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The Internationalization of Physics in Sweden, 1860—1930

The internationalization of modern science has come about through the way contacts between scientists of different countries have spread and multiplied. Such contacts have come to have important consequences for all aspects of scientific work; socially, organizationally, and cognitively. The varied, diffuse and often fortuitous nature of these contacts as well as their manifold consequences makes it difficult to examine them across the board. It is easier to study them with reference to a single discipline and a single country — in the present case, physics in Sweden. The main limitation of such a focus lies in its dispensing with the center-periphery dichotomy that has often been in the forefront of discussions of Scandinavian science (cf. Friedman, 1990; Lindqvist, 1990). As Crawford (1992) has argued it is not so much the "center" and the "periphery" as polar opposites that should be investigated but their complementarity. Such an investigation implies an international or at least a regional perspective; in the present case, the relationship of the Swedish physics discipline with that of Germany. This kind of broad perspective with disciplinary developments studied simultaneously in two countries was beyond the reach of the present study.

Instead, the focus will be on how Swedish physicists experienced an increasing social and intellectual proximity to their disciplinary colleagues in other countries. These colleagues were often German, but not exclusively so. The beginning of this process was coterminous with the modern science organization that began to emerge in the middle of the nineteenth century. It was boosted at the end of the century by a generalized internationalist ideology, which was also embraced by leading Swedish physicists, and by the creation of the Nobel institution (cf. Crawford, 1990; Crawford et al. 1992: 11—18).The process was completed by the late 1920s when Swedish physics, dominated by the research school in X-ray spectroscopy headed by Manne Siegbahn became an integral part of the international specialty of theoretical and experimental atomic physics.

By placing foreign contacts in the cognitive, institutional, socio-political, and eco-

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Figure 1. Three generations and three dimensions: A schematic representation of the internationalization of physics in Sweden, 1860—1930.

	Generations: Physicists born between		
	1810—1840	**1840—1870**	**1870—1910**
Dimensions			
Work organization	**Individual**	=======>	**Collectivist**
Specialty formation	**Fragmentation**	=======>	**Bureaucratization**
Contacts with foreign physicists	**Push**	=======>	**Pull**

nomic contexts in which they occurred, one can hope to get a better grasp of the different facets of the process of internationalization. Overall, this process represents a slow transition from "cosmopolitan" to "international" science (cf. Ziman, 1991) with the former more oriented toward universalism and diffuse, informal contacts between scientists of different countries, and the latter emphasizing collectivism and foreign contacts channelled and structured either by international specialty communities or by links established between national scientific bodies, or both.

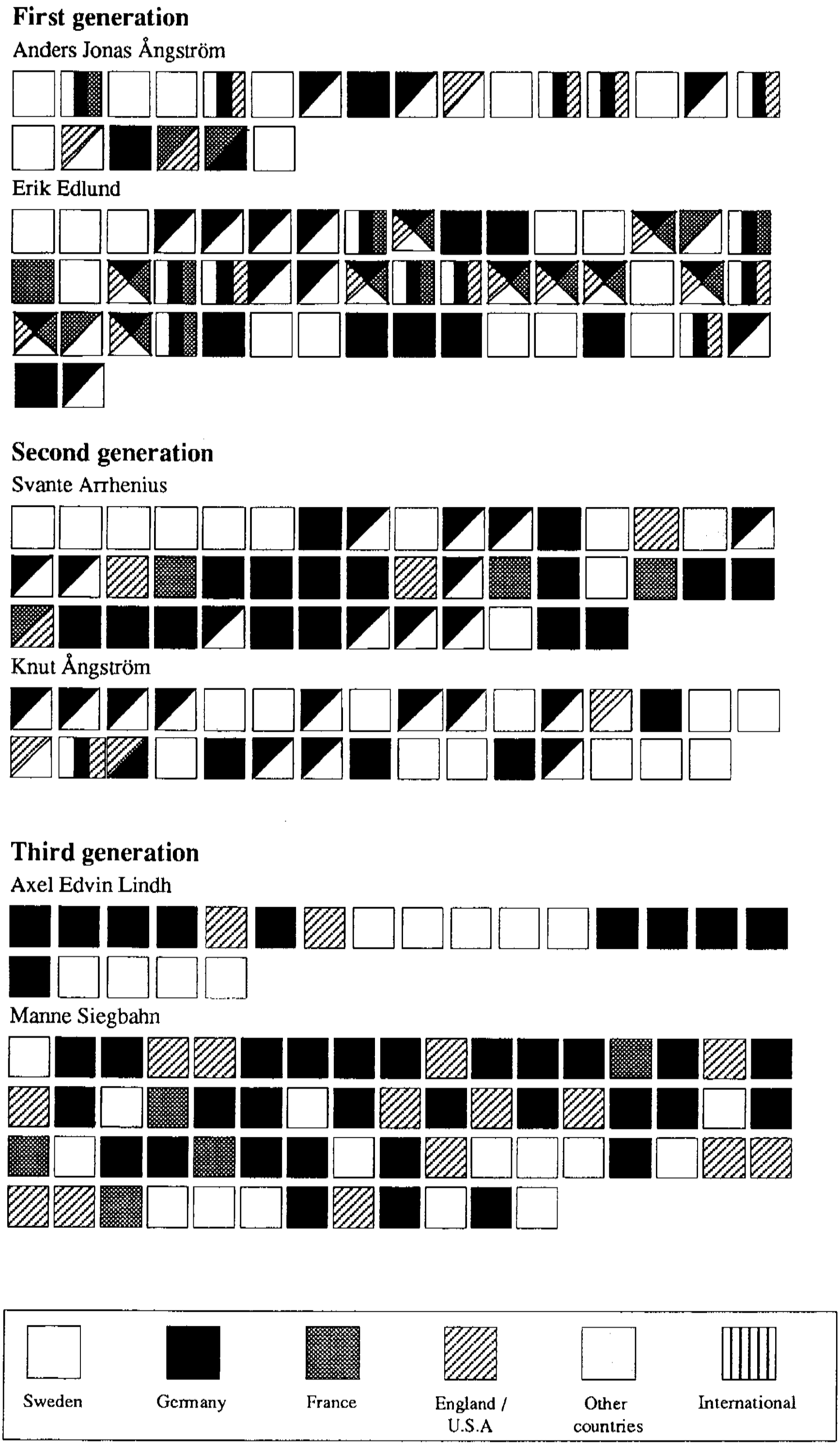
The three specific facets of this process that will be examined here are set out in Figure 1. They are: 1) work organization on the laboratory level, ranging from individualist to collectivist; 2) specialty organization both in Sweden and internationally, exhibiting increasing mutual awareness and dependence[1]; 3) foreign push or pull, that is, did foreign contacts come about by Swedish physicists going outside the country or did Sweden attract foreign physicists?

These three phases will be examined through the international activities of three successive generational cohorts. They are: 1) physicists born between 1810 and 1840 and active up to the 1880s; 2) those born between 1840 and 1870 whose most active years fall between 1880 and 1918 and; 3) those born between 1870 and 1910, whose international profiles we will study through the *Physics Citation Index, 1920—1929*. The small size of Sweden's physics community up until the time of World War I is evinced by the fact that the handful of men belonging to the first generation and who practised physics full-time in the universities represented practically all there was of academic physics in the country. The second generation was about double that of the first.

Because the activity of publishing is central to scientific work and has changed so little over time, publications are a good point of entry into the process of internationalization for the entire period 1860 to 1930. Publication patterns, in particular the foreign/local dimension are represented graphically for a few members of the three generations in Figure 2. (For the sources to the Figures cf. Crawford, 1991: Appendix II, 50—52.)

The figure shows the evolution from *cosmopolitan* publication patterns exemplified by the practice of publishing the same article in a Swedish and German, sometimes also a French and an English *general* science journal, to the *international* pattern where articles will appear only in one foreign, most often German, *specialty* journal. Each square in the figure represents a publication and the squares are divided into different fields depending on the countries where the articles were published, "country" being defined from the place of publication of the journal. This evolution is shown graphically in the way the figure changes tone from appearing as a quilt in its upper part to being more like a chessboard in its lower one. That these patterns are indicative of the different nature of the foreign contacts of the three successive generations of Swedish physicists will be demonstrated in the three main sections of the article: I) The first generation; 2) The inter-

Figure 2. Publications of three generations of Swedish physicists.



nationalists; and 3) The Siegbahn school of X-ray spectroscopy.

The first generation

Physics in Sweden was cosmopolitan from the time it received its modern definition in the eighteenth century. By cosmopolitan, we mean that Swedish physicists studied and travelled abroad, corresponded with foreign colleagues, and published in foreign journals, usually the proceedings of the great academies of science in Europe.

Although physics received its modern definition in the great restructuring of its subject matter and method that occurred in the eighteenth century, it did not acquire its modern organization until about a century later. Whereas the former was a prerequisite, it was the latter that provided the structures for the future internationalization of the subject. These structures were built on the important role of research in the careers of university teachers and in the training of students.

The products of research were the tangible means for contacts, the goods to be traded, between physicists, both at home and abroad. This, one might say, was not much different from the cosmopolitanism of the eighteenth century, and this is probably true for the parts of the discipline that applied advanced mathematics to general problems; mechanics or hydrodynamics, for instance. But the research imperative also drove the experimental part of the discipline and this had much more far-reaching consequences for international exchanges. It made for the creation of a transnational laboratory culture that constituted a scientific world of its own (cf. Crawford, 1990; Coleman and Holmes, 1988). Within this world would eventually move not only the products of research, but also the common instruments and standards that would make the products shared ones. Students, both doctoral and post-doctoral, would also travel through this world, acquiring research skills at foreign laboratories. Skills applied to the specialty areas that lent themselves to laboratory work — electricity, optics, and spectroscopy — would come to predominate.

For the first generation of Swedish physicists studied here, those entering academic positions by mid-nineteenth century, these developments were only slowly coming into view. They were most pronounced with respect to the research imperative. This was expressed by the notion that publishing was important not only for the chairholders, (in the 1870s, there were two each at the country's two universities, those of Uppsala and Lund), but also for the aspirants to chairs.

The shift from mechanics and applied mathematics toward experimental physics occurred more slowly. In the 1870s, for example, three of the four chairholders in physics still worked in the first-mentioned areas. Mechanics and mathematical physics were also the initial orientations of physics at the Stockholm Högskola, which opened in 1878 as a private, non-degree-granting institution primarily oriented toward the sciences. The major exceptions were Anders Jonas Ångström and his successor in the physics chair at Uppsala, Robert Thalén, both of whom pursued trail-blazing investigations in spectroscopy under primitive conditions. Another exception was the Physics Institute of the Royal Academy of Sciences, where the Academy physicist, Erik Edlund, carried out his investigations in electricity. In the late 1880s and early 1890s, new physics laboratories well-equipped for experimental work went up in both Lund and Uppsala. At the Stockholm Högskola, a physics laboratory was installed in a rented apartment. All of these would serve in the training of the next generation of physicists (cf. Crawford, 1984: 42ff.).

With respect to the three facets of the internationalization process — work collectivization, specialty bureaucratization, and foreign push/pull — the men just mentioned, like most of their colleagues in Sweden and abroad, engaged in individual rather than collective work. While both spectroscopy and electricity were specialties in the sense that they required expert knowledge, the "organization" that they evinced was that of loose networks built around journals, research groups, or schools. Such networks could be national or international; the existence of the former was not a prerequisite for that of the latter. The work of the spectroscopists in Uppsala and Lund, for instance, was not linked up until early in the twentieth-century but this did not preclude either group from maintaining contacts abroad.

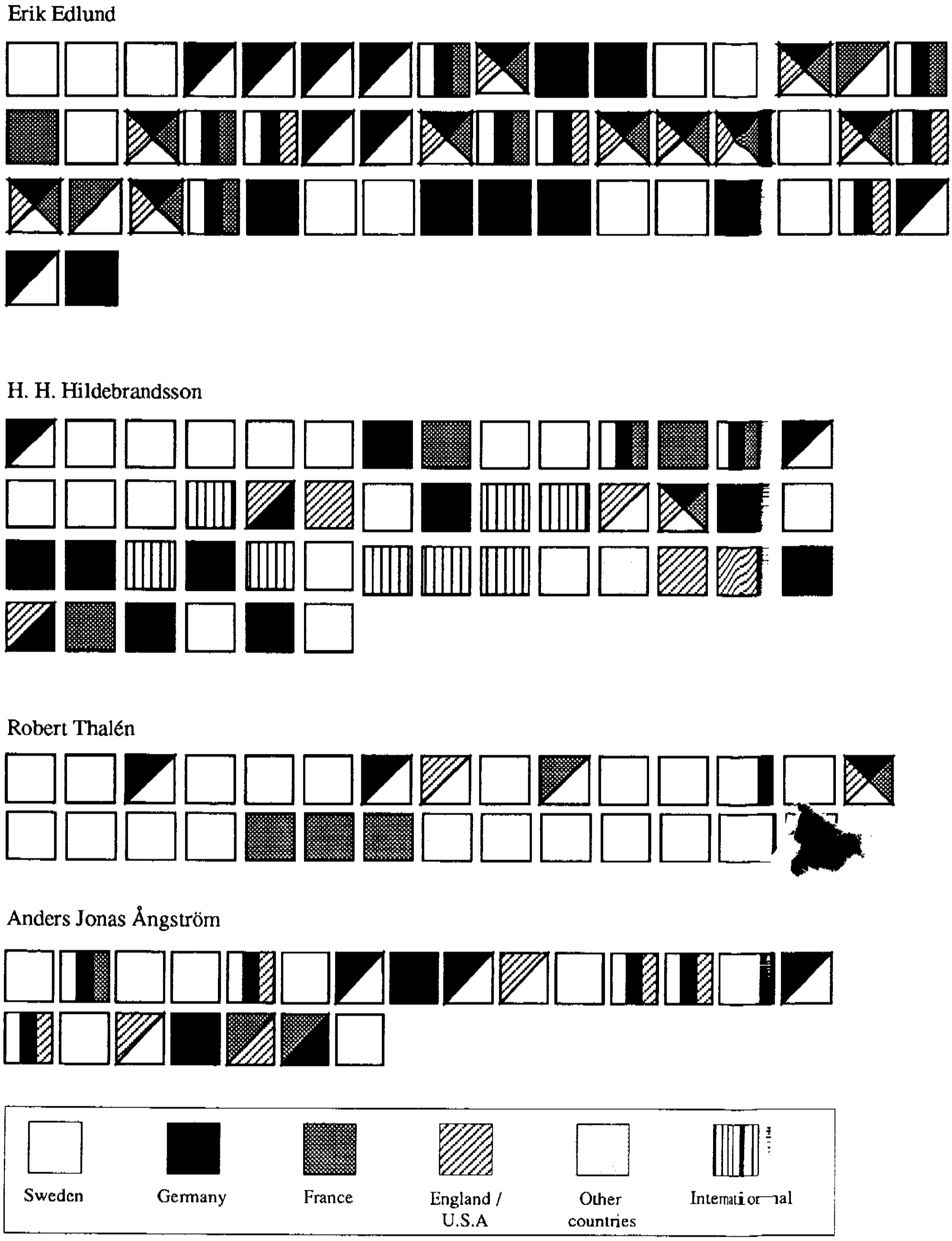
For the first generation, foreign push certainly dominated over pull since few continental scientists would venture as far north as Uppsala. That even the visit of a foreign student was sensational is illustrated by an exchange of letters between the two chemists, Oskar Widman and L.F. Nilson (and there is no reason to believe that the situation was different in physics) concerning the request from Wilhelm Königs, *ausserordentlicher Professor* of organic chemistry in Munich, that one of his students should work in Nilson's laboratory. "Most emphatically, I want to congratulate first of all you," writes Widman, "and then our country upon the really outstanding honor that a chemist from Munich is coming here."[2] Within the Nordic region — Denmark, Finland, which was part of Russia since 1809, and Norway, in union with Sweden since 1814 — there were regular contacts between established scientists in addition to the obligatory peregrinations of students. The main forum for the former were the meetings of Scandinavian natural scientists (Skandinaviska Naturforskarmötena). The first meeting was held in Gothenburg in 1839. It was followed in rapid succession by meetings in Copenhagen (1840), Stockholm (1842), and Oslo (1844). The meetings, which soon became large gatherings, were held, but at a less frenetic pace, throughout the nineteenth and early twentieth centuries (cf. Eriksson, 1991).

The first generation was pushed out of Scandinavia first of all for doctoral or postdoctoral studies but even this was not as generalized a practice as it became later. The reasons were partly financial for unless one had independent wealth, to spend several years abroad required winning one of the few fellowships that the Academy of Sciences or the universities had established for this purpose. Anders Jonas Ångström failed to find financing to go abroad and thus did not leave Sweden until he had become a professor. Edlund was awarded a scholarship from Uppsala University that allowed him to spend the years 1847—1849 abroad, first studying in Berlin under Hermann von Helmholtz and then learning the electrical researches that were to occupy him for the rest of his life from Wilhelm Weber in Leipzig. Thalén could travel on the continent in the 1850s having won the "byzantine fellowship" administered jointly by the Academy of Sciences and Uppsala University. The creation of the Letterstedt fellowships at the Academy of Sciences in 1860, one of which was specifically for foreign travel, added badly needed resources (cf. Thalén, 1878—1885: 103—130; Dahlander, 1886—1894: 286—301; Hasselberg, 1906: 229—231; Donationsfonder..., 1959: 7—10).

The push toward foreign centers also dominated over pull in the area of publications but here the situation was not as clear-cut as with respect to face-to-face encounters. The main publication outlets in Sweden for physics research were the *Handlingar* (Proceedings) of the Royal Academy of Sciences. There were also the different *Acta* published in Uppsala and Lund. Receiving articles from foreigners was relatively rare for all these publications.

The foreign/local publication practices of four members of the first generation, as represented graphically in Figure 3 reveal a general push toward making their work known abroad by publishing in foreign journals. That the first generation, represented here by Erik Edlund, H.H. Hildebrandsson, Robert Thalén and A.J. Ångström, was cosmopolitan rather than international is indicated by the diffuse, universal nature of their foreign publications, most of which appeared in the general physical science journals of the European centers (Paris, London and Berlin). The cosmopolitanism was somewhat less pronounced for Thalén and Hildebrandsson than for the two others; Thalén seems

Figure 3. First generation.



to have preferred to publish at home, and Hildebrandsson, as will be described below, became involved early in international meteorological work and published in the proceedings of international conferences.

Reaching a foreign audience did not mean overlooking local outlets since, as indicated by the large number of squares (each representing a publication) divided between two, three and even four countries, a significant portion of articles had been published in Sweden before being republished abroad. Edlund, who was a master of this "trade" often published an article in the Academy *Handlingar* and then republished it in three other journals; *Annalen der Physik und Chimie, Philosophical Magazine,* and the *Journal de physique et de chimie,* for example. In this way, the ambition to reach foreign audiences could be reconciled with the necessity to remain in contact with one's peers at home and to support local publication outlets.

Outside of publications, foreign contacts arose in the context of the efforts at international scientific organization that began in Europe in the 1870s. Two examples will suffice. For the Uppsala spectroscopists (A.J. Ångström and R. Thalén) who were mapping out spectra, exactitude in wavelengths was naturally of primary importance. Already during Ångström's lifetime, a systematic error was found in his measurements. When the "Uppsala meter" used as the standard meter by Ångström was checked by Robert Thalén at the International Bureau of Weights and Measures in Sèvres outside Paris in the late 1880s, a difference of 0,13 mm., truly astounding even at the time, was found between the Uppsala meter and the international prototype. As a result, Thalén had to undertake the arduous task of recalculating the standard scale based on the wavelengths of the solar spectrum mapped out by his predecessor. Thalén thus had a direct interest in the international collaboration concerning metric standards that centered on the International Committee on Weights and Measures and its research arm the International Bureau of Weights and Measures both set up in 1875. Logically, he occupied the Swedish seat on the committee (cf. Crawford, 1984: 45—46; Hasselberg, 1906: 229—231).

The other example is the professor of meteorology, H.H. Hildebrandsson, who from the 1870s and onward took a strong interest in the part of synoptic meteorology that concerned the formation and movements of clouds as indicators of the state of the atmosphere. He shared his ambition to arrive at standardized vocabularies and mapping of clouds with other European meteorologists. This way but also as a general meteorologist, he became involved in the international organizing efforts in meteorology that started with the international congress held in Vienna in 1873. At the Munich conference of 1891, the proposal by Hildebrandsson and others to establish a commission specifically for cloud studies was accepted, and Hildebrandsson was made its first president. This led to an intensive period of international work for Hildebrandsson that lasted until 1906 when the Cloud commission, having finished its main task was absorbed into the Aeronautic commission.[3]

The internationalists

The three decades immediately preceding World War I were the golden age of internationalism in science. This period witnessed the organization of more international scientific congresses than had been held during the entire nineteenth century, the creation of a great number of international scientific associations, and the formulation of the ideology of internationalism in science. This ideology went further than the belief proclaimed in the universalist ethos, that is, that the acceptance or rejection of knowledge claims is totally independent of the personal attributes of those who make them and that knowledge therefore by definition transcends national boundaries. The ideology was internationalist and not just universalist, because it held as a demonstrated truth that science and scientists through their practical work for the betterment of the human condition could further the peaceful evolution of mankind. The Nobel institution, which started to function in 1901 incarnated both the universalist and internationalist creeds. (The influence of the Nobel prizes on physics in Sweden is discussed in Crawford, 1991: 24—26 and 39—41.)

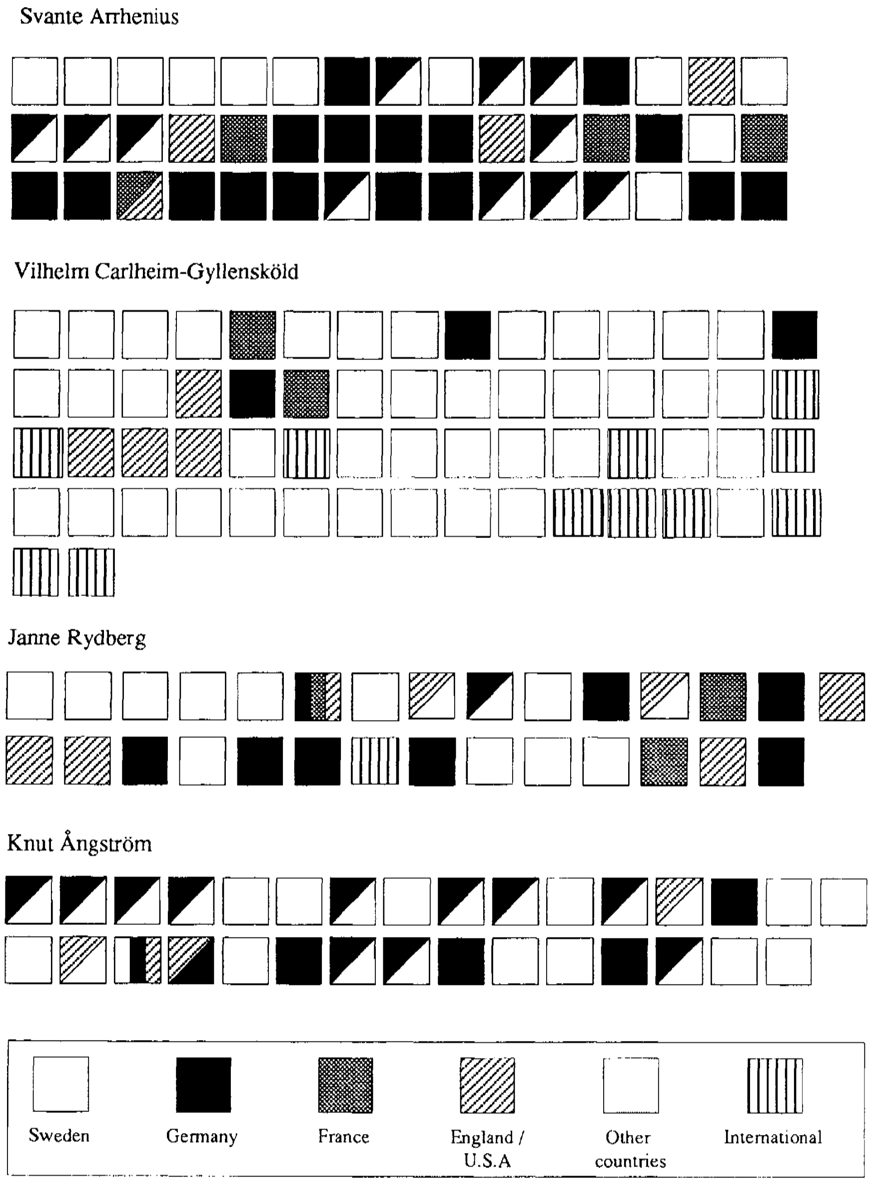
The generation that took up chairs in physics in the 1880s and 1890s experienced the golden age of internationalism in science very differently depending on their backgrounds, personalities, and chosen area of research. At one extreme, there were the confirmed internationalists like Svante Arrhenius and Otto Pettersson. The former moved within his extended international network in physical chemistry, the latter organized international oceanography almost single-handedly. Both were professors at the Stockholm Högskola, where internationalist ideals went hand in hand with liberal political views and optimistic evolutionism (cf. Crawford, 1984: 37—40; 114—115). Somewhat in the middle one finds functional rather than ideological internationalists, that is, those for whom the main value of foreign contacts lay in the way they enriched their work and also made it better known abroad. Here physicists working in areas close to the field sciences, such as meteorology and geodesy, that had been the objects of efforts at international organization already in the 1860s and 1870s were clearly better served than those in laboratory physics. We have already seen how H.H. Hildebrandsson had been involved in international activities in meteorology early on. Among the new generation, Vilhelm Carlheim-Gyllensköld participated actively in international work in geodesy (cf. Molin, 1935). Although mostly a laboratory physicist, Knut Ångström had nevertheless made an instrumental innovation — the compensating pyrheliometer — that had to be calibrated at different geographic locations. It also involved him in international work when, in 1905, the pyrheliometer was accepted as the standard instrument for measuring solar radiation by the International Union for Cooperation in Solar Research (cf. Hildebrandsson, 1913). At the opposite end of the confirmed internationalists, finally, there were physicists who were only active locally. Gustaf Granquist, for instance, who succeeded Knut Ångström to the general physics chair in Uppsala in 1910, devoted himself to the building program that led to a new physics institute and laboratory in 1908.

As previously for the first generation, the three dimensions of work collectivization, specialty formation, and foreign push/pull will give a close-up view of the process of internationalization. All the physicists of the internationalist generation engaged in individual rather than collective research. The extent to which they could relate to socially and cognitively structured specialties within physics varied considerably depending on their work and their foreign contacts. The latter will be examined first.

As in the case of the first generation, push dominated foreign contacts and was experienced most widely when it came to graduate and post-graduate study. Few travelled as extensively as Svante Arrhenius, whose *Wanderjahre* (1885—1890) were of vital importance to his work in physical chemistry. It was more common to remain in one place as did Knut Ångström, who spent the year of 1884 learning experimental physics in A.A. Kundt's well-equipped laboratory at the University of Strasbourg (cf. Hildebrandsson, 1913: 306).

For the internationalist generation of physicists, the main type of foreign contact, was still to publish in journals outside Sweden. As indicated in Figure 4, the foreign publication patterns of the four physicists chosen to represent the internationalist generation (Svante Arrhenius, Vilhelm Carlheim—Gyllensköld, Janne Rydberg, and Knut Ångström) were less diffuse and universal than those of the preceding generation. This manifested itself particularly in that the practice of publishing the same article both in Sweden and abroad became less frequent. When this occurred, it usually involved only the Academy's *Handlingar* and a German journal, most frequently one of the specialty journals — *Physikalische Zeitschrift* founded in 1899 or *Zeitschrift für physikalische Chemie* (1887) — that had superseded more general science journals such as the *Annalen der Physik und Chimie.* The internationalists also published somewhat more frequently in Anglo-Saxon journals than their predecessors. Here, too, specialty journals rather than a general science journals such as *Philosoph-*

Figure 4. Second generation.



ical Magazine took over. Janne Rydberg, for example, published a series of articles in the *Astrophysical Journal* founded by G. E. Hale in 1895.

For the internationalist generation of physicists, travel and especially travel to international congresses — the first one specifically for physics was held in conjunction with the 1893 Universal Exhibition in Chicago — became more frequent under the influence of the transport revolution, in particular, the boom in railways. At the turn of the century, the Atlantic began to be crossed by Swedish academics, not just, as in earlier times, by emigrants. Not surprisingly, the most internationalist of Swedish physicists at the time — Svante Arrhenius — was one of the first to travel to a scientific meeting in America: the Congress of Arts and Sciences, held in conjunction with the 1904 Universal Exhibition in Saint Louis (cf. Crawford, 1992, Ch. 2). Still, the closest contacts were still within Scandinavia. The meetings of Scandinavian natural scientists continued to be important for maintaining such contacts. There were also new opportunities for employment at the Stockholm Högskola where V. Bjerknes and W.C. Brögger from Norway and Gösta Mittag—Leffler from Finland held professorships (cf. Crawford, 1984: 36—37).

For most physicists, publishing and travelling abroad was mainly a way to learn about new instruments, data, experimental set-ups, and teaching methods, all of which enriched their teaching and research. They would not have been able to benefit from these contacts had their work not been cast in the general positivist and empiricist style that characterized German physics, and had it not fallen within the purview of the specialty orientations — spectroscopy, optics, and electricity — that dominated in Germany. Knut Ångström, the leading member of the third generation of Uppsala experimental physicists specializing in radiation measurements (in Ångström's case solar radiation) was typical of the merging of German and local traditions. Although his general approach was that of German "measuring physics," it was exaggerated by local tradition into an "experimenticism" that made precision in measurement an end in itself (cf. Crawford, 1984: 54—58). By contrast, Janne Rydberg in Lund set a highly personal goal for his spectroscopic work, that of developing a formula (leading to what is now known as Rydberg's constant) concerning the regularities in spectra which eventually would give information about the nature and the structure of the atom. In this he was guided, as Manne Siegbahn (1952: 218), his successor to the physics chair in Lund, pointed out, by his training in mathematics and an "original research talent, the strictly individual nature of which gave a special character to his scientific method." Although the full significance of Rydberg's work would only be apparent after his death, he enjoyed an international reputation in his life-time; he was a foreign member of the Royal Society, for instance, and one of the two Swedish physicists (the other being Svante Arrhenius) invited to lecture at the large physics congress held in connection with the Paris Universal Exhibition of 1900.

The one physicist for whom the utility of international contacts went beyond learning new skills and exchanging information was Svante Arrhenius. In capsule form, Arrhenius's foreign trajectory went as follows. He left Sweden in 1885 having failed to gain recognition by the Uppsala science faculty for what he considered to be the new theory of electrolysis contained in his doctoral dissertation. Between 1886—1890, thanks to the Letterstedt travel grant awarded him by the Academy of Sciences, he spent time at the universities of Riga, Würzburg, Graz, Amsterdam and Leipzig where he worked with, among others, Wilhelm Ostwald, Ludwig Boltzmann, Friedrich Kohlrausch, and J.H. van't Hoff. During this time, he formulated his theory of electrolytic dissociation (1887) and witnessed both its success in Germany and the criticisms launched against it in England, most notably at the 1887 and 1888 meetings of the British Association for the Advancement of Science (cf. Dolby, 1976; Root-Bernstein, 1980: 1—15).

His international movements played a major role in the congealing of the interests and work orientations of several individuals into the new specialty of physical chemistry before its institutionalization in academe. For us, his migrations are of interest chiefly for what they brought, or rather did not bring, of this new specialty orientation to Sweden. Arrhenius's return migration to the Stockholm Högskola where he became an assistant professor in 1891 and a professor of physics in 1895, initially seemed to hold promise for the transplantation of the new specialty to Swedish soil. There were courses in physical chemistry and Ostwald sent him postgraduates to work in the Högskola laboratory. In the period 1893 to 1900, fifteen postdoctoral students registered to work with him at the Högskola most of them freshly *Promovierte* from Leipzig University. Many of them would eventually get university positions in physical chemistry in their home countries; Harry Jones in the United States, Thomas Slater Price in England, Ernest Cohen in the Netherlands, and Richard Abegg, Georg Bredig, and Victor Rothmund in Germany.[4] For the first time physics in Sweden was in the position of pull vis-à-vis the outside world. How important this was to Arrhenius and to the Stockholm scientific community is shown by his effusive thanks in his letters to Ostwald and his statement that "there is nothing here that impresses as much as foreigners" (cf. Körber, 1969: 115 and 117). As a private institution dependent on legacies and donations, however, the Högskola could not provide the necessary financial base for the new specialty. Hence, the specialty transplantation that should have followed from Arrhenius's return migration did not occur. A chair in physical chemistry was instituted in 1912 but at Uppsala University and not at the Stockholm Högskola.

The third generation: The Siegbahn school of X-ray spectroscopy

In the years following World War I, the determined efforts of Manne Siegbahn and his disciples brought an important part of physics into direct contact with the rapidly moving international research front of atomic physics both experimental and theoretical. While international science and, most particularly, the internationalist ideology were shattered, in Sweden, the war represented something of an intermission, which prepared for the postwar drive toward internationalization. The war was important in three respects.

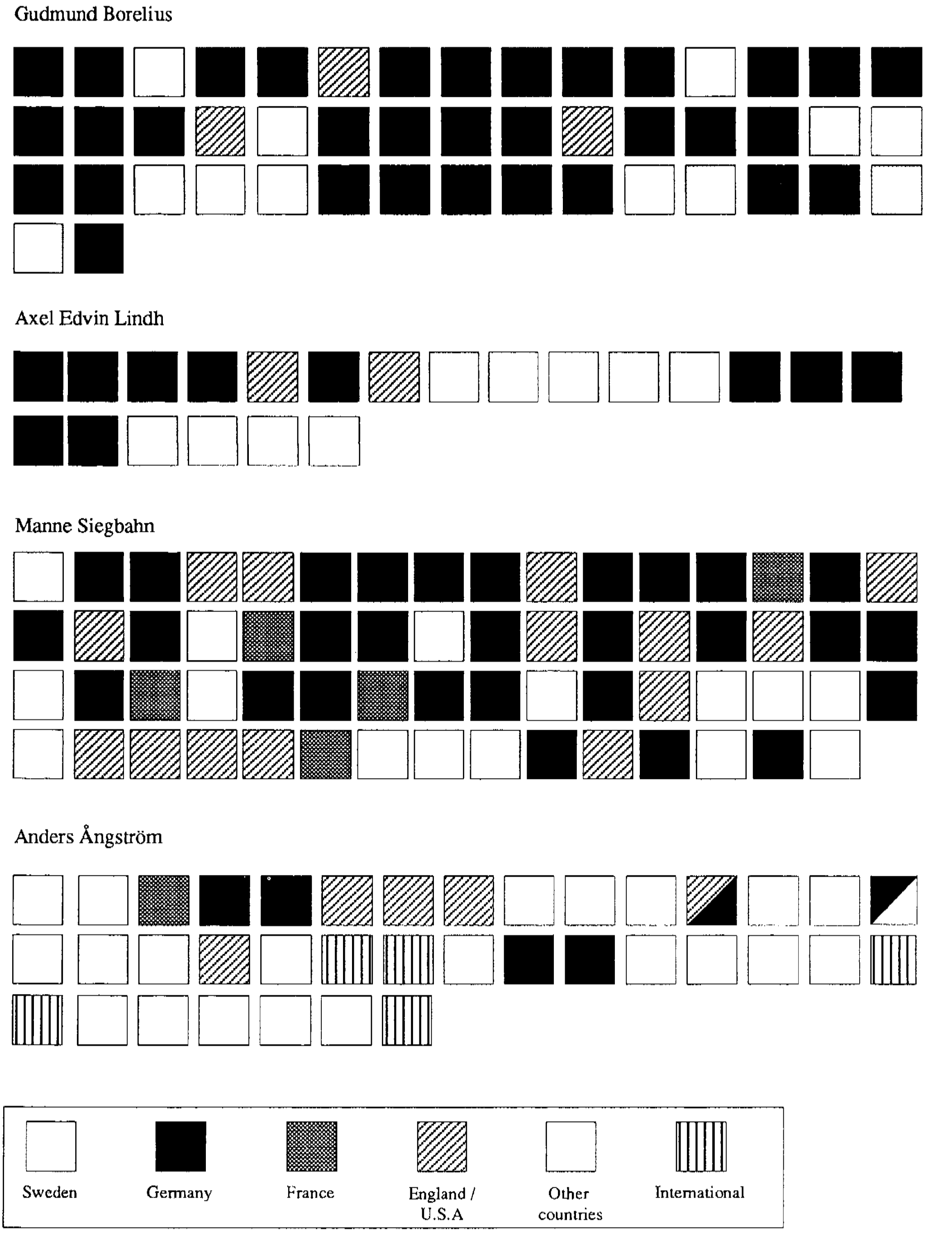
First, the war eased the shift from the prewar internationalist generation to the interwar one. For internationalists, like Svante Arrhenius, the war was a mental blow from which he never recovered. He knew it spelled the end of an era. It also had practical consequences for what little remained of his international network after the estrangements caused by the war, disappeared in the immediate postwar period with the deaths of its most prominent members. The advent of the next generation shifted the emphasis to new areas of physics: X-ray spectroscopy in the case of Manne Siegbahn, and theoretical physics in that of C.W. Oseen, to mention only the two more prominent representatives of the new generation.

Second, the war put a temporary end to graduate and post-graduate sojourns outside Sweden. This was a boon to Siegbahn, in particular, because it provided him with manpower for building a research school and restricted outlooks to the program he had set for the school.

Third, because Sweden was officially neutral during the war, Swedish physicists could remain in close contact with their German colleagues, intellectually as well as socially. They kept *à jour* with progress in quantum physics, since in contrast to physicists in Allied countries, they received mail and journals from Germany. They also purchased instruments both from Germany and England (cf. Eld Sandström, 1987: 5). All this made them more able to compete internationally after than before the war.

During the interwar period, the transition from cosmopolitan to international relations was accomplished for a major part of the national physics enterprise. That the publication patterns of the third generation of physicists had lost all the universal and diffuse traits of those of earlier generations is shown by Figure 5. With the exception of Anders Ångström, a meteorologist, the three physicists chosen to represent the third generation — Gudmund Borelius (mathematical and technical physics), Manne Siegbahn, and Axel Edvin Lindh (Siegbahn's successor to the physics chair in Uppsala) — published mostly in foreign journals. Although the German ones, in particular *Physikalische Zeitschrift* and the *Zeitschrift für Physik*, predominated, British and American journals were on the rise.

Figure 5. Third generation.



As previously for the first and second generations, the three dimensions of work collectivization, specialty formation, and foreign push/pull will give a close-up view. Because the research school of X-ray spectroscopy headed by Manne Siegbahn dominated physics at the time, this view will initially be restricted to that school. We will later treat theoretical and mathematical physics where international relations retained many elements of cosmopolitanism.

The process of internationalization was spurred by the collectivization of research introduced by Manne Siegbahn. Siegbahn directed his own energy and that of his group toward X-ray spectroscopy. Having come in contact with the field of X-radiation while visiting Arnold Sommerfeld's laboratory at the University of Munich in 1909, Siegbahn devoted himself entirely to X-ray spectroscopy from 1915 until the early 1930s. The major aim of his work was to improve the precision of wavelength measurements (initially the K and L-series, and later the the M and N-series, the latter discovered by Siegbahn) and extend these to a large number of elements in the periodic table. This was made possible by innovations in instruments (X-ray tubes, spectrographs, spectrometers, etc.) and the dexterity and perseverance of Siegbahn and members of his group when handling these (cf. Friedman, in press; Hulthén, 1951; Nordhult (Larson), 1951; Bergström, 1988).

Siegbahn introduced organized research into physics assembling groups of young coworkers first in Lund where he became a *docent* in 1911 and professor in 1922 (succeeding Janne Rydberg), and subsequently as professor of physics at Uppsala University (1922—1937). In Uppsala, in the late 1920s, his group had come to number some thirty persons. Forming the initial group was possible because of an unprecedented rise in the number of physics students in Lund shortly before World War I. Those who went on to complete their doctoral dissertations during or shortly after the war — among others, Ernst Anton Bengtsson Knave, Erik Bäcklin, Elis Hjalmar, Erik Hulthén, Wilhelm Stenström and Karl Axel Wingårdh — constituted the nucleus of the Siegbahn group. Since there were few opportunities for long-term academic employment, most members left, usually to become physics teachers in the *gymnasium* (high-school), after having completed their dissertations and perhaps put in a year or more of postdoctoral studies. The considerable turnover that ensued made it even more important to find new ways to create group cohesiveness.

Siegbahn was the natural leader of the group and it was he who portioned out the topics for research among the students in accordance with the overall program. After having studied the relevant literature for a few weeks, novices were put to work assisting their somewhat more advanced comrades in their experiments. When they were able to fend for themselves, they were given their own instruments (or assisted in the construction of these) and assignments, which, if they were promising ones, would become dissertation topics. Weekly seminars where the doctoral candidates reported on their work and where new results from articles published in foreign journals were discussed provided members of the group with an overview and showed how their individual topics fitted the overall program. The technicians in the group were another source of continuity and cohesiveness. The one instrument-maker attached to the group in Lund eventually became three in Uppsala where a draftsman and a secretary were also added to the staff (Eld Sandström, 1987: 7—18).

The international impact of Siegbahn's introduction of organized research will be discussed below drawing on citation and publication data. Here, two important aspects of the impact of the Siegbahn school *in Sweden* will be brought to the fore. First, *the Siegbahn school was national rather than local,* because he moved from Lund to Uppsala (and subsequently to Stockholm) and in the process brought not only students and technicians with him but also his research program and the collective organization of work described above. Second, *the Siegbahn school embraced a significant portion of the* *national physics enterprise in the interwar period.* This is brought out by Table 1 that lists the physicists who worked in Sweden during the 1920s and who figured in the *Physics Citation Index, 1920—1929* (see below). Of the 48 Swedish physicists who figured in the index (both the source index and the citation index), 29 were members of the Siegbahn group.

The foreign contacts of Siegbahn and his school were greatly facilitated by the way atomic physics (theoretical and experimental) became constituted as an *international* specialty after the war. The story of how this happened has not yet been told. We can surmise though that this process depended, especially in its initial phases, on informal networks and personal initiatives. Siegbahn acted vigorously to establish foreign contacts even while the war was being fought. The rising international star of Niels Bohr made him an ideal advisor. In 1915, Siegbahn consulted Bohr on his plans to apply for a scholarship to work at Rutherford's Institute in Manchester the following year. He was forced to remain in Lund, however, when Janne Rydberg was taken ill.[5] As the war was drawing toward an end, Siegbahn took up with Arnold Sommerfeld, whose chair and laboratory in Munich were focal-points for the further development, drawing on X-ray spectroscopic data, of Niels Bohr's theory of the constitution of the atom presented in 1913. Siegbahn and Sommerfeld corresponded intensively between 1917 and 1921. In September of 1919, Siegbahn and his co-workers in Lund organized the first postwar meeting on atomic physics attended by both Sommerfeld and Bohr. Sommerfeld's referring to Siegbahn's invitation "als erste wirkliche Friedens-Traube" shows how important this opportunity to break the isolation of German physics caused by the war was to him.[6] In 1920, Siegbahn expanded his contacts trekking across the European continent on a traveling scholarship from the University of Lund. In six weeks, he visited laboratories in Berlin, Leipzig, Munich, Stuttgart, Tübingen, Zürich, Paris, Leyden, Utrecht, and Amsterdam. Next year, he was on the road again visiting London, the National Physical Laboratory in Teddington and, finally, Rutherford at the Cavendish Laboratory in Cambridge before attending the Solvay conference in Brussels.[7]

Table 1. Physicists included in Physics citation index, 1920—1929. Members of the Siegbahn school are indicated by an asterisk.[a]

*1. Gustaf Arvidsson	*25. Axel Larsson Nordhult
2. Carl Benedicks	*26. Arvid Leide
*3. Ernst Bengtsson Knave	*27. Ernst Lindberg
*4. J. Bergengren	28. Jonas Otto Linde
5. Carl Bergholm	*29. Axel Edvin Lindh
*6. Albert Björkeson	30. Ragnar Lundblad
*7. Yngve Björnståhl	*31. Osvald Lundquist
*8. Helge Bohlin	32. Carl Vilhelm Oseen
9. Gudmund Borelius	33. Gösta Phragmén
*10. Erik Bäcklin	34. Erik Gustaf Rudberg
11. David Enskog	35. Ernst Sedström
*12. G. Eriksson	*36. Manne Siegbahn
13. Hans von Euler-Chelpin	*37. Rolf Sievert
14. Hilding Faxén	*38. J.Stenman
*15. Einar Friman	*39. Nils Stensson
16. F. Gunneson	*40. Wilhelm Stenström
*17. Torsten Heurlinger	*41. Robert Thoraues
*18. Elis Hjalmar	42. Ivar Waller
19. Sven Holgersson	*43. Ina Wennerlöf-Bäcklin
*20. Erik Hulthén	44. Arne Westgren
21. Carl Hugo Johansson	*45. Torsten Wetterblad
*22. G. Johansson	46. Paul Wetterfors
*23. Edvin Jönsson	*47. Karl Axel Wingårdh
*24. Gunnar Kellström	48. Anders Ångström

[a] The initial sorting of the overall population according to whether they were members of the Siegbahn group or not was done by me. It was based on the subjects of their publications, the year and the place of the dissertation, and on the names of persons cited. The list was submitted to two former collaborators of Siegbahn's and to his secretary, who confirmed my decisions to consider the person a member of the group in almost every case. That my informers were quite certain as to who was or was not a Siegbahn co-worker was in itself an indication that the Siegbahn group was indeed a tight-knit one. In the few cases, where both they and I were hesitant or lacked biographical information, I have made the person a non-member of the Siegbahn group , even when there was a suspicion that the person was indeed a member.

This offensive abroad would not have brought success, had not Siegbahn's X-ray data been of such high interest and utility to the theory-builders in atomic physics. Siegbahn not only mapped the characteristic X-rays of a large number of elements, he also did so with a hitherto unachieved degree of accuracy. It was this new degree of accuracy that made possible one of the first hits scored by the Siegbahn group; their finding the so-called relativistic doublet K-transitions predicted by Sommerfeld in 1916. Subsequently, the data produced by Siegbahn and his students, interpreted by Sommerfeld, Kossel and other theoreticians, would not only lead to important modifications of the principles for the "one-quantum ring atom" advanced by Bohr in 1913 but also deepen the understanding of the production of X-ray spectra (cf. Heilbron, 1967). When Siegbahn's important textbook *Spektroskopie der Röntgenstrahlen* appeared in 1924, and was translated into English the following year, his position as the leading X-ray spectroscopist in international physics was no longer in doubt. Although his experimental results were not of the same interest to theoreticians later in 1920s as they had been previously, the many advances of his school in X-ray measures during this period, enumerated in the biographies of Siegbahn, still made his work hold the attention of atomic physicists.

Largely as a result of Siegbahn's efforts, balance was achieved between push and pull in the foreign relations of Swedish physics and physicists during the interwar period. As already noted, World War I limited the possibilities of graduate and post-doctoral students to spend time at foreign centers of learning and research. This practice was resumed in the 1920s with American universities as an important new addition to the traditional itineraries in Europe. Two of Siegbahn's students were the only Swedish physicists of their generation to receive fellowships from the Rockefeller-funded International Education Board. They were Erik Hulthén who spent 1925—1927 at the University of Michigan at Ann Arbor and Axel Edvin Lindh who was at the University of Halle, 1926—1927.[8]

Siegbahn's international reputation gave him considerable pull when it came to attracting foreign graduate students and postdoctorates anxious to learn precision X-ray spectroscopy. Although it has not been possible to ascertain their exact number either in Lund or Uppsala, it must have exceeded the 15 students who came to study under Arrhenius during his tenure at the Stockholm Högskola. One of the first arrivals after the war was Dirk Coster from Holland, who spent 1920—1922 in Lund. He went on to Bohr's Institute in Copenhagen where he put the skills he had learnt from Siegbahn (and also equipment borrowed from him) to good advantage by linking up X-ray experimental data with Bohr's theory of atomic structure and the periodic table of the elements. In the process, he located, together with George Hevesy, the missing element 72 (baptized hafnium) which, in conformity with Bohr's theory was found in the titanium group (Hevesy, 1951). Other foreign students (V. Dolejsek, J. Valasék, and A. Zacek) arrived in Lund from Prague where Siegbahn had been offered the chair of physics shortly after the war. With the transition to Uppsala where more spacious facilities were available than in Lund, the foreign element would eventually include physics students from the U.S., Denmark, Germany, India, and Japan.

The triple effects of work collectivization, close ties to a specialty community, and foreign pull are apparent in the publication and citation patterns of Siegbahn and members of his school throughout the 1920s. The *Physics Citation Index 1920—1929* (PCI) (Small, 1981) — a major resource for historical, bibliometric studies — makes possible the quantitative mapping of these patterns. The procedure used was as follows. An examination of the PCI yielded a list of 48 physicists (or physical chemists) who worked in Sweden in the 1920s and who had both published *and* been cited in one of the sixteen rather loosely defined core physics journals on which the PCI is built. None of the core journals was published in Sweden. That there were so many physicists publishing in such well-known foreign journals is in itself an indication of the national physics enterprise coming of age internationally. The overall population of 48 physicists was divided into two groups: members of the Siegbahn school (29 in all) and others (19).

Table 2. Publication and citation patterns of members of the Siegbahn school and other Swedish physicists, 1920—1929.

	Siegbahn school	Others
Publications		
Mean number of articles published in core journals	3,10	3,84
Total number of articles published in core journals	90	73
Articles in German core journals	74	62
	82%	85 %
Citations		
Mean number of citations received per article published 1920—1929	9,87	5,20
Total citations in articles	1060	1172
Citations given to other Swedish authors	301	116
	28%	10 %

Source: Physics Citation Index, 1920—1929, 2 vols. Philadelphia: Institute for Scientific Information, 1981.

The *publication* patterns of the groups were similar in several important respects. (See Table 2). The mean number of articles published in core journals during the period 1920—1929 was not that different: 3,10 per person for the Siegbahn group and 3,84 for the others. Members of both groups (82 percent for the Siegbahn school and 85 for the others) published primarily in German journals, that is, *Annalen der Physik*, *Physikalische Zeitschrift,* or *Zeitschrift für Physik*. The large majority of the remaining articles appeared in British (10 percent for members of the Siegbahn group and 12 percent for the others) and American journals (5 and 3 percent respectively).

The *citation* patterns of the two groups reveal important differences that are explained by the collectivization of work in the Siegbahn group and its functioning as a school. A high ratio of intra-school citations can be expected as a consequence of both the more dense communications network typical of a school and the portioning out of research topics related to the overall program of the school. Citations made to other Swedish authors is only a crude measure of intra-school citations, but they have the advantage of allowing comparisons between the Siegbahn group and other Swedish physicists featured in the *PCI.* This comparison reveals that 28 percent of the citations (that is, 301 out of 1060) made by authors in the Siegbahn group in articles published in core journals, 1920—1929, went to other Swedes, almost exclusively other members of the school. By contrast, only 10 percent of the citations (116 out of 1172) made by those who were not members of the school went to other Swedes. As befitted the leader of the school, Siegbahn himself received the largest share (50 out of 301, or 17 percent) of the citations made to other Swedes by members of his group.

That the members of the Siegbahn group were much more effective in attracting international attention for their work is indicated by the mean of 9,87 citations per article published in core journals that they received in the period 1920—1929. This was almost double the 5,20 citations per article received by those who were not members of the school. The higher citation count of the Siegbahn group is partly a result of a greater tendency toward the intra-school citing described above. Given that the latter kind of citing was practised in core journals, and hence enhanced the international visibility of the group, we have seen no reason to discount it. On the contrary, it underscores our point that the strengthening of *national* links brought about by the school and evinced by its higher portion of intra-school, Swedish citations resulted in a higher *international* profile. This is also in line with our hypothesis of a link between collectivization and internationalization.

The foreign contacts of theoretical physicists were more cosmopolitan because in general they were dependent on individual rather than group action. The chief actor was C.W. Oseen, who took over Lundquist's chair in Uppsala in 1909 when its name was changed from mechanics to mathematical physics. For Oseen, it was first of all a question of modernizing the teaching of theoretical physics in Sweden. After the First World War, Oseen made a determined effort to introduce atomic and quantum physics into Sweden and to establish contacts with major foreign research centers. Oseen himself was best known internationally for his work in hydrodynamics and turbulence, a classical form of theoretical physics (Waller, 1948). It was left to his students then to assimilate the new physics into their work. David Enskog and Ivar Waller became the best-known internationally, but this did not occur until the 1930s.

A more unusual road into the new physics was taken by Oskar Klein, who started in physical chemistry under Svante Arrhenius around the time of the First World War. Having finished his thesis on the theory of solutions in 1921, Klein departed for Copenhagen where he spent the 1920s as a collaborator of Niels Bohr. His return to Sweden in 1930 to take up the chair of mechanics and mathematical physics at the Stockholm Högskola represented a collectivized push for the internationalization of theoretical physics in Sweden similar to that spearheaded by Siegbahn for experimental physics. Whereas Siegbahn's international contacts involved a range of foreign research centers, Klein's were channelled through the Bohr institute in Copenhagen. His students were sent on sojourns there and guests to Copenhagen frequently also made their way up to Stockholm (Haglöf, 1990). Bohr's role as a go-between and that of his institute as a jumping-off point for Swedish physicists would be an important topic for further study.

Conclusions

In this article I have outlined the process of internationalization of physics in Sweden from the late nineteenth century to the 1930s. I found that after World War I, the foreign contacts of Swedish physicists changed from being *cosmopolitan*, that is, individualistic and universal, to *international*, that is, they became part of organized research and strategically chosen research topics at home, and of a tight-knit network of physicists working in the same specialty area abroad. I argued that this transition was brought about, and even hastened, by two concurrent events; one, the rise of the Siegbahn school of X-ray spectroscopy in Sweden, and, two, the emergence of theoretical and experimental atomic physics as an international specialty. I showed how Siegbahn's move from Lund to Uppsala and then to Stockholm — the country's three major universities at the time — made his school national and one that eventually came to predominate over the country's academic physics establishment.

This brief and schematic outline of the article has to be nuanced in several important respects. First, the progress from cosmopolitan to international relations was neither straightforward nor inevitable. As in any important change in the social relations of science, there was complexity, hesitation and a fair amount of muddling. Second, it was not possible to be more specific about the international elements that interacted with national ones to bring about the change. Because the history of international atomic physics in the interwar period is yet to be written, we lack systematic and detailed information about the networks, centers, sources of funding, and research problems that populated the new international space in which Swedish physicists had to find their bearings. That it was indeed a world in the making is evinced by the fact that even its most advanced part — atomic physics — functioned mostly through informal networks. Hence, most of the features that would make up post-World War II international physics — international collaborations, trans-or supranational research facilities and funding agencies, and the like — had yet to be invented. Third, the change when it was instaured did not affect the entirety of the national physics enterprise; theoretical physics lagged behind as evinced by the slow introduction of quantum mechanics into Sweden. Although it has only been possible here to touch on geophysics, one may suspect that its international relations too were different.

For all these caveats, the unique role of Siegbahn and his school in the process of internationalizations remains. It was Siegbahn's strategic choice of a research specialty of crucial importance (at least for a while) to atomic theory-builders, his orchestration of work by members of his school, and his determined push to establish foreign contacts that propelled Swedish physics as a collective rather than an individual undertaking onto the international scene. The payoff came in the form of the high international visibility of the group's publications (that is, a high citation count) and its considerable pull when it came to attracting foreign graduate students and postdoctorates. These were permanent gains for experimental physics in Sweden, for once the rules of the international game had been learnt, they would be passed on to the next generation.

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NOTES

1. Whitley identifies two forms of dependence: 1) *functional dependence* refers to the need to coordinate task outcomes and demonstrate adherence to common competence standards; 2) *strategic dependence* refers to the extent to which researchers have to persuade colleagues of the significance and importance of their problem and approach to obtain a high reputation from them. A high degree of both leads to Whitley's analytical category of *conceptually integrated bureaucracies* . Theoretical physics from the 1920s and onward is an example of the latter. Whitley's conceptual framework is suggestive but will not be applied stringently here. Richard Whitley, *The Intellectual and Social Organization of the Sciences*, Oxford, Clarendon Press, 1984, 88—89 and 203.
2. Letter from Oskar Widman to L. F. Nilson, n.d., Nilson Papers, Center for History of Science, Royal Swedish Academy of Sciences, Stockholm (hereafter referred to as KVA).
3. H.H. Hildebrandsson, "Självbiografiska anteckningar," (Autobiographical notes submitted after election to the Royal Swedish Academy of Science), Sekreterararkivet (Archive of the Secretary), KVA, n. d.
4. "Främlingsboken vid Stockholms Högskola," (Register of foreign students), Stockholm Högskola Collection, National Archives, Stockholm.
5. Manne Siegbahn to Niels Bohr, October 15 and November 6, 1915. Archive for the History of Quantum Physics (AHQP).
6. Arnold Sommerfeld to Manne Siegbahn, June 5, 1919, Siegbahn Collection, KVA.
7. Manne Siegbahn, "Till Större Akademiska Konsistoriet, Lund, December 17, 1921, (Travel report), Manuscript Department, Lund University Library.
8. Personal communication curtesy of Erwin Levold, archivist at the Rockefeller Archive Center, Pocantico Hills, N.Y.

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