's department was, however, a newcomer in all the fields of engineering and research technology that were involved, such as high voltage technology, vacuum technology and radioactivity experimentation and research. Most other groups entering accelerator physics had an expertise in at least one of these fields, like the Cavendish Laboratory, Bothe and Gentner at Heidelberg and Irène Joliot-Curie and Frédéric Joliot at Paris. Most of the laboratories possessing experience in traditional radioactivity research but none in high-voltage, ordered their high voltage equipment more or less ready made. An interesting exception was Bothe and Gentner's Van de Graaff generator at Heidelberg.[444] The electrical engineer Robert J. Van de Graaff and his collaborators remained preoccupied with the technical problems of the large MIT generator at Round Hill and did not managed to use it for any nuclear disintegration experiments. Hafstad, Tuve and Dahl had some years of experience with the Tesla device and its discharge tube when they changed over

[442] Holtsmark's demonstration of a Wilson chamber in his lectures is mentioned in Ormestad, Tangen and Wergeland, 1944, p. 4.

[443] The conversion of the Cavendish Laboratory from the scintillation method to Geiger-Müller counter arrangements has been described in great detail in Jeff Hughes, 1992. See also Hughes in Gaudillière and Löwy, 1998. The cloud chamber method is described by Hughes as "*elaborate and time consuming, demanding much labour for little reward*". When applying a remote control camera, in Trondheim under consideration in 1935, large numbers of photographs had to be taken. See Hughes, 1992, Chapter 2, Section 4.3.

[444] See Bothe and Gentner, 1937, and Schmidt-Rohr, 2001, p. 33 f.

to the Van de Graaff generator. Before long they managed to build a working machine and to adopt the new high voltage source. Devik at Trondheim had also collected some years of experience with his Tesla device. But he had left for Bergen before Holtsmark started to involve in the accelerator project. As a result, there was no personal or material continuity at Trondheim.

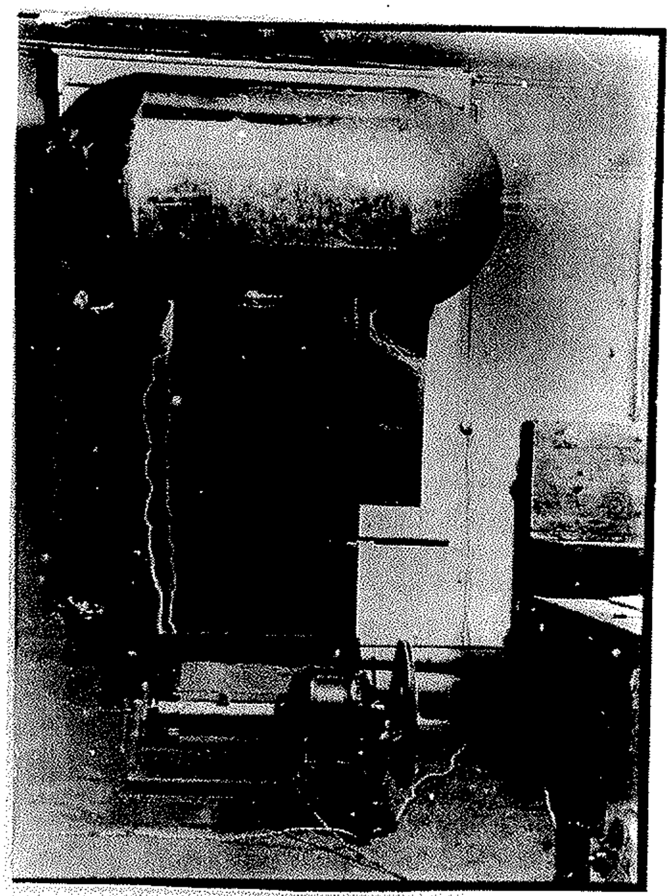

Fig. 5.5: The running Van de Graaff generator at its high voltage limit. Heavy sparking can be observed along the insulating column at left and corona discharge from the sphere towards the wall at right, about 1935 (Photo: Statsarkivet i Trondheim).

We will now look closer at certain aspects of the realisation of the Van de Graaff generator at Trondheim. We will begin with Holtsmark's assistants, beyond doubt his most important resource.

5.7.1. Teams of electrical and chemical engineers: Knowledge transfer and division of labour

When Holtsmark started to plan the accelerator project, it was not his intention to involve in the practices of instrument design or of nuclear experimentation himself. In contrast with Devik, who did everything himself, including most basic mechanical work, Holtsmark saw his role in administrating the project. He was ensuring funds, establishing international contacts and, not the least, delegating practical work to yet inexperienced but motivated assistants. As an experienced researcher, competent in modern physics and quantum mechanics, Holtsmark had a good overview and contributed essentially in the planning as well as in the writing of publications. He would, however, never become a nuclear physicist himself.

As we have seen in Chapter 3, Section 4.4., Holtsmark did not have any physics students at Trondheim who could be hired as assistants. Holtsmark was successful in hiring his assistants among the graduates of the departments of chemical and electrical engineering. The two groups, chemical and electrical engineers, had very different educational backgrounds. Generally they also had very different motivations and perspectives when engaging in research at the physics department. Regarding the Van de Graaff generator project this diversity had a clear advantage. The field of accelerator based nuclear physics was constituted as a merger of very different research fields, research traditions, research practices and research technologies. In this perspective, the combination of chemical and electrical engineers as assistants made perfect sense for the Van de Graaff accelerator project.

As mentioned in the account on the beginnings of nuclear physics, traditional radioactivity research before the age of accelerators was to a large extent carried out in radiochemistry, as by Ellen Gleditsch at the chemistry department at Oslo University. Many of the laboratories engaging in accelerator technology originated, at least partly, from this research tradition, like Rutherford at Cambridge and Irène Joliot-Curie and Frédéric Joliot at Paris. A number of chemical engineers at Trondheim, like Lars Onsager and Sverre Westin, had carried out the research for their Diploma thesis in the laboratories of the physics department of NTH. By 1933, chemical engineers had also worked as assistants in research fields like spectroscopy, X-ray crystallography and electron scattering. Especially the example of Bjørn Trumpy had shown that a chemical engineer from NTH could successfully be converted into a physicist.[445] Many graduating chemical engineers had a decent interest in and understanding of the principles of physics, especially of the then developing theory of quantum mechanics. Many research technologies and experimental techniques were used in both physics and chemistry laboratories. In contrast to other engineers, the chemists had a deep tradition in laboratory research, similar to or sometimes even exceeding physicists. Consequently, in Holtsmark's scheme, it was the chemical engineers' role in the project to stand for experimentation and to balance the electrical engineers' focussing on electrical machinery. It was the chemical engineer who was thought of to plan the experiments, to understand its physical contents and to interpret the results.

The role of the electrical engineer was quite different from the chemical engineers' role in Holtsmark's scheme. It was their role to build and run the accelerator as an electrical machine. In the first phase of the project, when the various components of the accelerator had to be built, the role of the electrical engineer as an instrument builder was dominating. Several engineers were assigned at the same time to build different components. After the accelerator was finished and the experiments had begun, one electrical engineer would be sufficient to maintain the generator and to carry out improvements. The electrical engineer as an instrument builder and designer did not reduce the importance of the department's instrument-maker shop for instrument building. On the contrary, one mechanic solely appointed to build mechanical parts for the accelerator laboratory increased the workforce of the instrument-maker shop under direction of senior instrument maker Thorvald Reed. As we have seen in Chapter 2, Section 3, however, the role of the craftsmen in scientific instrument making had changed significantly during the interwar period. Earlier scientific instruments were generally built by craftsmen according to design or sometimes only according to the suggestions of scientists. During the interwar period simple devices were developed into complex measurement systems with the accelerator laboratory as its most prominent example. Mechanical measurement principles were exchanged for electrical ones and radio technology revolutionised scientific instrument design. Consequently, scientific instrument design and building became more the field of electrical engineers. The instrument makers in the shop were no longer building instruments primarily after the suggestion of a scientist, but parts of complex devices after the drawings of engineers.

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[445] The chemical engineer Bjørn Trumpy had defended his *dr.techn.* thesis in 1927. By 1933 Trumpy had been a Rockefeller scholar and was offered a professor's position in physics at the Ohio State University. See Statsarkivet i Bergen, Arkiv fra Bergens Museum, Trumpy's application as Professor of Terrestrial Magnetism and Cosmic Radiation in 1934.

As discussed in the previous chapter, all the electrical engineers assigned by Holtsmark to the accelerator project had a background in amateur radio. Until 1933, all the electrical engineers engaged in instrument building and research at the physics department had worked exclusively in electroacoustics. This experience in using electrical engineers for scientific instrument design and making could now be mobilised for other research fields as well. Since everything had to be self-made, Holtsmark's accelerator project could not have done without these electrical engineers. Most early accelerators were designed and built by electrical engineers or physicists with electrical engineering and amateur radio background. The first electrical engineer who was appointed by Holtsmark on the Van de Graaff project was Einar Kulvik who had graduated from telecommunication engineering in the autumn of 1933. Kulvik worked at the physics department for three months in the winter of 1933/34 and elaborated the first construction drawings for the high voltage generator, before he accepted an appointment at the *Allgemeine Elektrizitätsgesellschaft* (AEG) in Oslo. The first team of an electrical and a chemical engineer taking over the Van de Graaff project in spring of 1934 were Wilhelm Ramm and Sverre Westin. Ramm, who had graduated from telecommunication engineering like Kulvik in autumn of 1933, headed the construction of the main components of the accelerator until autumn of 1936. Other electrical engineers involved during this period were Eilif Bjørnstad and Oddvar Johannesen. Holtsmark's expectations of the electrical engineers become very evident in the letters of reference he wrote for his assistants, especially in contrast to the references he wrote for the chemical engineers. Electrical engineers were expected to be capable designers and builders of electrical devices, whereas chemical engineers would show the capability to understand and solve complex theoretical problems and have a deeper understanding of physics.[446] There was one electrical engineer, Roald Tangen, who would surpass this expectation. Tangen succeeded in bridging the gap between instrument building and nuclear physics experimentation and became one of Norway's first nuclear physicists. All other electrical engineers involved in the Van de Graaff project followed the destiny of Einar Kulvik: they achieved leading positions in Norway's growing electrical industry but never worked in nuclear physics again.

A chemical engineer who surpassed Holtsmark's expectations regarding the chemists' instrument making ability was Sverre Westin. Westin had already worked at the physics department's X-ray laboratory during his diploma thesis in spring of 1933. As a subsequent research field for his postgraduate project, he took over Holtsmark's research on electron scattering, which has been discussed in the previous chapter. Westin came in contact with the Van de

[446] Archive *NTH-Fysisk institutt*, box Da: 5, 1-6 Administrasjon: attester, erklæringer, Statsarkivet i Trondheim.

Graaff generator through the development of advanced vacuum pumps and vacuum systems which had to be developed for both evacuating the accelerator tube, as well as for Westin's scattering chamber. The characteristics of the development of this vacuum technology will be discussed in grater detail in the next section. However, Westin's involvement in the Van de Graaff project reached beyond mere vacuum problems. The team of Westin and Ramm had co-operated well until both abandoned the Van de Graaff accelerator in autumn of 1936, shortly before it was completed.

5.7.2. Making good vacuum

One of the first problems that all accelerator groups had to face was developing more efficient and powerful vacuum pumps than the ones that were generally available. Until the early 1930s mercury diffusion pumps constituted the state of the art high vacuum technology. Mercury diffusion pumps were developed by Wolfgang Gaede in Germany in 1915 and by Irving Langmuir at the General Electric Company in the USA in 1916. They operated on the principle of transferring momentum from high velocity mercury vapour molecules formed by heating, to the gas molecules that were to be removed from the system.[447] The replacement of mercury by refined low-vapour-pressure hydrocarbon oils by C. R. Burch in England in 1928 and K. C. Hickman in the USA in 1929 allowed lower pressure with easier constructions and higher pumping speed. Another problem of the mercury pump was the mercury amalgamation with most metals, for example with brass, which was widely used in instrument making. Much precaution was needed to avoid small portions of mercury from evaporating into the apparatus to be evacuated. Most larger accelerator groups had moved over to the use of oil diffusion pumps, like Lawrence at Berkley, Tuve, Hafstad and Dahl at Washington, and Cockcroft and Walton at Cambridge.[448]

Holtsmark and his assistants Ramm and Westin took as their starting point the oil diffusion pumps of Tuve, Hafstad and Dahl, for which they got drawings sent over from Washington. They did not merely copy the Washington design but improved and adjusted it to their own needs. What was most characteristic

[447] See Unzeitig 2000, p. 62 ff.

[448] The oil diffusion pump solved the evaporation problem only partly since the vacuum oil also evaporated into the evacuated system. Therefore, small amounts of vacuum oil were always present in the accelerator tube. This impurity, mainly containing carbon, could lead to unwanted nuclear reactions and neutron radiation.

of the Trondheim approach, was that they did not develop a vacuum pump system exclusively for the accelerator, but a movable vacuum station that could be taken around in the department wherever needed. Advanced vacuum technology was the inevitable base of many research fields and research technologies, like radio tubes, cathode ray tubes, X-ray tubes, Geiger-Müller counters, etc. In Trondheim, vacuum technology was for example used in X-ray crystallography.[449] Also Sverre Westin needed to develop a vacuum system for his experimental research on electron scattering.[450] Vacuum technology thereby constituted an intersection between the department's involvement in electron scattering and nuclear physics research. Like in the example of the transfer of radio technology to electroacoustics as well as to nuclear physics research instrumentation, the intersection between electron scattering and nuclear physics was constituted not on a theoretical level but on the material level of research technology. Taking advantage of these intersections was Holtsmark's strategy to run the small department with its few members and several advanced research agendas.

The first two scientific publications Ramm, Westin and Holtsmark submitted in connection with the Van de Graaff project in 1936 were consequently about advanced vacuum technology, and only about vacuum technology.[451] That these pumps and valves were meant to be used to evacuate an accelerator tube was only noted in the margin. To develop the vacuum technology needed for the accelerator as an all-purpose technology was the physics department's strength when it came to maintaining all the different research activities. However, when it came to getting the accelerator finished as fast as possible, this was an obstacle. As Dahl pointed out in his letter to Tuve in June 1936, and as Holtsmark was well aware, time was *very expensive* in the accelerator business, with the race to higher energies and more advanced technological principles moving with an enormous pace. The Trondheim Van de Graaff was one of the first accelerators working successfully in Europe when finished in 1937. It was, however, already then quite a small machine by international comparison. Developing the vacuum technology quasi-independently from the rest of the accelerator resulted in Ramm and Westin becoming very busy developing state of the art vacuum technology. The alternative would have been, in a Jack of all Trades manner, to get something working that would suffice for the vacuum requirements of the accelerator but not be good enough for a scientific publication. Especially the time taken by

[449] See Brækken: *Ein Universal-Röntgenapparat für Kristallstrukturuntersuchungen*, 1932.

[450] See Westin, 1946/1949 p. 69 ff. The collision chamber for the electron scattering in gases was evacuated with an oil diffusion pump and then filled with a gas from a container.

[451] Ramm and Westin, 1936, and Holtsmark, Ramm and Westin, 1937.

Ramm and Westin to write the 25 page treatise *Arbeitsmethoden der Hochvakuumtechnik* could have been better invested, as other accelerator groups would have argued.[452]

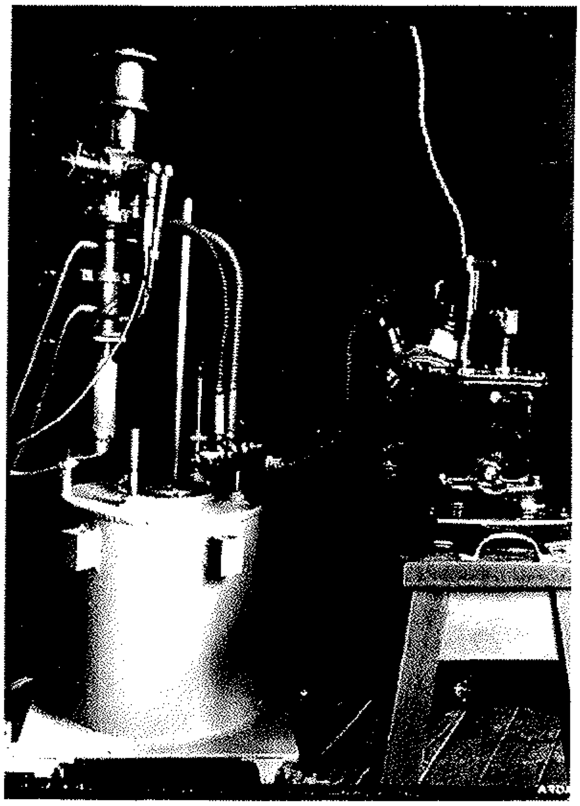

Fig. 5.6: Movable vacuum station of Ramm and Westin at NTH, about 1936. At left: Pfeiffer rotary vacuum pump to supply the diffusion pump with a pre-vacuum. At right: oil diffusion pump for high-vacuum mounted on pre-vacuum tank. The pre-vacuum tank was needed to balance the uneven vacuum of the rotary pump (Photo: Statsarkivet i Trondheim).

This was true for the accelerator project then. The Trondheim group was, however, not concentrating solely on accelerator technology but was following a broader perspective of research activities at the physics department. The Trondheim physics department came to profit well from Westin's involvement

[452] See Dahl to Tuve, June 5, 1936, cited in this chapter, Section 7.4.

in vacuum technology later. When Westin came back to NTH after WWII and was appointed Professor of Technical Physics in 1949, his design of oil diffusion pumps and his expertise in vacuum technology came to play a crucial role in the research activities he organised. Today, Sverre Westin is mainly forgotten among Norwegian physicists for his involvement in the accelerator project but in Trondheim well remembered, for his expertise in vacuum technology.

5.7.3. The transnational network of a local research project: Other international contacts of the Trondheim Group

At the beginning of the accelerator project in Trondheim in 1933 and 1934, contacts with the American groups were of critical importance. As presented in this chapter, Section 5, contacts with Odd Dahl at the Carnegie Institution of Washington and subsequently with Van Atta at MIT played a decisive role in entering the field of accelerator physics and in the decision for the Van de Graaff technology. During Dahl's visits to Trondheim, especially the second one when Dahl managed to get the first beam out of the machine, he could transfer practices of accelerator building and using from Washington to Trondheim which could scarcely be learned from an instruction letter. One would, however, have a limited perspective of Johan Holtsmark's activity as a research entrepreneur with a global perspective if one would think that the international character of the Van de Graaff project would stop here.

The first international collaboration of the newly emerged Trondheim nuclear research technologists was established with Professor Harald Norinder at the Uppsala Institute of High Voltage Research (*Uppsala universitetets institut för högspänningsforskning*). Norinder had carried out research for the Swedish *Kungl. Vattenfallsstyrelsen* since 1922 to solve problems of high voltage discharge and flashover in long distance electricity transmission of hydropower. In 1931, the Institute of High Voltage Research was founded with Norinder as its director. Its research field was defined partly as discharge and flashover in high voltage electricity transmission, partly as the investigation of atmospheric discharge. The impressive high-voltage laboratory was finished in 1933. It was 30 meters long, 14 meters wide and 18 meters high. Its instrumental equipment, completed in 1934, included a high voltage impulse generator estimated to deliver a maximum of 2.3 million volts as well as especially designed high voltage cathode ray oscilloscopes to record, for example, the characteristics of atmospheric lightning discharge.

Like the NTH group, Norinder started to build a Van de Graaff electrostatic generator in 1934, and a lively correspondence took place between Trondheim and Uppsala. At an early stage of the project Holtsmark let his assistants take charge of the contacts. The correspondence with Norinder was taken over by Ramm. Norinder was more experienced in high voltage research, whereas the Trondheim scientists held the contacts with the Americans, especially with Dahl and Van Atta. Because of its infrastructure the Uppsala Institute would have been a perfect place for nuclear physics research carried out with high voltage generators. There is no indication that Norinder was ever interested in nuclear physics. Most of the institute's publications of the 1930s were dealing with atmospheric discharges and their effects on radio broadcasting and overland high voltage power cables. For Norinder, the Van de Graaff generator was a novel and unique high voltage electrostatic generator, which he added to his collection. The two Van de Graaff generators built at Norinder's Institute were almost perfect copies of a machine described by Ervin H. Bramhall in the *Review of Scientific Instruments* in January 1934. They did not contain any voltage measurement or voltage control device. As far as known they have never been used in any scientific investigation but only as demonstration examples for the principle of the Van de Graaff electrostatic high voltage generator.[453]

In October 1934, Holtsmark participated in the large International Conference on Physics at London which was mainly devoted to nuclear physics. On the same journey he visited Cockcroft and Walton at the Cavendish Laboratory. He was, however, also visiting the Acoustics Department at The National Physical Laboratory at Teddington and the research laboratories of the British Broadcasting Corporation (BBC) at Nightingale Square in London. To mix activities in acoustics, high voltage nuclear disintegration and electron scattering at the physics department was continued when three of the department's assistants, involved in different research fields, carried out a study trip Great Britain and the European continent. In summer of 1935, Wilhelm Ramm, heading the Van de Graaff project, Sverre Westin, organising his research on electron scattering and Reno Berg, heading the acoustical laboratory, visited altogether six research laboratories in three countries. The list included, again, The National Physical Laboratory, but this time its high voltage installation. Obviously, the Cavendish Laboratory was a main station on the trip. The Trondheim physicists also went to see William Lawrence Bragg's laboratories at Manchester University. After leaving Britain for the Netherlands, Ramm and Westin visited the Philips Laboratories at Eindhoven where they were especially interested in the high voltage installations. The fifth

[453] Norinder, 1939, especially p. 33-34 and personal communication with Olof Beckman and Stig Lundquist.

station of the Trondheim physicists was Berlin, where the program included the Siemens laboratories and the *Heinrich Hertz Institut für Schwingungsforschung*.[454]

The same summer Holtsmark also set up a study trip for Ramm and Westin to the Soviet Union. Holtsmark spoke Russian and had close contacts to Soviet scientists. The Soviet accelerator laboratories had reached far in their development compared to most other European countries. The adventurous tour to the high voltage laboratories of Leningrad and Harkow was planned to be done by motorcycle, among other reasons to keep the travelling budget low. It was surely also a culture of adventureness that brought up the idea. Vebjørn Tandberg, another assistant of the physics department whom we know from Chapter 4, had in the 1920s driven a motorcycle to Africa and back. Odd Dahl was certainly Norway's most prominent science adventurer. Not only had Dahl participated in Amundsen's polar expedition: in 1925 he had crossed South America from Peru to Brazil down the Amazon river after he had visited the Carnegie's magnetic station at Huancayo. In 1928, Dahl crossed Asia together with his wife, also this time being involved in magnetic measurements for the Carnegie Institution. During Dahl's engagement in accelerator building at Washington the American press liked to title Dahl an adventurer who had given up travelling around the world for diving into the world's new adventures of atom splitting. Back in physics' "golden 20s and 30s", science as life's ultimate adventure was a tempting self-image for young scientists and engineers. Coming back to our local history, Ramm and Westin's motorcycle adventure to the Soviet Union in summer of 1935 did not happen eventually, most probably because of political reasons.

Already at an early stage of the project Holtsmark had sent out his assistants to study other high voltage and nuclear physics laboratories. It was, after all, the assistants and not Holtsmark who had to learn to build and to run all the different parts of the accelerator, and, last but not least, to carry out the experiments. The know-how for these activities could not be learnt out of a book, but only be acquired in practice. The importance of learning about accelerator technology at an established laboratory in order to transfer it to a different location is well documented for the case of early cyclotron accelerators. Basically all laboratories around the world that engaged in cyclotron technology either sent a scientist for a research stay to Berkley or got a Berkley-man for their laboratory.[455] The Trondheim accelerator scientists and

[454] The Cavendish Laboratory was visited in the end of June and the Philips Laboratories in the middle of August. The chronological placing of the other visits, especially at Berlin, is not possible since the archive only contains Holtsmark's letters of introduction. See Archive *NTH-Fysisk institutt*, box Da: 19, 16 Studiereiser, Statsarkivet i Trondheim.

[455] Heilbron and Seidel, 1989, p. 317 ff.

engineers never went to the USA during the interwar period but took advantage of the closer European facilities. At other laboratories they could experience technology and experimentation comparable to what they would build and perform themselves at Trondheim. In this perspective it is interesting that none of the assistants of the Trondheim Van de Graaff group was sent for a longer stay to another accelerator laboratory.

Holtsmark's close contact to Niels Bohr and the Institute at Copenhagen played a major role when it came to the theoretical framework of the nuclear physics experiments at Trondheim. Holtsmark had lectured on Bohr's compound nucleus theory for the Royal Norwegian Society of Science and Letters in Trondheim in May 1936, before demonstrating the beam of the Van de Graaff generator. One month later, he took his assistants Ramm and Westin to the informal 1936 Copenhagen conference.[456] It was probably on the 1936 Copenhagen conference where Ugo Fano, a young collaborator of Enrico Fermi at Rome, first got in contact with the Trondheim physicists. Two years later in 1938, Fano tried to come to Trondheim in order to join the accelerator laboratory. Holtsmark rejected Fano's application and excused the rejection in a letter to Fermi with the lack of funding for foreign scientists in Norway.[457]

The annual conference at Copenhagen was also visited by the group's foremost theoretician, Harald Wergeland, on his 1937 journey to Germany. In Germany, Wergeland went to see Bothe and Gentner's accelerator laboratory at Heidelberg and Holtsmark's former mentor Peter Debye, now head of the *Kaiser Wilhelm Institut für Physik* at Berlin-Dahlem. Debye, however, made clear that there was not much to see at Berlin since the accelerator project was still in its initial stage.[458] As a young Norwegian physicist it was difficult not to stop by in Copenhagen on the way south to the continent. As we have seen in this chapter, Section 4, the theoretical circle around the Copenhagen Institute started in the early 1930s to move towards the physics of the atomic nucleus. The Copenhagen engagement in nuclear physics did, however, not stop with theory. Niels Bohr's establishment of an accelerator laboratory at the Copenhagen Institute of Theoretical Physics in the mid 1930s has to be understood, as Finn Aaserud has shown, in the context of several events: the dismissal of Jewish and other unwanted scientists by Nazi Germany and Niels Bohr's efforts to create positions for refugee physicists, the establishment of the experimental biology program of the Rockefeller Foundation in 1933 and the attempted re-establishment of a close relationship between theory and experiment at the Institute. Niels Bohr at the Copenhagen Institute started later

456 For the 1936 conference, see Aaserud, 1990, p. 235 ff.

457 Fermi to Holtsmark, September 27, 1938 and Holtsmark to Fermi, October 4, 1938.

458 Holtsmark to Wergeland, June 5, 1937 and Debye to Holtsmark, June 10, 1937.

than Holtsmark at Trondheim to build up an accelerator laboratory. However, the Copenhagen re-direction towards accelerator based nuclear physics was much more decisive and on a very different scale. It included Rockefeller money, a number of Nobel Laureates and the parallel installation of several accelerator technologies.[459] Still, the Trondheim physicists were able to contribute, especially with high vacuum expertise and materials. Now it was the Trondheim group's turn to send out drawings for diffusion pumps.[460] A longer stay by Njål Hole and Roald Tangen at Copenhagen in 1941 fizzled out because of war difficulties.[461] After the war in 1946, Tangen finally came to Copenhagen for a longer stay and helped to start experiments with the Institute's 1.8 MV Van de Graaff generator.[462]

[459] The Copenhagen accelerator laboratory, which was mainly financed by the Rockefeller Foundation's experimental biology program, started to take form in 1935. A cyclotron, a Cockcroft-Walton high voltage accelerator and a Van de Graaff generator were installed more or less simultaneously. The Copenhagen cyclotron produced its first beam in August 1938. The Cockcroft-Walton installation was first used as an accelerator about New Year 1939. The Van de Graaff generator went into operation only after the war. For the redirection of research at the Institute of Theoretical Physics at Copenhagen towards nuclear physics, see Aaserud, 1990.

[460] See, for example, Bohr to Holtsmark, September 1, 1937, Jacobsen to Holtsmark, March 20, 1939 and Koch to Holtsmark, December 23, 1939, all Niels Bohr archive, Copenhagen.

[461] Holtsmark to Bohr, August 28, 1941 and Bohr to Holtsmark, September 5, 1941.

[462] At this point I do not want to go further into this post-war history, told by Tangen in the 1990 interview. The results of the Copenhagen experiments, which became famous and entered an number of textbooks, were published in *Physical Review*, see Broström, Huus and Tangen, 1947.

5.7.4. The completion of the accelerator and the beginning of experiments

In May 1936, after he had transferred positions from Washington to Bergen, Odd Dahl visited Trondheim a second time for the accelerator. During the nine-day visit he helped to assemble the accelerator tube and produced the first beam of the accelerator. Dahl wrote about his impressions to his former colleague and friend, Merle Tuve:

> *"... I went up there [to Trondheim] for a second vissit and spent nine days there working like hell all the time, and when I left we had a high-voltage spot focused on to a screen. The spot landed smack in the center first shot.*
>
> *Enclosed one of many klippings, regular USA. publicity.*
>
> *You will all enjoy these pictures. Too bad I dont have a general picture of the whole thing; but as you well can imadgine, the generator and horizontal tube is in one room, going through the wall where you have the pumping station and magn. deflection and so on in an other room.- The tube design throws away quite a bit of glass in order to get fine adjustment on electrodes in a horizontal tube; but the tube seems to be good for the capasity of the generator anyway. It certainly looks like 500 Kv. on it; but the potential is not measured jet, as you can imagine. They plan to build a voltmeter right away.-*
>
> *It was a little hard to get everything adjusted as we had no gauges which we could use, because the gauges from USA. had not come.-*
>
> *They have an improved needle valve design, which is beautiful, and they have lots of figures on pumps, and the pumps are very well made, and they have made many of them, in two standard capasities.-*
>
> *Mechanically the lay out is excellent, and very permanent. That is of course one of the reasons why it has not been going very fast. The other reason is that they also have other duties, and as new in the field has been inclined to take things too seriously, and calculate and design on everything.-*
>
> *They have made a very practical all purpose vacuum testing station, with pumps and an assortment of flanges, portable, to be used where needed around in the institutt.-*
>
> *The group seems to have the right spirit, and if it was not for the language, it could have been in any peppy place in USA.*
>
> *It is hard for me to say much about their real qualifications for that kind of work; but they must have the needed theoretical groundwork, and I think they are making a serious attempt to enter the field.*
>
> *Prof. Holtsmark is the leading spirit, and he is fine and generaly accepted as a nut. He look at the present instalation as something to gain experience*

upon, and want to start something as big as possible We have of course gone into the details of the pressuresphere at great length together with full sanction from Helland-Hansen, and with extra very good luck some cooperative effort might get under way in due time, the hell of it is that time is so very expensive in this bussines.

Ramm the man tecknically in charge of the outfitt, will probably write to you and Hafstad for advise as to a scientific program suited for their equipment and as beginners, and I think they deserve advise. Well, this is enough of High-voltage.

..."

[Odd Dahl, 1936][463]

The letter gives us quite a unique view on the Van de Graaff project at this moment seen from the perspective of the Washington group. Dahl confirms the group at Trondheim to have dynamics and a work style typical for a comparable American group. The team of Ramm and Westin, with Holtsmark as the "*leading spirit*" seems to have worked well with little friction and high motivations. Dahl's comment also points towards the comparatively flat hierarchical structure and the informal working atmosphere at the Trondheim physics department. At the same time Dahl seemed to experience the Trondheim group to over-engineer their apparatus.[464] They were building mechanically very solid and well performing machinery which was delaying the accelerator's completion and thereby the beginning of experiments. According to Dahl one should have been less careful in the mechanical design and have won time for experimentation. At Washington the group had learned that "time was very expensive in this business" when they were beaten by the Cavendish group to produce the first nuclear disintegration.

Dahl mentioned that the Trondheim group had work obligations other than merely finishing the Van de Graaff generator. This comment was probably aimed at Westin who was engaged in both the accelerator project as well as in

[463] Dahl to Tuve, June 5, 1936, *Merle A. Tuve papers*, box 4, Library of Congress, Washington DC. Spelling not corrected.

[464] Dahl's instrument design at Washington had moved on a much faster pace. Tuve, Hafstad and Dahl ran into serious confrontations with the shop staff at the Department of Terrestrial Magnetism about who would have the authority over instrumental design, the workshop staff, or the experimental staff. Tuve described the workshop foreman Huff as a good designer for certain types of work, but a poor designer for experimental equipment because he over-designed! The conflict was solved by having installed workshop facilities for the nuclear physicists' own use, like a lathe and a drill press (Cornell, 1986, p 286 ff.). Such friction never occurred at Trondheim and the workshop was always credited to work in harmony with the experimental staff.

his own electron scattering research. Also Holtsmark was at the same time continuing, if not increasing his engagement in his true research interest, which was technical acoustics. Dahl's comment hints towards the complicated structure of the Trondheim physics department. The working conditions at Trondheim were very different from the Washington group at the Carnegie's Department of Terrestrial Magnetism. The Carnegie Institution was entirely financed by philanthropy and had no teaching responsibilities or graduate students at all.[465] The Trondheim physics department was heavily involved in basic physics teaching for engineering students and students of the Norwegian Teacher College. Some diploma students of the chemical and electrical engineering department carried out their experimental work in the physics laboratories. Holtsmark characterised his assistants as graduate students, who after their diploma would engage for some time in advanced independent studies. Their graduate studies would enable these engineers to live up to the requirement of modern production life.[466] As already mentioned, for most electrical engineering graduates involved, their work on the Van de Graaff project represented an intermediate station on their way to an appointment in the electrical industry. At the same time the assistants were engaged in various teaching activities and formed one of the cornerstones of the department's teaching system. Holtsmark, like other representatives of the university research community, continuously pointed out the unity of studying, teaching and research as well as the research assistant's central position in this unity. In this perspective the Van de Graaff project, like all other university research projects, was as much an educational and, as Holtsmark and his contemporaries would have put it, a cultural project.[467]

465 See Dennis, 1991, for a very interesting comparison between the economy of Charles Stark Draper's laboratory at MIT during the 1930s and Tuve's and his collaborators working conditions at the Washington Department of Terrestrial Magnetism. Dennis showed the different economics of a research department financed either by the marketplace or by philanthropy. He discussed the difference of cultures and practices at a department engaged in teaching and a department free of teaching duties. Dennis also pointed out the differences between the Department of Terrestrial Magnetism and other accelerator laboratories who had to secure their funding on the marketplace, such as Berkley, the Cavendish and Caltech. See for ex. Dennis, 1991, p. 220.

466 See Holtsmark in *Teknisk Ukeblad*, 1935, as cited in this chapter, Section 4.

467 See for example Holtsmark, 1935, *Kunstig Radioaktivitet*, p. 30, as cited above and Holtsmark to Devik, *forslag om forskningsstipendiater ved Fysisk Institutt*, 24. 11. 40, privatarkiv Devik.

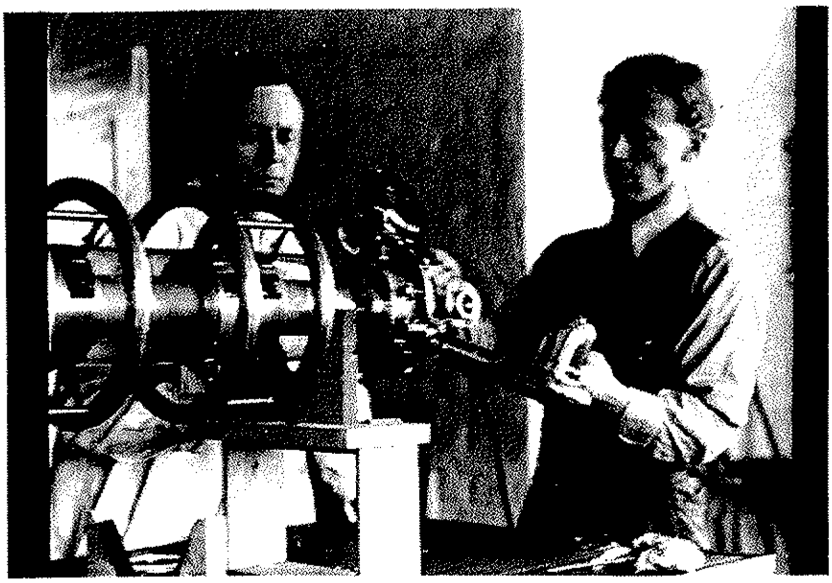

Fig. 5.7: Odd Dahl (at left) and Wilhelm Ramm assembling the accelerator tube during Dahl's visit at NTH at Trondheim in May 1936 (Photo: Statsarkivet i Trondheim).

Dahl's letter to Tuve confirms our suspicion that Holtsmark did not have a research program for his plant. Holtsmark wanted to enter the field of accelerator physics with the machinery in the foreground of concern. Experimentation would come later, basically as a result of two factors: first the potential of the machine and second the stage of experimentation that the international research community had reached when the machine was finished. The race for higher energies moved at an enormous pace, especially in the USA. Holtsmark was perfectly clear of the fact that his machine was relatively small, actually much smaller than the older Washington Van de Graaff. It was the maximum he could achieve with his means at the moment. It was a machine to enter the research field with, a machine to gain experience upon. Holtsmark looked at himself as the research entrepreneur who brought a certain research technology to Norway. The machine did not make sense in an isolated NTH or even Norwegian context but only in the international research context of accelerator based nuclear physics. What could be done with the machine could not be defined locally but would be determined by what was established else where. What the Trondheim group needed for their machine was a niche to start a reasonable research program. As we will see later this niche was found in developing the small Trondheim Van de Graaff into a precision machine. Here the careful design of the Trondheim machine, which was questioned, if not criticised by Dahl, contributed to the plant's accurate performance.

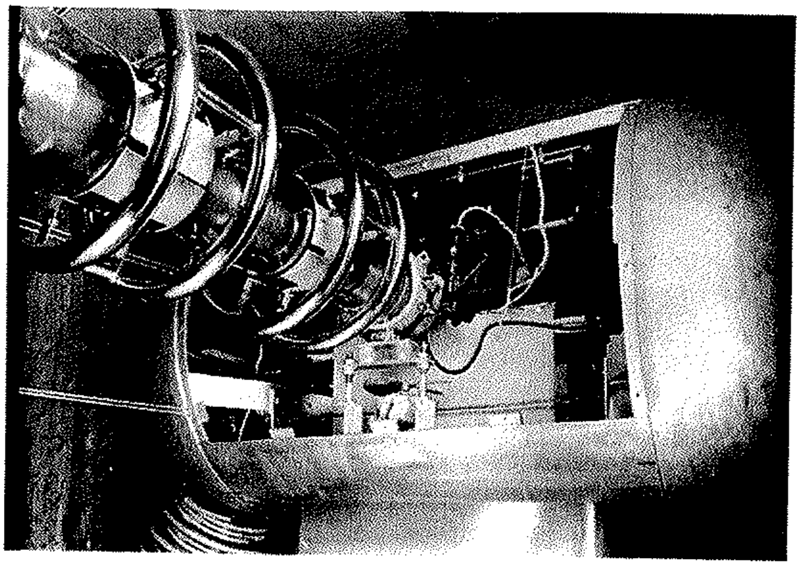

Fig. 5.8: Top of generator with open sphere, ion source and acceleration tube (Photo: Statsarkivet i Trondheim).

The completion of the phase of construction of an accelerator, the first beam of the machine and the first experiments tend to be a critical period for every particle accelerator built. The group of engineers and scientists has to overcome a long period of construction, usually covering several years. They have to overcome the temptation of being solely interested in instrument design and instrument performance and have to start experimentation. Put in other words: instrument builders have to become instrument users. In Trondheim, more than a year went by between spring of 1936 when Dahl came over from Bergen and got the first beam out of the machine, and summer of 1937, when the first experiments were carried out. By then the crew of assistants appointed to the accelerator project was replaced completely.

In accelerator based nuclear physics, as generally in experimental research, the effect to be observed had to be first produced. A nuclear reaction was created by the bombardment of a target with accelerated nuclear particles. The created effect under investigation, the nuclear reaction and the new state of the nucleus, could not be observed directly. Only the product of the reaction, the emitted radiation, could be registered with the detector. None of these performances were self-evident. The particle beam was still visible when emitting out of the accelerator tube. But neither the nuclear reaction nor the emitted radiation was directly accessible to the human senses. The experimental result that would appear later in the publication was the reading of the Geiger counter in relation to the voltage with which the bombarding particle was accelerated. The measured curve was then a simplification of the complex operations in the laboratory. Very different material performances had to be fine-tuned, like the production and stability of high voltage, the vacuum in the accelerator tube, the production of ions, the focussing of the beam, the separation of different ions, the target assembly and the performance of the counters. The scientists and engineers had to establish this well tuned balance, had to keep it stable under experimentation and to re-establish it if lost. The scientists and engineers' performance had to be in accordance with the performance of the instruments. Scientists and technicians developed a feeling for the well or ill performance of their apparatus. They knew how their apparatus sounded, smelled, vibrated, etc. The accelerator team developed a fixed procedure for starting the apparatus and performing the experiments. All this first had to be established at the Trondheim accelerator laboratory.

Experimentation in accelerator based nuclear physics was not newly developed in Trondheim but reproduced from other accelerator laboratories. Most of the accelerator technology at Trondheim was not novel design but modified design of apparatus used successfully at other laboratories. Also the first experiments, the nuclear reactions produced and detected, were reproductions of known experiments and results from other laboratories. This means that the Trondheim group had to relate itself to standards earlier developed elsewhere. The behaviour of the complex Trondheim accelerator laboratory still had to be stabilised locally. In this critical phase, the turn of the year 1936 to 1937, the project lost two of its very central members: Wilhelm Ramm and Sverre Westin. There is no single reference explaining why they both left the project at that point, especially after they had participated in the Copenhagen conference the same summer. Wilhelm Ramm moved in autumn of 1936 over to an assistant position at the electrical engineering department at NTH. According to Holtsmark, he still worked at the physics department in his spare time. Holtsmark's letter of reference in April 1937 stated that Ramm was an able designer and builder of electrical devices, and that he had built the high voltage generator as an electrical machine. This indicates that Ramm did not develop a strong interest in experimentation or nuclear physics.[468] Holtsmark's characterisation of Westin was quite different.[469] However, it had never looked like Westin would have stayed with the Van de Graaff project. Westin continued his research on electron scattering, which finally became his *dr.techn.* thesis.[470]

Another incident might have also influenced Westin's decision to abandon the Van de Graaff generator project. From at least 1935 onwards Westin was disabled from working in the laboratory because of a chronic mercury intoxication. According to the medical certificate of the senior physician Odd Stubb of December 1936, Westin had shown symptoms of mercury intoxication for about three years.[471] Through 1935, investigations about mercury contamination were carried out at the departments of physics and chemistry at NTH. High concentrations of mercury were measured in most of the physics laboratories and in the auditorium as a consequence of the excessive use of mercury in experimentation at the time, both in research and teaching. From 1936 to 1938 the physics department was busy changing floorings, upgrading the ventilation system and measuring mercury levels of all people working in the building. The chronic illness caused by mercury intoxication and NTH's inability to supply Westin with a mercury-free working environment most probably contributed to his decision to leave his research for a position at the Swedish lamp manufacturer *Luma* in 1937. Westin had to abandon the position at *Luma* as well because of his hypersensitivity to mercury caused by the chronic intoxication.[472]

Back to the Van de Graaff generator: about New Year 1937 the almost finished generator was in bad need for new personnel in order to start experimentation. The counter arrangement, which was started by Eilif Bjørnstad already in 1935, and which was the last missing part of the plant, was finished by the electrical engineer Anders Gohn in January 1937. Holtsmark stayed with his philosophy to appoint two assistants, Roald Tangen, an electrical engineer with amateur radio background, and Harald Wergeland, a chemical engineer, to the plant.

[468] Holtsmark, April 8, 1937. Holtsmark's omitting of Ramm's interest or qualifications for scientific or theoretical questions in the letter of reference is quite significant especially after Ramm had attended the conference at Copenhagen.

[469] Holtsmark, April 7, 1938.

[470] Westin, 1946.

[471] Stubb, December 22, 1936.

[472] For the whole story on mercury contamination at the physic department, see Archive *NTH-Fysisk institutt*, box Da: 9, 1-14 Kvikksølvsaken, Statsarkivet i Trondheim.

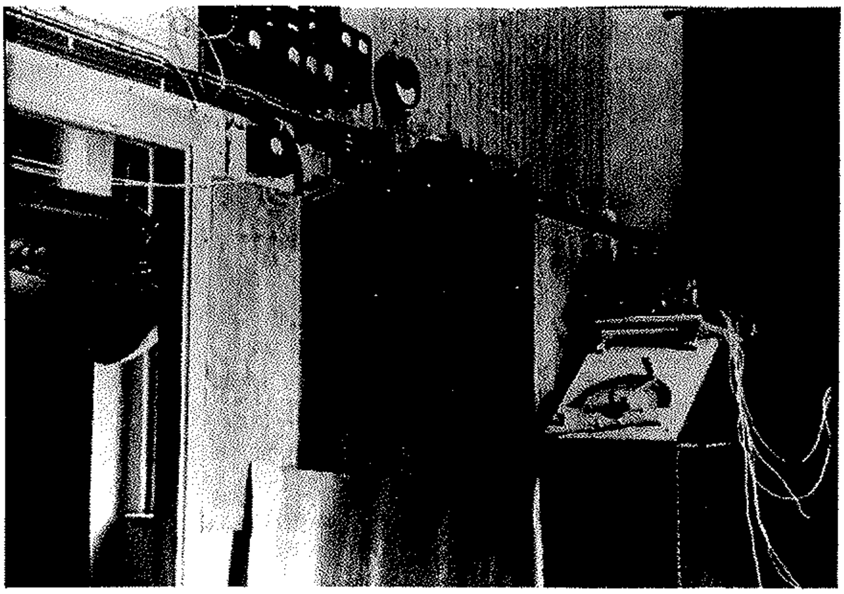

Fig. 5.9: View over the observation room with platform and into the generator room through the door opening (Photo: Statsarkivet i Trondheim).

In retrospective Tangen had described himself as an eager radio amateur in his youth. His interest in radio was the main motivation to study telecommunication engineering at NTH in order to become a radio engineer. Already as a student, Tangen had strolled around at the physics department trying to get small jobs. He described the physics department as a very exciting place and Holtsmark as a character to be known among students to work with all kinds of strange things. After graduating in autumn of 1936, Tangen was given a radio engineering assignment by Holtsmark that he had completed by spring of 1937. At that time Tangen must have impressed Holtsmark enough that he appointed Tangen for the Van de Graaff project. Tangen recalled to have accepted immediately.[473]

Wergeland had graduated from chemical engineering in spring of 1936. He first worked as Leif Tronstad's assistant on one of the Norsk Hydro Company's scholarships for heavy water research. In spring of 1937, he left deuterium research in order to join the Van de Graaff generator project together with

[473] Interview with Tangen, 1990.

Tangen. He remained an assistant at the chemistry department and thereby relieved the budget of the accelerator laboratory. Wergeland later mentioned himself and not Tangen as the head of the nuclear physics laboratory.[474]

Tangen recalled that Holtsmark set a deadline for him and Wergeland as summer of 1937 for the completion of the apparatus and the beginning of experiments. Tangen and Wergeland worked hard and managed to stay within the time limit: in summer of 1937, the first nuclear experiments were carried out at Trondheim. After more than three years of planning and construction, the accelerator was finally completed and working satisfactorily. As the first experiment Wergeland and Tangen reproduced Cockcroft and Walton's disintegration of lithium by the accelerated protons. The alpha particles detected by Geiger-Müller counters were made visible on a cathode-ray oscilloscope. This was believed to be the first nuclear reaction produced by an accelerator in Scandinavia.[475] This first successful experiment still left open the question about the research program for the Trondheim accelerator. Already in the article in *Aftenposten* in March 1935 Holtsmark had admitted that he did not have a research program for the machine under construction. First, one should finish the installation, since experimentation was moving on such a fast pace everywhere else. Also Dahl, in his letter to Tuve in June 1936, made clear that the Trondheim group was in need of a research program. The small size and the low voltage limit of the Trondheim Van de Graaff generator made the machine look out-dated before ever put to use. All the possible experiments using such low potentials seemed to have been done already by other accelerator laboratories. As a solution, Holtsmark and his assistants decided to develop their plant into a precision machine, taking advantage of its accurate performance. They carefully re-measured energy levels of lighter elements already investigated by other groups.

Tangen later recalled the development of the plant into a precision machine as a very fortunate decision. The experiments that the Trondheim laboratory concentrated on were so called radiative capture experiments, where a beam of protons was shot on a target of a light element. The yield of gamma radiation emitted by the nuclear reaction was measured over the voltage applied in the accelerator. The first results of experiments that were published in November 1937 in the Proceedings of the Royal Norwegian Society of Science and Letters were on the proton capturing of lithium showing the same resonance curves as other accelerator laboratories. The publication was merely a statement of the

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[474] Wergeland, vita for application for the position of Professor of Physics at NTH, September 14, 1945, Bohr archive, Copenhagen. Tangen, in contrast, in 1984 remembered himself as the one who lead the accelerator laboratory and Wergeland as the "*voluntary collaborator*" (Tangen, 1984, p. 96).

[475] Tangen, 1984, p. 96.

correct performance of the apparatus in relation to other laboratories and not the presentation of novel results. A detailed description of the accelerator followed in May 1938. The generator produced a maximum voltage of 550 kV when running in air and 700 kV when the accelerator room was saturated with carbon tetrachloride, both limited by corona discharge.[476]

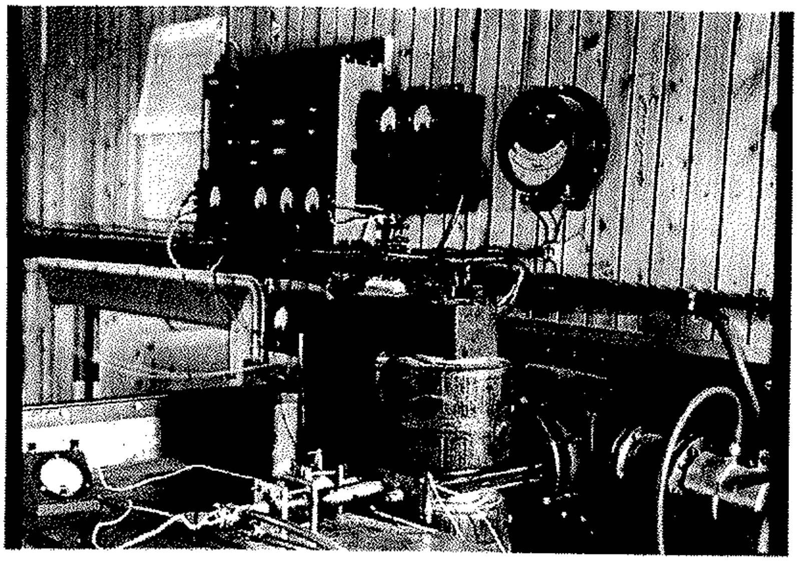

Fig. 5.10: On the observation platform. In foreground: deflecting magnet and target arranged in Faraday cage (Photo: Statsarkivet i Trondheim).

[476] Holtsmark, J.P., Tangen, R. and Wergeland, H. *Radiative Capture of Protons, Det Kongelige Norske Videnskabers Selskab Forhandlinger* X, no. 29, November 8, 1937, p. 107 - 108 and *A High Voltage Plant for Nuclear Investigation, D. K. N. V. S. Skrifter* no. 6, 1938.

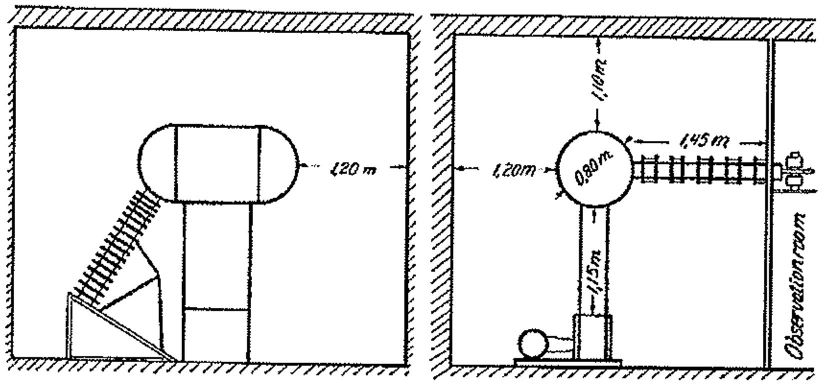

Fig. 5.11: Generator room with generator, accelerating tube and resistance for high voltage measurement (*D.K.N.V.S. Skrifter* no. 6, 1938, p. 4).

5.8. An electrostatic generator but never a static machine: Further experiments and improvements

In the course of 1937, experimentation had finally begun and the generator was working successfully. Tangen and Wergeland had started their experiments on the proton capturing of light elements. Parallel to the experiments Wergeland also worked on theoretical investigations on the structure of the nucleus.[477] On his visit to Germany in summer of 1937 this theoretical work brought Wergeland in contact with Werner Heisenberg, Germany's leading theoretical physicist. In February 1938 Wergeland was awarded a research grant by the NTH-fund for experimental work with the Van de Graaff accelerator. But in 1938, Wergeland left again for Leipzig and finally abandoned the Van de Graaff team.[478]

To replace Wergeland, another chemical engineer, Njål Hole, came to join the accelerator team in 1938. Hole started as a student to participate in the experiments and worked as Holtsmark's private assistant from November 1938

[477] Wergeland, 1937.

[478] It is questionable how much the mainly theoretically oriented Wergeland was ever interested in the accelerator experiments. His theoretical orientation was already mentioned by Holtsmark in Wergeland's letter of introduction to Heisenberg. Wergeland, however, stayed with nuclear physics for some time and published his *dr.philos.* thesis on the structure of the nucleus during WWII. See Wergeland, 1941.

to October 1941.[479] It was now Hole and Tangen who worked together in the Van de Graaff accelerator laboratory. In these years, they carried out systematic measurements, using targets of isotopes of all lighter elements which would be promising to show nuclear resonances under proton bombardment in the available energy range of 600 kV. Other accelerator groups had often rushed over these lighter elements. Neither the voltage measurements nor the voltage stabilities of most other laboratories were very good.

In order to develop the Trondheim plant into a precision machine, the experiments were accompanied by a series of improvements of the plant to enhance its performance and to increase the accuracy of the measurements. Both, the counter arrangement and the arrangement for voltage stability and control were re-worked and improved. Tangen also developed a magnetic separator for the ion source. Accordingly, only protons were entering the accelerator tube and the tube was free of the load of unwanted ions.[480] A lot of work was put into the assembly of targets that were of high purity and that could withstand the bombardment of the proton beam during the time of experimentation. These material improvements of the plant as well as the target assembly were mainly carried out by Tangen, whereas Holtsmark characterised Hole, like Wergeland, as more theoretically interested.[481]

The following story is mainly based on the interview conducted with Tangen in 1990 and a memorial lecture given by Tangen in 1984.[482] It has to be seen in accordance to the narrowness of the source it is derived from. According to Tangen, the Trondheim Van de Graaff generator was unique in its energy resolution. Tangen and Hole's measurements were clearly outrivalling other. Tangen pointed out that they could see effects previously not published. Tangen and Hole were discovering previously unknown weaker resonances and corrected others in the energy-location of resonance peaks and of their energy bandwidth. Until the end of 1939, Tangen, Holtsmark and Hole had published resonance curves of lithium^7, fluor^{19} and boron^{11}. All the papers were written in English and published in the Proceedings of the Royal Norwegian Society of Science and Letters at Trondheim. In early 1940, the Trondheim group started to publish in German journals, first in the *Naturwissenschaften.* Also publications in the Proceedings of the Royal Norwegian Society of Science and Letters were thenceforth partly written in German. The first articles were

479 See Holtsmark et al: *On the Resonances in Radiative Capture of Protons by Li^7 and F^{19}*, 1938, p. 92 and vita, Hole, not dated, about 1952, NTH Sentralarkiv.

480 Tangen, 1940.

481 Holtsmark, letter to Bohr, August 28, 1941. Hole also published two theoretical papers on wave mechanics in 1940 and 1941.

482 Tangen, 1984.

written and submitted before the German occupation of Norway. Accordingly, the turn away from English and towards the German language and German publication scene cannot be accounted for as a war-phenomenon.

The turn towards publishing in German can be, however, explained by the rejection of an article by the Trondheim accelerator group by the British journal *Nature*. Publishing results from the Trondheim accelerator laboratory in English was consistent with the audience, which was basically constituted by other accelerator groups. These were located mainly in the USA and partly in Britain. As mentioned earlier, accelerator development in Germany was slow and late compared to the British and American scene. As late as 1939, the only group of importance in Germany were Bothe and Gentner in Heidelberg. To publish the first significant results of the Trondheim group in the prestigious *Nature* seemed to be appropriate. According to Tangen, the Trondheim paper containing novel measurements regarding nuclear resonances in ^{20}Ne, was refused by the editor.[483] The journal's reasoning was that they just had received a similar paper of a British scientist containing the same results. When the Trondheim physicists saw the other article in print they realised that their results were much more accurate and extensive. As remembered by Tangen, Holtsmark got very angry and promised that he would never submit a paper to *Nature* again, a promise that he kept.[484]

Tangen did not give a date or year for his story. The Trondheim results for ^{20}Ne did not seem to have been published anywhere else.[485] To get papers published in German journals was easier for Holtsmark since he was well known to the German scientific community. Holtsmark had earlier published articles in, among others, the *Physikalische Zeitschrift*, the *Naturwissenschaften* and the *Zeitschrift für Physik* and was a frequent contributor to the *Physikalische Berichte*. In 1941, a longer article was published in the *Zeitschrift für Physik*, summarising the present measurements of the Trondheim accelerator group. The article contained resonance curves of lithium boron, carbon, magnesium, aluminium, silicon, and chlorine. Resonance curves of beryllium and phosphorus had already been published in the *Naturwissenschaften* in 1940.

483 Tangen, 1984, p. 96.

484 Interview with Tangen, 1990, and Tangen, 1984.

485 Also Tangen's *dr.techn.* thesis which else wise contains all the published results obtained with the Trondheim Van de Graaff generator does not refer to any measurements with Neon (Tangen, 1946). Tangen mentioned the measurements of ^{20}Ne only in his memorial lecture of 1984 whereas in the interview of 1990 he did not mention which isotope the measurements referred to. Tangen mentioned that results of the Trondheim group were subsequently published in German and American journals. However, the Trondheim group did not publish experimental results in American journals until after WWII. If Tangen's story can be placed at the end of 1939, it explains the shift towards the German scene.

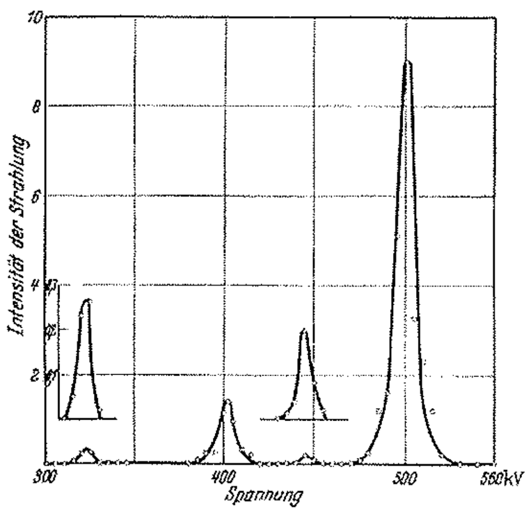

Fig. 5. Anregungsfunktion der Gammastrahlen von Aluminium. Die Resonanzen bei 325 und 445 kV sind auch in zehnfachem Maßstab wiedergegeben.

Fig. 5.12: Gamma yield curve for aluminium measured by Hole and Tangen. The weak resonances at 325 kV and 445 kV were hitherto unknown (Hole, Holtsmark and Tangen *D.K.N.V.S. Forh.*, 1940, p. 144 and *Zeischrift f. Physik*, 1941, p. 54).

In the first years of German occupation from 1940 to 1942, experiments were continued with the Van de Graaff generator at Trondheim. According to Tangen, the German occupants were not interested in the accelerator laboratory and "*nuclear physics* did not ring a bell for German officers". Wartime and occupation nevertheless changed everyday life in the laboratory with the rationing of parts and materials, the communication-cut with English and American groups, and the confiscation of all radio material. With the collaborator-government of Vidkun Quisling and the attempted Nazification of Norway, political suppression as well as resistance increased. In autumn of 1941, Hole had to leave Trondheim for political reasons and turned to Stockholm to join the Nobel Institute for Physics under the leadership of Manne Siegbahn and to work with the Institute's cyclotron. In November 1941, for the first time an assistant with a degree in physics, Hans Vilhelm von Ubitsch, joined the group. von Ubitsch had studied at Oslo and had carried out his *Hovedfag*-thesis with Bjørn Trumpy in Bergen. Besides measurements, von

Ubitsch also engaged in new constructions, as a voltage stabiliser for the Van de Graaff generator and an improved circuit for the counter arrangement.[486]

In 1942, Professor Holtsmark was appointed Professor of Physics at the University of Oslo. Tangen and von Ubitsch went with him. In 1943, the Van de Graaff accelerator was moved to Oslo as well. During the generator's time at Trondheim from 1936 until 1942, 17 scientific articles were published. Eleven of these papers were on investigations in nuclear physics done with the Van de Graaff accelerator, and six papers were on technical improvements and new constructions.

On November 30, 1943, the German occupants and Quisling's regime closed the University of Oslo.[487] Both Tangen and von Ubitsch were arrested. Tangen managed to leave the infamous German prison camp *Grini* in autumn of 1944. von Ubitsch remained imprisoned until the liberation of Norway in May 1945. Also former members of the Trondheim group were involved in war activities. Wergeland, by then at Oslo University as well, had served in the Norwegian resistance army (*Hjemmefronten*) and Hole had in Stockholm served as a spy for the British Secret Intelligence Service as well as for Leif Tronstad, who organised sabotage activities as a Major of the Norwegian Supreme Command in London.[488]

In 1945, the Van de Graaff was brought into use again. In 1946, Tangen submitted his *dr.techn.*-thesis based on experiments carried out with the Van de Graaff generator.[489]

At the University of Oslo, the Van de Graaff accelerator was used until 1963, and later given to the Norwegian Museum of Technology, where it rests to this day. When the accelerator at the Museum of Technology is compared to the one in the pictures taken in Trondheim around 1936, one discovers that, except for the frame of the high voltage generator, not a lot is left of the original apparatus. The Van de Graaff accelerator was never a static apparatus in its 26 years of operation. Repairs, improvements and reconstruction of various parts of the accelerator were constant throughout its active life.

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486 von Ubitsch, *En spenningsstabilisator for Van de Graaff-generatorer* and *En 5-reduktor*, both 1942.

487 See for example Collett, 1999, p. 167 ff.

488 The circumstances about Tronstad's activities during WWII, about heavy water and Tronstad's tragic death in a command mission 1944 are extensively treated in Per Dahl, 1999, and Brun, 1985, and need not be discussed here. After WWII Hole was decorated with the MBE, Member of the British Empire. Nothing is known about the closer circumstances of his espionage.

489 Roald Tangen, 1946. *Experimental Investigations of Proton Capture Process in Light Elements*, *D. K. N. V. S. Skrifter* no. 1.

5.9. Concluding remarks

In retrospect, the Trondheim Van de Graaff generator has to be characterised as a very successful machine. Holtsmark had managed to build Scandinavia's first working accelerator at a small physics department and with comparatively little funding. Holtsmark's establishment of the nuclear physics laboratory at NTH remains as an example of how it was possible to establish this new research field as a comparatively small-science activity within an international environment of growing big-science installations. Instead of limiting or closing down other research fields, like acoustics and electron scattering, Holtsmark managed to tie these research activities together and thereby maintained a variety of different activities. Holtsmark was aware of that under these conditions the NTH accelerator laboratory would not be an internationally leading research centre. However, to build up an internationally leading research centre did not seem to be his intention. The plant in Trondheim was something "one could gain experience upon". In order to think and work scientifically it was, according to Holtsmark, necessary to do *pure academic* and not applied research. NTH should provide the necessary conditions for *pure* research. The Van de Graaff accelerator laboratory was an example for such a project, which was not directed towards immediate application in the industry or other sectors of the society, but towards an international research community.

In the accelerator project the NTH graduates could learn how to build and control modern research instrumentation and to pursue advanced research agendas within an international community. In this perspective the Van de Graaff project constitutes an exercise in acquiring modern research practices and participating in an international research environment. Interestingly enough, Holtsmark's plan for the Van de Graaff accelerator laboratory as a project where NTH graduates could be transformed into scientists, seemed to have been quite successful. Several researchers who were involved in the Van de Graaff project in the interwar period, such as Tangen, Wergeland, Hole, and not to forget Holtsmark himself, obtained key positions in the post-war Norwegian physics environment. Most of these physicists did not stay with nuclear physics and accelerator technology, but moved into different disciplines of physics. Westin, for example, did not continue with nuclear physics research. But the vacuum technology developed by Westin and Ramm for the Van de Graaff generator had a significant influence on the post-war research in technical physics at NTH.

We can isolate a few specific factors which made the Van de Graaff accelerator project possible and which contributed to its success. The international orientation and contacts of Holtsmark, his experience in modern theoretical and experimental physics and his capability as an initiator of new research projects were important conditions for his success. Good contacts to the United States were based around Norwegian immigrants and connections through geosciences. The availability of motivated electrical and chemical engineers at NTH, who designed and built the various parts of the accelerator and carried out the experiments, made experimental nuclear physics research possible despite financial limitations.

Why and how did Holtsmark succeed where Devik failed? The Van de Graaff accelerator technology was already stabilised at other locations, and this stabilisation had to be achieved at the local accelerator laboratory in Trondheim. Holtsmark and his assistants managed to join an established research field. Devik, in contrast, tried to develop a novel device that did not resemble apparatus that worked successful elsewhere. Devik's device did indeed build on a long tradition of cathode ray research as well as the known Tesla coil. The combination of a Tesla coil within an evacuated discharge tube was, however, novel, even though followed by a number of research groups. It is doubtful that Devik, with the vacuum technology available to him, managed to reach a vacuum sufficiently low enough to get any noticeable results. Developing advanced high voltage technology and being able to apply it was, as we have learned, essential to all research groups in order to enter the accelerator business. There were also other technical problems involved in Devik's design, which should not be discussed in a historical thesis. These problems relate to the alternating voltage produced by the Tesla coil, and to the insight later gained by physicists that high vacuum actually does not insulate completely. None of the research groups involved managed to develop a successful accelerator based on the Tesla-coil principle.

Holtsmark did not seem to have been particularly interested in nuclear physics and had never attempted to become a specialist of this field. But he pointed out that Norway had to engage in this technology which at the moment was only a research technology but soon would gain strong importance in medicine and technology. Devik had shown the same conviction when he patented his unsuccessful Tesla device in 1928. Holtsmark and other Norwegian scientists made it a question of cultural and national importance for Norway whether the young nation could compete with others in the field of science, rather than only looking for short-term profits.

For most assistants involved the Trondheim Van de Graaff project, the accelerator was an intermediate station to some other place in science or engineering. It was Tangen who stayed with the machine and made it to the subject of his *dr.techn.* thesis. One of the most interesting aspects of Tangen's career is his transition from being an electrical engineer and instrument builder to becoming an instrument user and a nuclear physicist. When Tangen was appointed Professor of Experimental Physics at the University of Oslo in 1952 Odd Hassel made the criticism that Tangen had only worked in a very narrow field of physics, namely nuclear proton capturing.[490] This was not seen as a major problem by Tangen's defenders. The time was over that young scientists, like Holtsmark in his time, could allow themselves to dive into very different fields of experimental research and hope to make fundamental contributions in each field. Modern research fields, such as accelerator based nuclear physics, required a stronger specialisation. In this way, the complexity of the accelerator laboratory led experimental physics into a new era of research.

[490] See *Universitet i Oslo - Årsberening 1951-52*, p. 154 ff.

Postscript

In order to conclude my histories of physics at the Norwegian Institute of Technology during the interwar period, I want to present some short final remarks:

The establishment of knowledge as practices

In my histories I have followed the establishment of NTH's physics department as a modern research institution with a variety of different research fields. The successful local establishment of these research fields relied primarily not on the learning of a theoretical knowledge of the field, or *the knowing that*, but on the acquisition of the research practices in the field, *the knowing how*. Communities and sub-communities of scientists were not only constituted as collectives of thought but also as collectives of scientific practice. Research practices in experimental physics are directly linked to scientific instruments and practices of instrument building and instrument use. The discourse about knowledge in practice in history of physics should, however, not be limited to the performances of instrument makers and scientists in the workshops and laboratories but also applied to other everyday activities in science, such as practices of organising research, practices of financing research, practices of communication and practices of presentation. Above all, we should not ignore that, at an institution such as the Norwegian Institute of Technology, practices of research are inextricably connected to practices of academic teaching.

The teaching-research relation

Interestingly enough, historians of physics have focused merely on histories about research and largely neglected histories of academic teaching, although these two activities, teaching and research, can hardly be separated at an educational institution like NTH. The establishment of such institutions and the appointment of academic staff have generally been subject to teaching and not research agendas. Research laboratories, such as NTH's nuclear physics laboratory, the acoustics laboratory and the X-ray laboratory had a central role in NTH's academic teaching, inasmuch at it was here that undergraduate students carried out their investigations for their diploma thesis, and post-graduate students followed their independent research. At the same time as they followed their own advanced studies, post-graduate students contributed to undergraduate teaching as teaching assistants and advisors. Post-graduate students, or assistants, to use the more common terminology of the interwar period, represented Holtsmark's most important resource in the establishment of research agendas. The student's own interests and motivations played a decisive role in regard to which research agendas were established and how they were organised. The link between the Academic Radio Club and the establishment of technical acoustics research and teaching at NTH is an evident example for the relationship between student interests and the character of scientific activities.

Criteria of success - Local and global focus

Historians of science have long concentrated on a number of supposedly important scientists and big events. But the focus on mainly Nobel Laureates and breakthrough discoveries in 20th century physics fails to explain the emergence of large scientific communities, large academic institutions and the complex relationship between science, industry, the state, military, and other parts of society. The success of a certain research activity or research laboratory was not only determined by its knowledge contribution to the international community, or by its development of new practices and instruments that spread internationally. Criteria of success could be the local establishment of research practices and technologies, the local establishment of a research field which was important for the teaching agenda of an institution, transdisciplinary co-operations, or the successful co-operation with industry or parts of the public sector. The examples of the technical acoustics and nuclear physics laboratories at NTH show that the focus of research activities could be very different. Whereas technical acoustics was largely directed towards local activities, such as the establishment of radio broadcasting and sound motion picture, the research of the accelerator laboratory was directed towards an international research community and success could only be established by international comparison. The different research agendas of technical acoustics and atom smashing have not contradicted, but rather complemented one another at the small physics department.

Big Science small? How to establish a variety of research activities at a small institution

One of the most interesting features of Holtsmark's entrepreneurial activities at the physics department in Trondheim during the interwar period was his establishment of a variety of very different research fields and research laboratories. In a time of growing large institutions and big research installations, such as the Bell Telephone Laboratories and the Berkley cyclotron laboratory, Holtsmark managed to establish and balance these modern research agendas on a small scale. This diversity was favourable as regards to the structure of NTH as a teaching institution. With respect to the strong focus on technology at the engineering institution, Holtsmark managed well in maintaining a balance between general physics and applied research. For this regime of co-existing research activities, Holtsmark had to find intersections of research practices and research instrumentation between them. The use of electrical instrumentation, especially radio technology, in technical acoustics, electron scattering and nuclear physics constituted such an intersection. Holtsmark's research agendas benefited well from the motivated electrical engineering students organised in the Academic Radio Club. Being able to motivate students from chemical and electrical engineering for physics research, Holtsmark nurtured a new generation of physicists who, after WWII dominated physics research and academic teaching in Norway.

The impact of the interwar community of physicists at NTH for post-WWII physics in Norway

Even though this aspect exceeds the time period of in my history writing, a few words should be spent on the further career development of Holtsmark's disciples and their position in post-war Norwegian physics. As in most Western European countries, the Norwegian physics community experienced a rapid growth after the war. I do not wish to go into the complex details of this growth but want to mention that many of Holtsmark's disciples took over key positions in the expanding post-war Norwegian physics community. The ample plans for the extension of NTH were finally carried out and the career of technical physics with a separate curriculum was fully established. The number of professor positions was increased to three, and all candidates, who were appointed, were graduates from NTH and former assistants of Holtsmark.

Harald Wergeland was appointed as Professor of Physics in 1946 and later took over theoretical physics. Roald Tangen was appointed Professor of Experimental Physics in 1948 and Sverre Westin Professor of Technical Physics in 1949.

In 1952, Tangen was appointed Professor of Physics as Lars Vegard's successor at the University of Oslo. As Tangen's successor at NTH, Njål Hole was appointed Professor of Experimental Physics in 1954. At that moment, all three professors of physics at NTH had graduated in chemical engineering from the same institution and were at some point involved in the Van de Graaff accelerator project during the 1930s. Interestingly enough, the second Van de Graaff accelerator, who's construction was started by Tangen before he left for Oslo, never became a successful machine, in contrast to the new Van de Graaff generator built by Tangen at the University of Oslo. In 1948, the University of Bergen was established, and Bjørn Trumpy became its first Professor of Physics, as well as its first president.

In the early 1950s, Holtsmark and his disciples from NTH during the interwar period held six of the seven chairs of physics in Norway. The only exception was Egyl Hylleraas, Professor of Theoretical Physics at the University of Oslo. The three professors of physics at the University of Oslo during the interwar period, Sæland, Vegard and Bjerknes, had not been able to foster a successful new generation of physicists, whereas Holtsmark and his disciples from the small Trondheim physics department, none of them a physics graduate, had taken over.

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Archive of the Norsk Hydro Company. Norsk Hydro, Oslo.

Niels Bohr Archive. Niels Bohr Institute, Copenhagen.

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