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Shaul Katzir

**From academic physics to invention and
industry: the course of Hermann Aron's
(1845–1913) career**

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Hermann Aron had an unusual career for a German physicist of the Imperial era. He was an academic lecturer of physics, an inventor, a founder and the manager of a company for electric devices, which employed more than 1,000 employees. Born in 1845 to a modest provincial Jewish family, Aron went through leading schools of the German educational system, received a doctorate in physics and in 1876 the *venia legendi* - teaching privilege, with which he became a *Privatdozent* (lecturer) at Berlin university. However, rather than becoming a university professor - the desired goal of this career track - he turned to technology and then industry with the invention of an electricity meter and the foundation of a successful company for its development and manufacture in 1883. By 1897 he owned four sister companies in Berlin, Paris, London, and Vienna-Budapest and manufacturing factories in these cities as well as in Silesia.

While in the twentieth century such a career trajectory of a university teacher was not the common case, it was even less so in the late nineteenth century in physics; in many respects it was unique. Aron's was not the case of a newly qualified doctor hired by industry. He was an experienced lecturer, who founded his own enterprise to exploit his own inventions. Usually physicists, like most other scientists (perhaps excluding chemists) were not involved directly with the development of specific technologies beyond laboratory devices. Even those who developed commercial technologies did not become independent entrepreneurs but joined either extant or new partnerships, became consultants, or sold their patent rights to firms. For example, in the 1850s William Thomson was first an advisor and later a director in a telegraph company. Forty years later Ferdinand Braun was introduced to the radio by industrialists and entrepreneurs, who asked for his technical help, drew him to research and development on related devices and made him a partner for his patents and technical advice. Walther Nernst developed a new incandescent lamp on his own initiative but sold the patent to AEG, which undertook the necessary development to a working commercial device with his help.¹ Industrialists and engineers did not arrive from the teaching staff of the universities and engineering schools. They were very rarely holders of a PhD in physics (in chemistry that was more common). In Germany until the 1890s even those, like Werner Siemens, who valued highly the contribution of scientific knowledge and intensively employed it, seldom pursued high academic degrees or taught at institutes of higher education.²

1 Crosbie Smith and M. N. Wise, *Energy and Empire: A Biographical Study of Lord Kelvin* (Cambridge: Cambridge University Press, 1989), 661-64, Friedrich Kurylo and Charles Susskind, *Ferdinand Braun, A Life of the Nobel Prizewinner and Inventor of the Cathode-ray Oscilloscope* (Cambridge Mass.: The MIT Press, 1981), Florian Hars, *Ferdinand Braun (1850-1918): ein wilhelminischer Physiker* (Berlin: Verlag für Geschichte der Naturwissenschaften und der Technik, 1999) 131-152, Diana K. Barkan, *Walther Nernst and the Transition to Modern Physical Science* (Cambridge: Cambridge University Press, 1999) chapter 6, pp. 91-109. A case similar to Aron's is of Carl Auer von Welsbach, who invented successful incandescent mantle for gas light in 1885, and later a metal filament with osmium and wolfram, giving the name for the company that he founded "Osram." Auer was an active research chemist after receiving his PhD and also in the years that he worked at his technological devices. However, unlike Aron he did not embark on an academic teaching career. In addition, chemists had closer connections with industry than physicists. Ronald Adunka, "Carl Auer von Welsbach: Das Lebenswerk eines österreichischen Genies," *Plus lucis* (2000): 24-26.

2 During the 1890s experience in industry became an advantage for receiving a teaching position in electrical engineering at the *Technische Hochschulen* (thought not for the sciences their, or at the

Aron's special path deserves an explanation. Why did he move from academic physics to inventions and industry? What led to his success in those fields? At the time industry was not normally an option for a physicist who could not get an academic position.³ A private venture in technology was even rarer, and clearly could not provide an immediate income. Teaching at a highschool or in other institutes of higher education (as Aron did) was much more common. Aspirations towards financial gains were a weaker motive then than it is today, and at any case they are inadequate to explain a late transition from a scientific career. Those who left (or considered leaving) academic career for industry were often driven by external factors. For example, in 1888 Carl (Charles) Steinmetz fled Germany and abandoned his dissertation project in mathematics due to anti-socialists persecution. In exile he embarked on a highly successful electrical engineering career, as a means to earn his living. His comrade Leo Arons began the commercial development of a mercury arc lamp twelve years after he had invented it for experimental aims in 1904 following his dismissal from teaching as a social-democrat and the development of his invention by others.⁴ To explain Aron's transition, which did not follow such a rapid external influence, I follow Aron's scientific and early technological careers in their contexts. This discussion sheds light on a few aspects of the epoch's science and technology, among them the relation between the two, and the place of Jews in German science and technology.

Notwithstanding the exceptional character of Aron's move, some fields of the natural sciences and areas of technology and industry had close connections. The introduction of chemical and electrical technologies in the so called 'second scientific revolution' during the last third of the nineteenth century raised both scientific interest in and enthusiasm for connected technologies.⁵ It caused

universities), Wolfgang König, "Science-based Industry or Industry-based Science? Electrical Engineering in Germany Before World War I," *Technology and Culture* 37 (1996): 70-101, on 85, Wolfgang König, *Technikwissenschaften. Die Entstehung der Elektrotechnik aus Industrie und Wissenschaft zwischen 1880 und 1914* (Chur: G+B Verlag Fakultas, 1995), 132.

3 König examined the share of graduates of different kind of education among an elite group of scientists and engineers in the electrical industry. His findings suggest that the share of university-graduates (without distinction of degree) was small (13% of his sample until the end of the war), but somewhat higher in the 1880s when Aron joined industry (29%). The share of university graduate among all the technical staff of industry was probably lower. In contrast, university graduates were about half of the members of this group in the public services. *Ibid.*, 252-55; König, "Industry-based Science," (ref. ?), 78-79.

4 Unlike Aron, Steinmetz and Arons did not establish their own companies. Ronald R. Kline, *Steinmetz: Engineer and Socialist* (Baltimore, MD: Johns Hopkins University Press, 1992), 17-21, Stefan Wolf, "Die Quecksilberdampfampe von Leo Arons," in *Circa 1903: Artefakte in der Gründungszeit des Deutschen Museums*, ed. O. Blumtritt, U. Hashagen, and H. Trischler (Munich: Deutsches Museum, 2003), 329-348. Arons's dismissal was unique and required a special Prussian legislation.

5 Despite their connections and some overlaps, science and technology were (and are) different human endeavours with different aims, which were recognised as such at the time. While knowledge is the goal of science, artifacts and products are the goals of technology. Research in technology also leads to knowledge, but this knowledge is not an end of itself but a means to improve design (either by the researcher or others). Indeed it is not always easy to differentiate between means and ends and some researches aim both at knowledge and aiding design, which blurs the boundary between science and technology. Yet, this analytic definition serves well in differentiating between the two human endeavours. In particular, it is useful in understanding Aron's research. On design as an end of technological or engineering research see Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies From Aeronautical History* (Baltimore MD: The John Hopkins University Press, 1990).

interest also among industrialists and entrepreneurs in scientific findings and education. In particular the spread of electrical technology just when Aron made his move was directly relevant to his interests. Yet, to understand his transition one should look also at his particular context in Berlin's scientific and engineering communities, including his scientific experience. The examination of the factors within the worlds of science and technology that drove Aron to industry sheds light on the complex relations between and characteristics of science and technology. What kinds of elements within physics, if at all, facilitate Aron's move to technology? How much and in which ways did his scientific knowledge and experience contribute to (or disturb) Aron's success in technology? These questions have important bearings on the more general and controversial issue of the relation between late nineteenth century electrical technology and science. Against the common wisdom Wolfgang König argued that electricity was not a "science-based industry." His conclusion is based on the claim that scientific research was not a major source of knowledge to that industry. Here, however, I show that Aron did transfer knowledge (including methods and experience) from physics to technology, and that this knowledge was indispensable to his success.⁶ This, of course, does not eliminate the crucial role of specific research towards a viable design including the use of trial and error methods in Aron's development of technology.

One of the possible external factors that might have shaped Aron's career was his Jewishness. The German academia was and was known to be discriminative against Jews. Discrimination was especially strong in the process of getting a professorship. The chances of a Jewish *Privatdozent* (the low level of a lecturer who was not employed by the university but received only student fees) to become a professor were much lower than those of his non-Jewish colleague, and then his chances of becoming an extraordinary rather than an ordinary professor were higher.⁷ So, Aron's failure of

6 In this inference König explicitly excludes the contribution of fundamental scientific "discoveries from which later technological developments in industry originated" and research "performed at industrial research departments" from his interpretation of science-based industry. His denial of knowledge transfer from science to industry is based on two claims. 1) He shows that the share of university graduates was small in comparison with graduates of engineering at the *Technische Hochschulen* (technological colleges). Further, he claims that the basis of education in the latter institutes was in industry rather than in science, so they did not transfer scientific knowledge to their students. 2) In addition König claims that there was not a "transfer of [recent] research results from the universities to industry." However, as Forman points out "König had to ignore the stated fact (p. 81) that in the crucial founding decade of the 1880s most of those appointed to chairs of electrical engineering were physicists entirely without prior experience in industry." I will return to König's particular claims below. König, "Industry-based Science" (ref. 2), 73; Paul Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," *History and Technology* 23 (2007): 1-152, on 122, (n392).

7 While the proportion of Jews among the *Privatdozenten* was similar to that found in the student body, they had lower representation among the professors. In 1889/90 *Privatdozenten* were 47% of all "Jewish" (including people of Jewish decent) lecturers compare to 30% of non-Jewish, Simone Wenkel, "Jewish Scientists in German-speaking Academia: An Overview," in *Jews and Sciences in German Contexts: Case Studies From the 19th and 20th Centuries*, ed. Ute Deichmann and Ulrich Charpa (Tubingen: Mohr Siebeck, 2007), 265-295, on 266. Only 26% of the "Jewish" *Privatdozenten* at Berlin university received an ordinary professorship at the university versus 42% of the non-Jews (between 1871 and 1933). Most of the former were converted to Christianity. Aleksandra Pawliczek, "Kontinuität des informellen Konsens! Die Berufungspolitik der Universität Berlin und ihre jüdischen Dozenten im Kaiserreich und in der Weimarer Republik," in *Kontinuitäten und Diskontinuitäten in der Wissenschaftsgeschichte des 20. Jahrhunderts*, ed. Rüdger vom Bruch, Ute Gerhardt, and Aleksandra Pawliczek (Stuttgart: Franz Steiner Verlag, 2006), 69-92, on 75. See also Alexander Busch, *Die Geschichte des Privatdozenten* (Stuttgart: Ferdinand Enke, 1959), 148-162; David Lawrence Preston,

getting an academic position was probably connected, among others, to discrimination. It did not follow from lack of talent. His peer, Eugen Goldstein, thought that Aron was “arguably one of the most ingenious and creative heads of all times.”⁸ However, as mentioned, even if Aron had been pushed out from the university (which is not exactly the case) it would not have been sufficient to account for his move to industry.

Nevertheless, in a more convoluted way, discrimination might have pushed Aron towards technology. Antisemitism drove Jewish scientists to marginal and less prestigious fields which were often new and interdisciplinary, like that of electrical technology, which Aron studied in his way towards practical work.⁹ Volkov suggests that some of these fields “turned out to be particularly ‘creative niches’ where [Jewish] talents found ample room for development. Conditions in these niches placed a higher premium on inventiveness than elsewhere, allowed a greater deal of personal independence, and were particularly conducive to professional breakthroughs of all kinds.” If that was so, perhaps Aron found his ‘creative niche’ in electrical technology. However, by pointing at marked differences in the achievements of Jews in physical chemistry and biochemistry, Deichmann claims that discrimination and marginalization are insufficient to explain the success of Jews in some ‘peripheral’ fields.¹⁰ Volkov’s hypothesis attempts to explain the phenomenon of “Jewish science”, i.e. the facts that German Jews were over-represented in the sciences (also in comparison to similar social-economical groups) and excelled in them from about 1870s. A similar phenomenon appeared later in other places like the USSR and the USA. Social, cultural, historical and even biological explanations have been advanced to explain this phenomenon.¹¹ The explanandum of these explanans

Science, Society and the German Jews, 1870-1933 (PhD Dissertation, University of Illinois at Urbana-Champaign, 1971), 109-112, who also points at qualitative evidence for academic antisemitism: 191-92.

8 This appears in an article on quite a few scientists who do not receive the same kind of praises, Eugen Goldstein, "Aus vergangenen Tagen der Berliner Physikalischen Gesellschaft," *Naturwissenschaften* 13 (1925): 39-45, on 40.

9 However, unlike scientific fields, academic engineering including electrical engineering attracted very few Jews. On the proportion of Jews in new fields, which were less prestigious and thus more accessible to Jews, see Preston, *Science, Society* (ref. 7), 192-6 (however, Preston does not provide adequate examples for his claim that Jews investigated marginal fields unexplored by others); For more reliable evidence for the marginalization and consequently specialization of Jewish scientists, which is unfortunately based on a small sample of successful scientists, see the first part of Shulamit Volkov, "Jewish Scientists in Imperial Germany (Parts I and II)," *Aleph: Historical Studies in Science and Judaism* 1 (2001): 215-281, and for limited subdisciplines Ute Deichmann, "Erfolg und Fachdisziplin - Juden in Chemie und Biomedizin in Deutschland bis 1933," *Jahrbuch des Simon-Dubnow-Instituts* 3 (2004): 269-292.

10 Volkov, *ibid.*, quote on 254, Deichmann, *ibid.*, for a critique of Volkov’s suggestion see also Ute Deichmann and Ulrich Charpa, "Introduction: Problems, Phenomena, Explanatory Approaches," in *Jews and Sciences in German Contexts* (ref. 7) 3-36, on 22-29. Among others points, they suggest that the marginalization of fields like bio-chemistry followed the dominant position of Jews in them, rather than the other way around.

11 There is an almost universal agreement that the high rate of Jews among the urban middle class, and the practical exclusion from civil service account for part, but far from whole, the answer. Among other factors mentioned are: the high percentage of medical students for social-economical and traditional reasons (more below); an advantage external and critical point of view that arose from their marginal status in society; the Jewish culture of learning and that of Talmudic study in particular, or as a culture more versatile and open to controversies than the Christian; an attraction to universal ‘neutral’ cultural field like science as part of commitment to secular culture; a strong network of trust among Jews (based on common

was mostly withdrawn either from statistical data on Jews' role in the various levels of scientific activities, or from examples of highly successful scientists.¹² It is therefore instructive to consider the possible influence of Jewishness on the career of a scientist from the 'second echelon,' like Aron. Of course, one cannot draw positive conclusions regarding a question like the reasons for the Jews' success in science from one example.

In order to account for Hermann Aron's transition from the academy to industry this paper follows his intellectual biography to circa 1891, when his transition was solidified. It examines the kind of work in which Aron was engaged in physics and electrical technology and the role of his experience in physics on his inventions. The first part of the paper follows Aron from his background through education, research and teaching of physics and his research directed at technological improvements and innovation to his full engagement with his company, in roughly chronological order. To help the reader finding the details of Aron's biography I supply a chronology of relevant events in his life (with more details to 1890). The second part analysed the factors that led Aron to his invention of the electricity meter and to his earlier work at inventing an efficient secondary battery. From these I identify the major factors that led to Aron's transition from academic science to invention and industry, in section 8. The brief conclusions return to the Jewish dimension in Aron's career and to its lessons for the relations between science and technology at the time.

faith and for trade) transformed to science and the high rate of literacy. For a critical review of most of these see the reference in 10.

12 Volkov admits the methodological problem of examining only the most successful Jewish scientists, but only partially amends it by comparison with a similar elitist group of non-Jewish scientists. Recently Pawliczek attempted to combine qualitative evidence from the archive of Berlin University in her study of all Jewish *Privatdozenten* at that university. Deichmann went beyond the elite group in "Erfolg und Fachdisziplin" (ref. 9).

Table 1: A chronology of Hermann Aron

1.10.1845	birth in Kempen in the Pozen “Duchy” of Prussia
1861-1867	studies at the Köllnische Realgymnasium
1867-68	medical studies at Berlin university (two semesters)
1868-71	physics, mathematics and chemistry studies in Berlin and spring semesters 1869 & 1870 in Heidelberg
4/1872-?/73	assistant of Paalzow at the <i>Gewerbeakademie</i>
10/1873	reception of doctorate at Berlin university (dissertation on elasticity)
1873-1910	Teacher of physics at the <i>Vereinigte königliche Artillerie- und Ingenieurschule</i> (combined royal artillery and engineering school)
July 1876	Habilitation at Berlin university (on electric discharge)
4/1877-3/1895	<i>Privatdozent</i> for Physics at Berlin university
12/1879	a founding member of the <i>Elektrotechnische Verein</i>
1880	first paper on practical question (telegraph cables in powder magazine. Beginning of research on storage batteries
1881	marriage to Betty Landsberger
1/1882-11/84	first secretary of the <i>Elektrotechnische Verein</i>
6/1882	patent (first) on storage batteries, and publications on the subject until 1884
1883	alleged attempt at wireless telegraphy
1883	last two papers on non-technical physics (on symmetry in elasticity)
10/1883	beginning of the development of the electricity meter, foundation of a company
6/1884	patent on the electricity meter
12/1884	patent on electric clock
autumn 1885	Berlin’s choice of Aron’s meters and sell of first 100 meters.
6/1886	patent for mercury-alkaline (primary) battery
1888	“Titular Professor”
1890	opening a factory and a company in Paris
1890	reduction of teaching at the university to one weekly hour free of charge
1891	patent on “three-phase” electricity meter
1893	opening a factory and a company in London
1894	<i>Geheimer Regierungsrat</i>
1897	opening a factory and a company in Vienna and a factory in Schweidnitz in Silesia (Germany)
1912	Manfred, Hermann Aron’s son, replaced his father as director
1913	death of Hermann Aron
1935	purchase of Aron’s company by Siemens (through Deutsche Bank)

1. Early life and education

Hermann Aron was born on October 1st 1845, the fourth child of six to a traditional Jewish family in Kempen, a “shtetl” of about 6,000 inhabitants two thirds of them Jews, in the Prussian ‘Duchy’ of Posen (currently Kapno in Poznań district of Poland). Only three years later did the Jews of the ‘duchy’ gain full emancipation. His father, “a tolerant orthodox Jew,” was probably an occasional petty tradesman, a Torah teacher and a synagogue clerk; the family had limited economical means.¹³ Hermann first learnt at a “simple Jewish municipal school.” As an adult Hermann leaned to Reform Judaism.¹⁴ At the age of 16 he went to Berlin to study at a Gymnasium, being three to four years older than his class mates. Although not the common practice, leaving home to study in a Gymnasium at foreign city was not rare. It is unclear how Aron did support these studies and why did he postpone them. The answers to the two questions are probably connected.¹⁵ Aron decision to enter Gymnasium at this age is an early example for his diligence, persistence and ambition.¹⁶

Berlin’s Köllnische Realgymnasium, Aron’s school, was a prestigious old institute with innovative

13 An indication of the economical condition of the family can be found in the story that Hermann’s father could not buy himself a warm coat after he gave his to a poorer person. This story is recalled by Manfred Aron, Hermann’s son, who is probably also the most reliable source for his grandfather’s occupation, Manfred Aron, "Rede zur Gedächtnisfeier für Hermann Aron am 12.3.1922," unpublished manuscript in the Leo Baeck Archives, New York, 1-2. I thank Hans-Christian Förster for providing me the manuscript. Ludwig Geiger, "Geh. Reg.-Rat. Prof. Dr. H. Aron," *Allgemeine Zeitung des Judentums* (1913): 448-449. I thank Michael Aron for the information about Hermann siblings taken from census data etc. Michael is not sure that he tracked all the siblings. On Kempen see Rachel Grossbaum-Pasternak, "Kempno (in Hebrew)," in *Pinkas Hakehillot Polin: Entsiklopedyah shel Ha-yishuvim Ha-yehudiyim (Encyclopaedia of Jewish Communities, Poland, volume VI)*, ed. Abraham Wein and Rachel Grossbaum-Pasternak (Jerusalem: Yad Vashem, 1999), 111-113.

14 Geiger, *ibid.*, 448.

15 Manfred Aron, “Rede” (ref. 13), 2. Aron, vita in the dissertation in Humboldt university archive UA,Phil.Fak Nr.247. Jewish municipal schools at Posen district included secular studies (Wein, Introduction to Jewish Encyclopaedia, p. 4). Kempen probably did not have a Jewish highschool. (Grossbaum-Pasternak, “Kempen” (ref. 13)). It is thus unclear what Aron did before the age of 16. Hermann Aron’s father “died early,” probably before Hermann went to Berlin. Later his university records mention a guardian in Berlin, so Aron might have lived at his place as a Gymnasium student. Paul Hintzelmann, *Die Matrikel der Universität Heidelberg*. Teil VII: Register 1704-1870, Heidelberg, 1916; Gustav Toepke, *Die Matrikel der Universität Heidelberg*, Teil VI: 1846-1870 Heidelberg, 1907 in <http://unihdmatrikel.uni-hd.de>. One unreliable source suggests that a townsman from Kempen supported Aron’s studies but it does not provide any evidence, Felix Theilhaber, "Der Messer der magischen Kraft: Hermann Aron," in *Schicksal und Leistung: Juden in der deutschen Forschung und Leistung*, (Berlin: Welt-Verlag, 1931), 157-167, 158.

Pursuit of better education for the children was a prime reason for Jewish inner immigration in Germany. Another famous student who was sent alone was Paul Ehrlich, who went to Braslau, Avraham Barkai, "The German Jews At the Start of Industrialization: Structural Change and Mobility, 1835-1860," in *Revolution and Evolution: 1848 in German-jewish History*, ed. Werner A. Mosse and R. R. Paucker (Tubingen: Mohr, 1981), 123-150, on 128, Volkov, “Jewish Scientists” (ref. 9), 266.

16 Aron told a paradigmatic story about the power of diligence from his student days at Königsberger’s mathematical seminar. One day Königsberger returned mathematical works to his students announcing that that of the future mathematician Sonya Kovalevski is the best one. Aron returned to his work and improved it, and the teacher shared the first place between it and Kovaleski, Manfred Aron “Rede” (ref. 13), 3.

and liberal spirit. Its combination of traditional classical studies (Latin and Greek) of the other Gymnasia with modern culture (including English and French, which were later useful for Aron's research) and the sciences that were usually taught at the *Realschulen* was unique. Like the other Gymnasia it enabled admission to the universities, which did not admit graduates of *Realschulen* until 1871 (in Prussia).¹⁷ In October 1867, at the age of 22 Aron completed his secondary education and went to the study medicine at Berlin University. Aron's choice was typical among young persons of his background. More Jewish students studied medicine than all other subjected combined.¹⁸ The reasons for the choice of medicine were partly cultural-traditional. Jews had a long medical tradition rooted in the middle ages. They began its study in gentile German institutes in the 18th century. Notwithstanding, current social-economical conditions had probably a stronger effect.¹⁹ As a liberal profession medicine was less vulnerable to discrimination, especially in comparison with the civil services (the major employer of university graduates), and provided a relatively safe income and a possibility of upward social mobility. This made it especially attractive for students of modest background (at least until the 1870s). Moreover, Berlin was the popular choice of university for Jewish students from Posen district, including those who came from relatively poor homes, like Aron.²⁰

However, Aron did not complete his medical studies. After one year he moved to the philosophy faculty, where he studied physics, mathematics and some chemistry. In the lack of evidence, the historian can only speculate on Aron's reasons. It is highly likely that he was attracted to the sciences (whether by the first year studies in medicine or at the *Realgymnasium*),²¹ in which he probably displayed his talents. Whatever his reasons were, the move to the physical sciences was not 'practical' in the meaning of giving high priority to question of a future income. In 1868, physics suggests limited work opportunities.²² Aron stayed in Berlin for one semester and than moved for a

17 Kristiane Lichtenfeld, „Homer und Sokrates als Schutzgeister“ *Berlinische Monatsschrift*, 11/1998: 16-19 (<http://www.luise-berlin.de/bms/>). Carsten Reinhardt and Anthony S. Travis, *Heinrich Caro and the Creation of Modern Chemical Industry* (Dordrecht, Boston, MA: Kluwer Academic, 2000): 12-14. After 1882 the older *Realschulen* were termed *Real Gymnasium* but Köllnische Gymnasium was not of this kind. James C. Albisetti, *Secondary School Reform in Imperial Germany* (Princeton, 1983), 76-77.

18 In the years 1886/87-91 644 Jews studies medicine at the Prussian universities, while 490 studied all the other subjects combined. Among non-Jews medical students were 2827 in comparison with 5526 in the others (excluding theology). Since the share of medical students among Jews declined in the following years, it is plausible to assume that their share was even higher twenty years earlier when Aron went to the university. Arthur Ruppin, *Die Juden der Gegenwart*, 2. Auflage, (Cologne: Jüdischer Verlag, 1911), 124-25.

19 Deichmann, "Erfolg und Fachdisziplin" (ref. 9), 287-89.

20 In her examination of a group of distinguished German-Jewish scientists Volkov found that "a considerable percentage of lower-class fathers" among medical students born before 1850. Volkov, "Jewish Scientists" (ref. 9), 229. Kampe showed that many Jewish students came from relatively poor families. Two third of all Jewish students chose Berlin (in 1887-88). In particular it was preferred among students from Posen, Norbert Kampe, "Jews and Antisemites At Universities in Imperial Germany (I) - Jewish Students: Social History and Social Conflict," *Leo Baeck Institute Yearbook* 30 (1985): 357-394, on 367-68, 393.

21 Heinrich Caro's interest in science originated in the Könlische Realgymnasium, Reinhardt and Travis, *Heinrich Caro* (ref. 17), 12.

22 As König showed, jobs in the industry were limited. A teaching career was quite common but since the prestigious Gymnasia taught little science the number of physics teachers was small.

year and a half to Heidelberg and return to Berlin. This kind of academic tour was common among German students, at least among those who considered a career in science. For a student of physics Heidelberg had the attraction of the renown scientist Hermann von Helmholtz (then in physiology), the physicist Gustav Kirchhoff (who became the professors for experimental and theoretical physics at Berlin university in 1871 and 1875 respectively) and the mathematician Königsberger. In 1869 Kirchhoff and Königsberger established a mathematical-physical seminar dedicated to exercise and independent work beyond the lectures, which increased the attraction of their university. Arguably, the seminars provided the best education in scientific research, both experimental and theoretical. Problems given in seminars, like the famous one of Franz Neumann, in Königsberg, where Kirchhoff had studied, led to quite a few doctorate dissertations. In summer 1870 Aron was a member of the mathematical and the physical divisions of the seminar and received premiums in both.²³

2. scientific research

Kirchhoff's teaching left a clear mark on Aron's early independent research. The student surely impressed Heidelberg's Professor of experimental physics, who supervised Aron's dissertation - "the equilibrium and motion of infinite thin arbitrarily curved elastic shell," although the latter returned to Berlin, where he submitted it in July 1873.²⁴ This mathematical study of elasticity followed Kirchhoff's 1858-9 theory of the motion of infinite thin bars, which was further elaborated to the case of plates by Franz Eduard Gehring in 1860 and Alfred Clebsch in 1862. Aron generalized the earlier essentially two-dimensional treatments to three dimensions. This work contributed to the highly mathematical discussion of elasticity and manifested competence in the field, but did not provide a new physical insight. In 1877, however, Aron contributed a note relating to physical interpretation of elasticity, still following Kirchhoff's works.²⁵ Elasticity was also the subject of Aron's last publications on pure science from 1883. There he showed how the elastic constants of all crystal classes can be derived from considerations of physical symmetry, and compared the results of a specific case with extant observational data. Once again Aron extended a method of Kirchhoff, which the latter applied to a subgroup. Further, in this research Aron proved himself a true member of Franz Neumann's school, to which Kirchhoff belonged. The experimental results that he used were attained by Gustav Baumgarten at Neumann's laboratory. More significantly, the so-called principle of symmetry, which he employed, was applied systematically only by members of Neumann's school (who also called it after their teacher). According to this principle the symmetry of the physical

23 I am grateful for Kathy Olesko for the information on Heidelberg's mathematical-physical seminar and Aron's part in it taken from Generallandesarchiv Karlsruhe 235/3228 (1824-1901). I thank Thomas Schraven for the information from the registry of Berlin university. For matriculation in Heidelberg see Hintzelmann and Toepke (ref. 15). Aron was enrolled in Heidelberg at the summer semesters of 1869 and 1870. It is unclear what he did in-between. On Neumann's physical seminar see Kathryn M. Olesko, *Physics as a Calling: Discipline and Practice in the Königsberg Seminar for Physics* (Ithaca, NY: Cornell University Press, 1991).

24 The files on Aron's dissertation including Kirchhoff's Helmholtz's and Kumer's letters are in Humboldt university archive UA,Phil.Fak Nr.247, 211-215.

25 Hermann Aron, "Das Gleichgewicht und die Bewegung einer unendlich dünnen, beliebig gekrümmten elastischen Schale," *Journal für die reine und angewandte Mathematik* 78 (1874): 136-174; On the earlier works see I. Todhunter and Karl Pearson, *A History of the Theory of Elasticity and of the Strength of Materials From Galilei to the Present Time*, vol. 2 "From Saint-venant to Lord Kelvin," part 2, (Cambridge: University press, 1893) 53-68, 154-162, 181-183. Hermann Aron, "Ueber einen das elastische Gleichgewicht betreffenden Satz," *Journal für die reine und angewandte Mathematik* 83 (1877): 184, this note discusses the number of independent elastic coefficients in isotropic body.

properties is not lower than that of the physical form. Such theoretical considerations about the relationship between form and physical properties and of different ways to deduce relations that are often already known characterize the approach of the school and seem very far from technological applications. Moreover, Neumann's school emphasised mathematical and experimental precision, far beyond the needs of industry. Exact measurements were, thus, more common at this school than explorative researches, which might lead to discovery of applicable effects. Many researches at this school concerned subjects far remote from industrial applications like elasticity and crystallography. This kind of study seems unlikely to lead to novel devices.²⁶

Nevertheless, Neumann's followers studied also subjects that could be more applicable to technology, like electromagnetism. Within electromagnetism the issue of unsteady currents (i.e. charging and discharging conductors) was apt to application, since it discussed, among other issues, telegraphic signalling. Kirchhoff had studied unsteady currents since 1857. In 1864 he elaborated a theory for condensers' discharge, a subject which Aron picked-up a decade later for his Habilitation paper (the writing submitted to the university to receive the right to teach) submitted in May 1876. No immediate aim seems to explain Aron's choice of the subject, but one can reconstruct a few attractions that it had for him. The subject provided opportunity for showing both mathematical competence, (this time coupled with physical interpretation) and for experimental expertise. The choice of the field probably followed Aron's interest in theories of electromagnetism, arguably the most exciting subject of the time, as manifested in his later research (on science and technology) and teaching.²⁷

The departure point of the habilitation was a linear rule between current, capacity and voltage in rapidly charging and discharging cables by a constant electric voltage that Werner Siemens established experimentally 19 years earlier. Here, the cables were assumed to behave like electric condensers. On general theoretical grounds Aron claimed that Siemens's rule cannot have universal validity.²⁸ Further, he mathematically deduced a solution for a few cases, which showed the conditions that allow the use of Siemens's rule and the condition for another relatively simple rule. Aron's deduction was based on a general equation of an electric circuit in terms of electric potentials, from which he deduced a second order differential equation on charge, as a function of (in later terms) self induction, time (and frequency), resistance and capacity, and the voltage differences. This equation led to a general complicated expression for the current from which Aron gained the particular solutions in the proper conditions. He verified experimentally both expressions, and

26 Hermann Aron, "Ueber die Herleitung der Krystallsysteme aus der Theorie der Elasticität," *AP* 20 (1883): 272-279; Hermann Aron, "Ueber die elastischen Eigenschaften der Krystalle," *Verhandlungen der Physikalischen Gesellschaft zu Berlin* (1883): 59-61. On the role of Neumann's school in the development and use of symmetry, Shaul Katzir, "The emergence of the principle of symmetry in physics," *Historical studies in the physical and biological sciences* 35 (2004): 35-66, on Aron's contribution and its context there, 51. On Neumann's school, Olesko, *Physics as a Calling* (ref. 23) passim and Shaul Katzir, *the Beginnings of Piezoelectricity: A Study in Mundane Physics* (Dordrecht: Springer, 2006) passim especially chapter 5. This apparent discordance between the research in Neumann's school and technology excited my interest in Aron's transit to technology.

27 Aron's technological research was almost entirely on electric devices. His teaching included courses "on the different forms of the electrodynamic fundamental laws" (first given at his second teaching year 1877/78) on other issues of electrodynamics, and other branches of mathematical physics. *Verzeichnis der Vorlesungen der Berlin Universität* of the appropriate dates.

28 Since Siemens's rule disregards influence of resistance, it can lead to the absurd result that the current with a condenser would be higher than the current through the same resistor without a condenser. Hermann Aron, "Zur Theorie der Condensatoren," *AP* 159 (1876): 587-601.

qualitatively examined a third case to which he did not provide a simple expression.

Aron's general equation for the electric circuit was similar to the equation that Oliver Heaviside employed to deduce 'the telegraph equation,' at the same years. However, Aron's question was very different from the issues that occupied the theoretical discussion of telegraphy and led eventually to the 'telegraph equation.' In particular Aron did not solve questions of propagation and retardation of an electric impulse along a cable, the core of the theory of telegraphic signals theory.²⁹ His results did not supply new tools for the design of telegraphic lines or their use, nor were they intended to be so. What his deduction did give is a theoretical justification for a rule used for simple cases, and specification of the conditions in which it is justified.³⁰ It connected Aron to a side issue of telegraphy that of capacity measurements. He explained that his mathematical conditions show that one should be cautious in the use of Fleeming Jenkin's method of capacity measurement, which assumed Siemens's rule.³¹

3. Academic career

Aron's academic career had begun before he submitted his dissertation. In April 1872 he became an assistant to Adolph Paalzow, the professor of physics at the *Gewerbeakademie* (academy of trade), which would be merged with the *Bauakademie* (academy of architecture) to form Berlin's *Technische Hochschule* in 1879. Paalzow was probably instrumental in securing Aron a teaching position in the *Vereinigte königliche Artillerie- und Ingenieurschule* (combined royal artillery and engineering school) after the latter was granted doctor degree in 1873.³² Aron continued teaching physics to cadet officers until his retirement in 1910. Although antisemitic attitudes were common in the military, apparently, Aron's religion was not a hindrance for hiring him to teach at this military school. The school provided two years of tertiary studies that included three to six annual hours of physics (mechanics, electricity and magnetism, heat, optics, etc.). The teaching of the courses was divided between two physics teachers. While Aron taught at the school, it introduced "instruction to experimentation" for small groups of artillery officers. These courses were probably given at the physical laboratory of the school, which was opened in 1876.³³ It is unclear whether Aron carried out

29 Aron did not examine a change of a signal with the distance. He does not have a variable for distance (and by that it is unlike the equations that Heaviside used). Thus, his theory is strictly valid only for one segment of a cable (he used only one condenser in his experiment). By examining average current and by the choice of special cases Aron avoided retardation in his solutions.

30 Yavetz suggested the term 'limited reference theory' for this kind of a solution of a general theory in specific conditions. He further suggests that such a theory is often developed for engineering use. Ido Yavetz, "Oliver Heaviside and the significance of the British electrical debate," *Annals of science* 50 (1993): 135-173, on 156-8. However, the structure of Aron's paper and the way the mathematical conditions are expressed (without explicit discussion of their physical significance) suggest that Aron did not aim at clarifying these conditions for an engineering audience. It seems that he was more interested in reconciling Siemens's experimental findings with electric theory.

31 On Jenkin's method see James C. Maxwell, *A Treatise on Electricity and Magnetism* (New York, NY: Dover Publications, 1954), vol 2. pp. 419-20. Aron knew it from Jenkin's original publication of 1867.

32 Paalzow taught at the combined school until 1873, so he probably recommended his fresh doctor assistant to replace him. A. Rubens, "A. Paalzow," *Verhandlungen der deutschen physikalischen Gesellschaft* 10 (1908): 451-462; Aron, vita (ref. 15).

33 The experimental courses resemble the idea of the physics seminar at the universities. It is plausible that the latter was a model for the new courses at the military school and that Aron was central in their design. These courses were introduced sometime between 1868 and 1889, probably around 1876 with

his own research at that laboratory.³⁴ The job at the combined school probably provided the physics teacher a salary about the average in education and much higher than the average income, but probably still too low to sustain a family at a middle class status. However, it was a substantial basis for adequately supporting such a family with an additional teaching like lecturing as a *Privatdozent*. As a bachelor, until 1881, it surely provided Aron's needs.³⁵

In the summer semester of 1877 Aron delivered his first course at the university. As customary it was open to the student free of charge, which means that the lecturer did not receive salary for teaching. He gave a similar course in the next semester and from the 1878 summer semester began to receive students' fees. Until 1890 Aron taught two to four weekly hours every semester. His courses were theoretical and mathematical, partly due to his interest and knowledge in the field and partly due to the needs of the physical institute. Experimental courses were taught mainly by the ordinary professor, in this case Helmholtz, who had access to the laboratory and demonstrating instruments. Aron taught a wide range of physical theories: electrodynamics, hydrodynamics, elasticity, optics, mechanical theory of heat and mathematical methods. Apparently Helmholtz and Kirchhoff, the two professors of physics of the university, had high esteem of Aron's teaching. In 1884 the faculty requested the Prussian minister of Culture to promote Aron to an extra ordinary professorship. The request praised Aron's teaching in the various branches of mathematical physics for a considerable number of listeners, and announced its present and future value for the faculty. Helmholtz's intention to reduce his teaching of theoretical physics would create a gap, which

among its affiliated *Privatdozenten* the faculty considers Dr. Aron as the most suitable to fill. The papers that he published must present the most significant basis for this judgment. Indeed these papers are not many and not of outstanding importance, but they show the direction and manner in which he

the building of the physical laboratory and after the 1874 decision to strengthen the instruction in the natural sciences and mathematics. Before that in 1868 (a year on which the curriculum is given) cadets studied physics only in their first year. It is also plausible that around that time the school hired Friedrich Neesen as a second teacher of physics. Like Aron, Neesen was also a *Privatdozent* at Berlin university (from 1875). Bernhard Poten, *Geschichte des Militär-Erziehungs- und Bildungswesens in den Landen deutscher Zunge*, vol. 4 "Preussen", (Berlin: Hofmann, 1896), 388-546, especially 388-89, 438-39, 446-49, 459, 461, 465-67, 546.

34 Goldstein ("Aus vergangenen Tagen," (ref. 8)) recalled that Aron worked in a laboratory at Dortheenstraße, where the physical institute of the university had its rooms, so he probably did not perform all his research at the combined school.

35 Paalzow, Aron's predecessor, earned at the combined school 500 Thaler (1500 Marks) annually in the 1860s. (Rubens,"Paalzow," (ref. 32), 455). Beef costed about 1.5 marks per kg, flour about 0.5 marks and oil about 0.4 marks in Berlin in 1872. Two years earlier the average annual income of workers in all industries and handicrafts (in Prussia) was 506 marks; employees in education received 1,306 marks, and white collar employees in industry 1,871 marks. The great majority of physicians in Berlin earned up to 3,000 marks per annum. Later salaries for ordinary and extraordinary professors in Berlin were 7411 and 2644 marks respectively (the highest in Germany). From 1884 a special fund gave *Privatdozenten* (probably only a few) 1500M per year for up to four years. Aron, thus, received from the military school a similar income over all the years. Volker R. Berghahn, *Imperial Germany, 1871-1914 economy, society, culture, and politics* (Providence: Berghahn Books, 1994), 8-9, 302, Lewis Pyenson, "Audacious Enterprise: The Einsteins and Electrotechnology in Late Nineteenth-century Munich," in *The Young Einstein: The Advent of Relativity*, (Bristol: Adam Hilger Ltd, 1985), 35-57, on 55-56 (n33), On the *Privatdozenten*, Busch, *Geschichte des Privatdozenten* (ref. 7), 113-14. "Ward-Devereux 1872/8, Several Cities" http://gpih.ucdavis.edu/files/Ward-Devereux_P_1872-78.xls.

works, and justify thereby the aforementioned conclusion.³⁶

It is plausible that Aron was advised to strengthen his publication portfolio towards his application, since he published two papers on his above-mentioned research on symmetry in elasticity in 1883. Other factors that might have stimulated these publications are his teaching of the subject, and Woldemar Voigt's 1882 different treatment of the same issue.³⁷

Nevertheless, the ministry rejected the request. One can only speculate about the reasons for the ministry's decision. No German university had more than two professors for physics (usually one of them extraordinary). So, the ministry might have objected granting a third position of physics. In addition, it might have objected to the theoretical character of Aron's publications (in physics) and teaching (still regarded as inferior to experimental physics, despite the faculty's needs). Antisemitic discrimination might have been another factor and additional ones can be suggested.³⁸ Whatever were the reasons, Aron had to be content with the title of a professor, without any practical implications, which he received in 1888. Six years later he was awarded the states' high honorary title of *Geheimer Regierungsrat* (usually translated as privy councillor), but he was probably granted that at least partly on his technological and industrial accomplishments. By 1894 he was fully immersed in industry, invention and improvement of technological devices. Already a decade earlier, when the faculty ask to promote him an extraordinary professor, technological questions occupied most of his research. In retrospect, 1884 seems as the crucial year in Aron's turn not only from science to technology but also from the academy to industry. Both transitions, which were intimately connected, were gradual, as Aron was not quick to cut his connection with the search of pure knowledge (in the cognitive realm) and with the community of physicists (in the social realm).

36 “. . . die Lücke, die dadurch entstehen würde, auszufüllen, hält die Fakultät unter den ihr angehörigen Privatdocenten Dr. Aron für den geeignetsten. Für dieses Urtheil mußten die Abhandlungen, die er veröffentlicht hat, die wesentlichste Grundlage bilden. Es sind allerdings diese Abhandlungen nicht groß an der Zahl und nicht von hervorragender Bedeutung, aber sie lassen die Richtung und die Art, in der er arbeitet, erkennen und berechtigen dadurch zu dem genannten Schlusse.” “Fakultät an Minister mit dem Gesuch von Aron um Berufung zum Extraordinarius,” 15.07.1884, Das Geheime Staatsarchiv Preußischer Kulturbesitz Berlin - Dahlem, Rep 76 Kultusmin., Va Sekt. 2 Tit. IV Nr. 47 Bd. 19, Bl. 247f. I thank Aleksandra Pawliczek for kindly providing me this document.

37 Aron taught theory of elasticity in the summer semester of 1880 and again in 1882, Katzir, "Emergence of Symmetry in Physics" (ref. 26), 50-51.

38 As the biggest university (by number of students), in 1889 Berlin was approved a third (extraordinary) professor for physics, but only for a partial position. Friedrich Neesen, who was appointed to the position, was not more distinguished a physicist than Aron. He was Aron's colleague both at the combined military school and at the university. Although he began teaching at the university two years before Aron, in 1884 the faculty considered Aron as more suitable for the job. The replacement of Helmholtz and Kirchhoff by Kundt and Planck in 1889, might have changed the faculty's priority regarding an additional professor. Neesen continued teaching the same amount of hours after his appointment (three-four weekly) and thus kept his job in the combined school. On Neesen *Verzeichnis der Vorlesungen der Berlin Universität 1875-1898*; *J. C. Poggendorff's biographisch-literarisches Handwörterbuch zur Geschichte der exakten Naturwissenschaften* (Ann Arbor, MI: J. W. Edwards, 1945) vol. 3, p. 959, vol 4, p. 1060. On the preference to theoretical physics and the establishment of a second chair in most German universities during the 1870s and 1880s, see Christa Jungnickel and Russell McCormach, *Intellectual Mastery of Nature: Theoretical Physics From Ohm to Einstein* (Chicago, IL: University of Chicago Press, 1986), vol. 2 esp. 33-41, 159-60.

4. research on technology

Aron's first publication on a technological device was a brief paper on the theory of microphones written in a short time in late 1878. It addressed the validity of Helmholtz's acoustic theory of hearing, which was put in doubt in the wake of the scientific interest in understanding the telephone (invented in 1876). Ludimar Hermann, a professor of physiology in Zurich and a former student of Emil du-Bois Reymond (a leading electro-physiologist, a professor in Berlin and a close associate of Helmholtz), claimed that his former teacher's analysis of the telephone in support of Helmholtz's theory of tone colour is erroneous, and that a proper examination shows that the basic assumption of the theory is invalid. Helmholtz was quick to answer Hermann with a fresh account of the telephone using his theory of sound. Aron joined the camp of his senior Berliner colleagues and complemented Helmholtz's treatment with a theoretical analysis of the telephone's microphone, which Helmholtz neglected.³⁹ His paper suggests a physical analysis of the microphone in the range useful for telephony, a condition which had concrete physical and consequently mathematical implications. Under these circumstances, Aron formulated an equation that relates the electric current in a microphone to the changes in its resistance due to its mechanical vibrations and to its electromagnetic properties. The bulk of the argument is the solution of the equation. It shows that the higher the tone the bigger the phase difference between the change in the electric current and resistance, and the lower is the amplitude (i.e. the strength of the signal). These effects are exactly opposite to effects of the earpiece as found by Helmholtz employing his theory of sound. So their combination gives a full compensation without change of phase or amplitude with the frequency of sound. While the subject matter of Aron's paper was technological, the issue that was at stake was not. The question was the validity of a physical theory, which should be applied to natural and artificial objects and their phenomena alike. Like his theory of condensers, two years earlier, Aron's analysis of the microphone was not aimed at helping in the design of instruments. Thus, it was not "engineering science" aimed at improving artifacts or methods, but part of the study of physical phenomena. The cognitive aspect of these researches was reflected in their social acceptance as contributions to physics by their publication in the *Annalen der Physik*, the major organ of German physics.

While these works showed an intellectual interest in technology and in its implication on current theories of physics and physiology, in 1880 for the first time Aron offered a research with implication for the technological design. He examined the risk in using over-ground and underground telegraphic cables in powder magazines from atmospheric electricity, either by lightning or by electric tension. Unlike, Aron's earlier paper, this one did not include any mathematical deduction. Instead the author examined the question by an experiment on a model of telegraphic cables and their insulators. The experimental procedure included an attempt to detect a feeble electric current for which Aron used the older technique of a frog's leg and the new telephone's earpiece.⁴⁰ He showed that in some

39 Ludimar Hermann, "Notiz über das Telephon," *Archiv für die gesammte Physiologie* 16 (1878): 264-265; id., "Ueber telephonisches Hören mit mehrfachen eingeschobenen Inductionen," *ibid.*: 314-316, Hermann Helmholtz, "Telephon und Klangfarbe," *AP* 5 (1878): 448-460; Hermann Aron, "Zur Theorie des Mikrophons," *AP* 6 (1879): 403-407. Since 1867, when Hermann directly criticized du Bois-Reymond's theory of electricity in muscles the teacher and the student "never saw eye to eye." The older controversy, which did not resolve until after du Bois-Reymond's death, probably gave further stimulation to this one on acoustics, Gabriel Finkelstein, "Emil du Bois-Reymond vs Ludimar Hermann," *Comptes Rendus Biologies* 329 (2006): 340-347.

40 In this case Aron, like many experimentalists, used the technology of the telephone for his needs, but did not contribute to its improvement or understanding. John Victor Wietlisbach, a student of Helmholtz, used the telephone with a Wheatstone bridge in a similar manner in 1879, Kline, *Steinmetz* (ref.

conditions atmospheric electricity influenced his model underground cables and thus can affect telegraphic underground cables. Yet comparing his results with insulators in use, he concluded that they are sufficient to prevent the effect, except for the effect of direct lightning, for which a regular lightning rod is sufficient. This is a practical result, which could be implemented in the planning of a telegraphic line near a powder magazine. The immediate context for this research can be found in the combined military school in which Aron taught. Beyond the apparent interest of engineering-officers in the use of telegraphy, the experimental course at the institution gave Aron a direct stimulation to study the issue as they included inspection of telegraphic equipment. Neesen, Aron's colleague, also published on technological questions related to interests of the military school.⁴¹

The technological content of Aron's research on cables was reflected also in the audience that he chose. He published its results in a journal on technology, rather than in a physical or mathematical journal in which he had previously published.⁴² The *Elektrotechnische Zeitschrift*, in which Aron published, was the organ of the *Elektrotechnische Verein* (association for electrical technology) founded in December 1879. Aron was an active founding member of the association: its first secretary from 1882 to 1884, an active lecturer and a member of the its first two inspection committees.⁴³ Among the 36 founding members of the association six were lecturers at the universities and *Technische Hochschulen* (among them Kirchhoff and Paalzow); two others taught at military schools; the larger group belonged to the civil services: 16 from post, i.e. telegraphy,

4), 78. In his 1880 physics textbook Kohlrausch described such a technique for measuring electrolytic conductivity, David Cahan, "Kohlrausch and Electrolytic Conductivity," *Osiris* 5 (1989): 166-185, on 182. The use of frogs' legs at that time was probably more common among physiologists than physicists. Aron might have learnt the technique at the laboratory of du Bois-Reymond, where it was still in use. Sven Dierig, "Urbanization, Place of Experiment and How the Electric Fish Was Caught by Emil du Bois-Reymond," *Journal of the History of the Neurosciences* 9 (2000): 5-13, on 7-8. On Aron's connection with du Bois Reymond see below note 48.

41 Hermann Aron, "Zur Frage der Influenz der Kabel durch atmosphärische Elektrizität und der Gefährlichkeit ihrer Einleitung in Pulvermagazine," *ETZ* 1 (1880): 94-97. These researches are modest in comparison with the technological studies of scientists during World War I, not to compare with the second war and its aftermath, but they testify to the influence of the connection between scientists and the military establishment. This was neither new nor confined to Germany. The British *Journal of the Society of Telegraph Engineers* published a summary of Aron's paper (9 (1880): 195). The record on the school's experimental course "facilitated through inspection of the telegraphic equipment of the state printing shop" is from 1889, but it is plausible it began at the late 1870s, Poter, *Geschichte des Militär-Erziehungs- und Bildungswesens* (ref. 33), 461. Neesen published two papers on ballistics in the military engineering journal, *Poggendorff's biographisch-literarisches Handwörterbuch* (ref. 38), vol. 4, p. 1060.

42 The journal in which Aron chose to publish was a new one and the first devoted to electric technology in German, but older technical journals like Dingler's *polytechnisches Journal* published among others articles on electrical technology.

43 The list of founders in *ETZ* 1(1880), 3. Aron was appointed first secretary in January 1882, when he replaced his colleague Neesen (who, however, was not a founding member) and signed the reports of the association until November 1884 (in 1884 there was no distinction between first and second secretary), *ETZ* from 1882 to 1884 especially 3 (1882), 51 and 5 (1884), 51. Aron gave four lectures in the first five years of the association and published five papers in its journal. The lectures review the current stage of the art in addition to a description of Aron's own contribution. After 1884 he continued lecturing and publishing but infrequently. He was a member of the committee on ground current established in 1881 (with nine members), and one on protection from lightning from 1885 (with eleven members). Emil Naglo, *Die ersten 25 Jahre des Elektrotechnischen Vereins* (Berlin: Hermann, 1904), 58-64.

military and railroads departments; and twelve were from industry. This combination of science and technology, scholars and industrialists, technicians and officials was central for the *Elektrotechnische Verein*, “whose task is the cultivation of the whole field of electric technology (*Elektrotechnik*) in its scientific research as well as in its practical application.”⁴⁴ The founders saw the association as a meeting place that would encourage: electrical engineers to advance their scientific, technical and commercial interests, the application of electricity for the improvement of daily life, and the utilization of technology for the advancement of science. So, they regarded the union between science, technology and industry as a powerful strategy for the advancement of the three. The relations that they prescribed, however, were not symmetrical. Science was the source of knowledge, while technology only provided the former equipment and experience. No commercial influence on science was considered (unlike the case for technology). Their view that scientific knowledge can be instructive for technology, and that helping technologist is an object of scientists was the dominant one at the time,⁴⁵ and it influenced Aron’s career.

As the list of founders testifies, the purposed link between science, technology, industry and government had a concrete personal dimension in the relations between practitioners from the different realms. Werner Siemens was in particular instrumental in the establishment of the *Elektrotechnische Verein*. Siemens himself embodied the ideal: an inventor who became a highly successful industrialist, who also contributed to the scientific study of questions related to technologies that he used. Like a considerable share of the association’s members especially among the active ones (including Aron), Siemens was active also in Berlin’s physical society. Most of the active participants of dual membership came, unlike Siemens, from the academia. Physicists were prominent among them, testifying for the interest in the new electric technology and its development among members of the discipline.⁴⁶ Thus, the association both promoted and presented a vivid

44 K. Ed. Zetzsche, “Unser Ziel,” *ETZ* 1 (1880), 1-2, on 1. The manifesto puts this comprehensive attitude against that of societies in “other countries,” which are confined to technological application. A nationalistic overtone is evident in the short declaration, which ends with the announcement that the advancement of science and technology (*Technik*) would contribute to “the well being of the fatherland and the to glory of the German name” (p. 2). Although the aim of bringing science and industry together was expressed by societies in “other countries,” e.g. the British Association for the Advancement of Science, it is true that other societies devoted for electricity were dedicated to technological applications, even if they thought that science is essential to technological progress, and sought the participation of scientists, e.g. the British Society for Telegraphic Engineers W. J. Reader, “‘The Engineer Must Be a Scientific Man,’: The Origins of the Society of Telegraph Engineers,” *History of Technology* 13 (1991), 112-118; Jack Morrell and Arnold Thackray, *Gentlemen of Science: Early Years of the British Association for the Advancement of Science*, Oxford: Clarendon Press, 1981, pp.256-66.

45 The view that scientific knowledge can lead to novel useful artifacts and processes was very old, at least since the seventeenth century. This view was translated into concrete endeavours at late eighteenth century France and consequently in other parts of the West. In particular circa 1880 electric technology was regarded as apt to benefit from theoretical knowledge; Robert Fox and Anna Guagnini, *Laboratories, Workshops and Sites: Concepts and Practices of Applied Research in Industrial Europe, 1800-1914* (Berkeley CA: Office for the History of Science and Technology, University of California, 1999), chapters 1, and 4.

46 Among the eleven persons of dual membership that gave more than two lectures in the years 1880-82, nine were associate with an institute of high learning (yet one of them Brix was also the head engineer of the imperial telegraph ministry). The only exception, apart of Siemens himself, was his employee and holder of PhD in physics Oskar Frölich. These participants contributed 31 of the 68 lectures in the *Elektrotechnische Verein*. On the link between the societies see Horst Kant, "Zu einigen Aktivitäten

network of teachers of physics and engineers, inventors, practising engineers and industrialists. Its location in Berlin was not accidental. Berlin was not only the political capital of Germany (and thus the seat of governmental ministries) but also a centre of high education (partly due to a deliberate effort) and an industrial centre with an electric industry. This combination of strong industry and research in the natural sciences was rare, especially with such strong communities of natural scientists, engineers and industrialists.⁴⁷ Through his functions at the association, and probably through many unofficial channels Aron was in contact with leading engineers and industrialists. Werner Siemens was an acquaintance since 1880 at the latest. Yet, most of the scant remarks on Aron's personal connection point at scientists. In addition to Kirchhoff, Paalzow and other physics teachers in Berlin, Aron was in scientific contact with Emil du Bois Reymond, who had strong interest in electricity. Aron collaborated also with junior scientists, like himself, among them the physicist Eugen Goldstein (a student of Helmholtz, who studied 'cathode rays' (electrons) and discovered 'canal rays' (positive rays) in 1886), the polymath chemist, physicist, philosopher and scholar of Goethe's scientific writings Salomon Kalischer, and the physician and physiologist Erwin Herter.⁴⁸

In the early 1880s with his activity at the *Elektrotechnische Verein*, Aron conducted research aimed at improving technology. The study of the danger of telegraph cables was followed by a long term research on storage batteries (accumulators), which can be divided into three kinds: a) an attempt to produce an improved battery, i.e. an invention, b) a study of the mechanism of the batteries and the causes of their deterioration, c) development of general criteria to compare efficiency of batteries regardless of their mechanism. These researches could have been conducted independently of each other, as some other researchers did. Yet, the link between them is obvious, and Aron partly employed his understanding of the mechanism in inventing a new battery. Aron presented results of the first and second kinds of research with basic elements of the third together. This connection between different kinds of knowledge and the construction of new devices reflects the aim of the

von Physikern im Berliner Elektrotechnischen Verein zwischen 1880 und 1890," in *Wissenschaft und Technik - Humanismus und Fortschritt (XVI. Internationaler Kongreß für Wissenschaftsgeschichte)*. Kolloquienheft Nr.22 des ITW der AdW der DDR, (Berlin, 1981), 59-63 (on the lectures on 61); id., "Werner Siemens und sein Wirken im Berliner Elektrotechnischen Verein sowie in der Preußischen Akademie der Wissenschaften," in *Werner von Siemens. Studien zu Leben und Werk* (= PTB-Texte Bd.2), ed. D. Hoffmann and W. Schreier (Brunswick, 1995), 117-134.

47 Bernal mentioned six European university cities that had strong industry: Glasgow, London, Copenhagen, St. Petersburg, Moscow and Berlin. Among these London and Berlin had clearly the largest scientific community. Wolfgang Girnus, "Zwischen Reichsgründung and Jahrhundertwende 1870-1900," in *Wissenschaft in Berlin: Vor den Anfängen bis zum Neubeginn nach 1945*, ed. Hubert Laitko (Berlin: Dietz Verlag, 1987), 174-304, on 228-253.

48 Aron mentioned a conversation with Siemens in 1880, Aron, "Influenz der Kabel" (ref. 41), 96. In 1874 du Bois Reymond mentioned an unpublished research of Aron on the astatic deviation of magnetic needles, Emil du Bois-Reymond, "Ueber aperiodische Bewegung gedämpfter Magnete, Vierte Abhandlung," in *Gesammelte Abhandlungen zur allgemeinen Muskel- und Nervenphysik*, (Leipzig: Veit & Comp., 1875), 368-388, on 382. He later lent Aron a commutator for the latter habilitation project, Aron, "Condensatoren" (ref. 28), 587. Kalischer commented on Aron's work on secondary battery in its early phases. Herter provided Aron his laboratory for measuring specific weights, in the same research. Hermann Aron, "Theorie der Akkumulatoren und Erfahrungen mit denselben," *ETZ* 4 (1883): 58-60,-100-107, on 59, 106. Goldstein recalls his periodical visits in Aron's small laboratory. Around 1884 he used Aron's storage batteries, which were not produced commercially, Goldstein, "Aus vergangenen Tagen,"(ref. 8); id., "Ueber elektrische Leitung im Vacuum," *AP* 24 (1885): 79-92, on 85.

The common storage battery of the time was the invention of the French industrial Chemist Gaston Planté, originally in 1859. Planté chose lead for both electrodes of the battery and sulphuric acid (H₂SO₄) electrolyte (a principle still in use in current car batteries). Aron identified two shortcomings of this battery, which he wished to repair. First, Planté's electric process of "formation" of the battery before its first use was tedious and time consuming. Second, the capacity of the accumulator was very low and was diminishing with time.⁴⁹ Aron, thus, searched for a simpler and quicker formation method that would result in a lead-acid battery of higher capacity. For this end he examined the use of porous lead plates, and the pasting of minium (red lead Pb₃O₄) on the cathodes, without much success. Meanwhile, Camille Faure in France applied minium successfully. Unlike Faure, Aron found that the minium is solved in the acid and loses its effect. To get over the latter problem, Aron employed a paste of collodion (nitrated cellulose) on the plates.⁵⁰ Since collodion is an insulator, he mixed it with metal oxide, in this case lead oxide. In June 1882 Aron filed a patent on the use of metallic collodion in storage batteries and to refresh the cathodes in primary elements (batteries of the first kind).⁵¹

In developing the metallic-collodion technique, Aron systematically analysed the battery employing chemical knowledge to interpret his observations (for example of a gray material which he identified as lead oxide (PbO) that impedes the desired electric process). Similar considerations led him to examine an alternative technique.⁵² Yet, overall his search was a kind of trial (though instructive) and error. This approach is evident in Aron's description of his crucial decision to examine the use of the insulator collodion: "However, when Faure came out with his work, I thought, if so much goes, why shouldn't this go [*wenn so Vieles geht warum sollte auch nicht gehen*], and I tried again with collodion."⁵³ Beyond the question of method, the aim of the research was technological in a most direct sense - the design of a device and method, in this case of a more efficient storage battery. What was as an efficient battery could not be defined by a scientific understanding of its mechanism but from its supposed functions in contemporary technologies, and so society. For Planté capacity was of secondary importance as he designed the battery as a current convertor for the needs of telegraphy. The development of the dynamo, the electric motor and incandescent lamp in the 1870s, made the storage of electric energy desirable. From about 1880 developers of the battery, therefore, view it as an electric storage device, and judged its efficiency according to this function. Capacity became central in determining the batteries' efficiency.

Aron began original study of the storage battery only when he was already in the midst of exploring

49 On Planté's work and motivation, Richard H. Schallenberg, *Bottled Energy: Electrical Engineering and the Evolution of Chemical Energy Storage* (Philadelphia, PA: American Philosophical Society, 1982), 24-46.

50 The aim of these methods was to enlarge the operational surface of the plates as the capacity is proportional to it. Materials that hang to the surface block the lead and its useful products on the plates from taking part in the chemical reactions of charging and discharging.

51 Aron, "Theorie der Akkumulatoren," (ref. 48) (first part); Hermann Aron, "Herstellung eines neuen Stoffes aus Metall und Cellulose für elektrotechnische Zwecke," German patent DE21957, filed 22-6-1882, issued 1883.

52 Kalischer informed Aron that etching forms a crystalline layer in materials, so Aron tried to chemically etch the lead electrode using nitric acid, and than to remove it by oxidizer. This attempt led to a useful technique, whose results, however, were inferior to the metal-collodion technique. Aron, "Theorie der Akkumulatoren," (ref. 48), 59-60.

53 Ibid., 59.

methods to construct a more useful battery. Earlier he reviewed and compiled the knowledge in the field. In such a synthesis of earlier results, he inferred that batteries would be too heavy to operate an electric tram.⁵⁴ His original analysis of the lead-acid battery followed the study of its chemistry by John Gladstone and Alfred Tribe, which just appeared in print. The two British chemists divided the basic chemical reaction of the accumulator to sub- and by-processes, and explained Faure's formation process. While they examined the battery by a chemical method (identifying a few byproducts), Aron suggested a physical examination, in which he inferred the consumption of a chemical ingredient from decrease in the solution's specific weight.⁵⁵ He further supported his conclusion by measurements of the heat that evolves in the plate, drawing conclusions from Julius Thomsen's thermo-chemical theory and data.⁵⁶ Yet he applied also chemical techniques similar to those of Gladstone and Tribe. By such a method he inferred that oxygen is absorbed in the plate before discharge and so it increases the initial discharge voltage. This observation had immediate implications for the design, as it showed that the positive plate should not be covered in any way, as inventors like Faure and Aron himself had done. So, at least partly the study of the lead-acid process was viewed as a means for providing information for improving battery's design. Gladstone and Tribe also applied conclusions from their research to "make one or two suggestions in regard to the economic aspects of [the forming of a good secondary battery.]"⁵⁷

Another part of Aron's investigation was a measurement of the efficiency of the lead-acid accumulators and its decrease with recharging. One object of this research was to find whether the cathode or anode first loses its activity, (by mixing new and used electrodes). A connected object was to identify reasons for the sharp decrease in its performance. Estimating the efficiency of the accumulators to possible uses was another aim. However, Wilhelm Hallwachs claimed that Aron's definition of efficiency in terms of charge is inadequate. In his own research, which he submitted as his dissertation in physics in Strasbourg in 1883, Hallwachs carried out a more complex experiment to measure the physical work (i.e. the multiplication of the charge square by the resistance) needed for charging the accumulator and the work (i.e. energy) that it produced. Apparently, Hallwachs's critique stimulated further work of Aron on the subject. The latter adopted his opponent's principal claim and elaborated the concept of efficiency by dividing it into four levels (where the charge and electrical energy are the first two), useful for comparing different storage batteries and settings.⁵⁸

54 Aron examined an example of specific law velocity (10 km/h) and concluded from the failure of a tram at that velocity to the impracticability of any tram on battery. As he later realized his assumption about the weight to capacity ratio of batteries were too pessimistic. Aron, *ibid* and Hermann Aron, "Die sekundären Elemente und ihre Anwendung," *ETZ* 3 (1882): 222-228, the calculation on 227-28.

55 In this way Aron supported the assumption of Gladstone and Tribe that lead-sulphate (PbSO_4) is formed in the process. John Gladstone and Alfred Tribe, "The Chemistry of the Planté and Faure Accumulators," *Nature* 25 (1882): 221-23, 461-463, Aron "Theorie der Akkumulatoren," (ref. 48), 101-102.

56 Aron displayed command of novel theoretical approaches. He remarked that Helmholtz novel thermodynamic theory of free energy of chemical reactions agrees in cases like this with the claims of the earlier thermochemistry. This suggests a closer connection between Helmholtz's thermodynamics and the older thermochemistry than some of the former's partisans (like Pierre Duhem) claimed. Aron, *ibid.*, 102, on the relation between the two see R. G. A. Dolby, "Thermochemistry Versus Thermodynamics: the Nineteenth Century Controversy," *History of Science* 22 (1984): 374-400.

57 Gladstone and Tribe, "Platé and Faure" (ref. 55), 463.

58 In his more detailed experiment Hallwachs examined the influence of variables like the batteries' inner resistance, the manner in which they were charge and discharge etc. Still his examination was on the external physical operation of the battery, taken as "a black box," without an effort to probe into its inner

At those years Aron worked in “a small laboratory in a rear building,” probably connected to the physical institute of the university. Eugen Goldstein recalled that “when I asked him in intervals of 8 or 14 days how far his particular research is advancing, then he gave me the regular answer, ‘This does not interest me at all anymore [*Das interessiert mich gar nicht mehr*], now I pursue a totally different idea.’ But this new beautiful idea had again only very short lifespan, and its fruits did not reach publication.” Among the ideas that did not reach publication, Goldstein mentioned an attempt at wireless telegraphy on the Wannsee lake, which other dated to 1883.⁵⁹ Yet, Goldstein somewhat exaggerated. A few ideas (like the batteries) attracted him for more than two weeks; a few of his researches did lead to publication, like one on the artificial production of graphite (or a similar state of carbon) with high durability in high temperatures for use in incandescence lamps (then of carbon filament). He reported about that in May 1883 between his papers on the storage batteries. This research, like the use of a new paste for batteries and the endeavours mentioned by Goldstein were directed at improving (or inventing) specific technologies for general use (rather than one restricted to the laboratory). The year 1883 was fruitful for Aron: he published analysis and theory of technology (storage batteries), suggestions for improving technology (batteries and incandescence lamps) and scientific papers on symmetry in elasticity. His scientific teaching gained respect at the university and his research and suggestions on technology were discussed at home and abroad.⁶⁰ However, his ideas did not prove of value in practice. In November 1884 we could hope that, unlike his previous ideas, his “new work will luckily pass this difficult challenge.” Aron’s new work was the electric meter, on which he had been working since October 1883 in a new laboratory, opened for its development.⁶¹

process. Aron stayed at this level in elaborating concepts of efficiency, although earlier he explored the mechanism of the device. Aron and Hallwachs continued to argue on insignificant points. Wilhelm Hallwachs, “Über die elektromotorische Kraft, den Widerstand und den Nutzeffekt von Ladungssäulen (Akkumulatoren),” *ETZ* 4 (1883): 200-208; id., “Bemerkung über die Berechnung des Nutzeffektes von Ladungssäulen,” *ETZ* 4 (1883): 301-302; Hermann Aron, “Zur Berechnung des Nutzeffektes von Akkumulatoren,” *ETZ* 4 (1883): 342-344.

59 Goldstein, “Aus vergangenen Tagen,” (ref. 8), 40. Earlier mentions of Aron’s attempt of wireless communication suggested fewer technical details, so Goldstein probably did not rely on them. Gottschalk, “H. Aron,” *ETZ* 34 (1913): 1047-1048; J. W. Fr. Hofmann, “Geh. Reg.-Rat Prof. Dr. Hermann Aron,” *Elektrotechnik und Maschinenbau* (1913): 797-800, on 798. Aron’s laboratory was near the physical institute of the university in Dortheenstraße. Goldstein claims that Aron was also the “first discoverer of the gas incandescent mantle,” which enabled a hotter gas flame and thus a brighter and whiter light from gas lamps. Its discovery is usually attributed to Carl Auer von Welsbach’s work beginning in 1885. Unfortunately, no other source supports Goldstein claim. If indeed Aron worked on the subject, it was probably connected to his study of graphite, with a similar aim of finding materials indestructible in high temperatures. He continued to be interested in related questions later, as shown by his patent Hermann Aron and Arthur Geiger, “Improved Method of Decarbonizing Filaments for Electric Metallic-filament Lamps,” British patent GB190815079 1908-10-22 (application 16.7.1908).

60 Hermann Aron, “Ueber künstlichen Graphit,” *ETZ* 4 (1883): 248-249. The French *La Lumière électrique* gave long reports on Aron’s publications. Aron’s main communication which described his own invention was published also at the Journal of Berlin’s physical society and at the *Journal of the Society of Telegraph Engineers and Electricians* (London). Aron’s research was also discussed in books and papers on the subject such as Edmund Hoppe, *Die Akkumulatoren für Elektrizität* (Berlin: Springer, 1888) 118, 150-54, 2nd edition (1892): 182-83, 187-90; Frank Gerald, “Sur un essai de locomotion par l’emploi des accumulateurs,” *La Lumière électrique* 9 (1883): 422-425 and later (more critically) Franz Streintz and G. Neumann, “Beiträge zur Theorie des Secundärelementes,” *AP* 41 (1890): 97-112.

61 Hermann Aron, “Ueber einen neuen Elektrizitätszähler,” *ETZ* 5 (1884): 480-489, on 489.

5. The electricity meter

5a. the device

Like many good ideas the principle behind Aron's electricity meter was quite simple. He took the pendulum clock, the most exact meter (of time) and modified it to measure electric charge and energy. The period of a pendulum depends on the force applied on its bob. A variation in the force would lead to a predictable change in the period of the pendulum and consequently in the movement of the clock's mechanism. Aron decided to exercise variations by a magnetic force produced by the electric current in the circuit. A coil below the bob (A in fig. 1) became an electromagnet by the passage of a current through it. The coil was connected to the system whose consumption of charge it measured. When a current passes through it, the coil exerted a magnetic force on a permanent magnet (M in fig. 1) that replaced the regular pendulum's bob. The consequence change in the period of the pendulum and therefore in the retardation or advance of the clock's dials is approximately proportional to the electric charge (multiplication of a current by time) that went through the coil.⁶² One then is left to compare the reading of the modified clock with that of a regular clock, to determine the amount of charge consumed. In an advanced model the two clocks were connected by a differential gear that showed directly the charge consumption (fig. 2). By replacing the permanent magnet in the bob with another coil connected to the measured circuit, the same principle can be used to register the electric

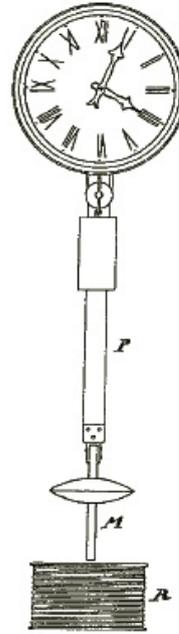


Figure 1 : A simple pendulum clock meter, whose pace is changed in proportion to the total current that passed through the coil A. M is a permanent magnet. (source Aron (ref. 64))

62 The duration of one swing of a pendulum (i.e. half a period) T under gravitational force alone is:

$$T = \pi \sqrt{\frac{M}{PL}}, \text{ where } M \text{ is the moment of inertia, } P \text{ the weight and } L \text{ the distance between the axis and}$$

centre of mass. The number of oscillations n at a time t is therefore $n = \frac{t}{\pi} \sqrt{\frac{PL}{M}}$. When a magnetic

force is applied on the pendulum by a current J in the coil, the period changes to:

$$T' = \pi \sqrt{\frac{M}{PL + aH \cdot J}}, \text{ where } H \text{ is the magnetic moment of the pendulum's magnet and } a \text{ is a}$$

constant of the device (depended on the coil and its relation with the magnet). N the number of oscillations

under a current is: $N = \frac{t}{\pi} \sqrt{\frac{PL + aH \cdot J}{M}}$, with simple algebra this becomes: $N = n(1 + \frac{J}{C})^{1/2}$

where $\frac{1}{C} = \frac{aH}{PL}$ this lead in the first order approximation to $Q = nJ = 2C(N - n)$, where Q is the total charge that passed through the coil. Ibid., 484.

energy consumed by the system.

The details, however, were not as simple as the principles. While the change in the number of pendulum vibration is approximately proportional to the charge, Aron's more exact mathematical analysis showed that in some cases it leads to a diversion of 2.5% between the calculation from the modified clock and the actual consumption.⁶³ Aron thought that this error made the meter impractical. Consequently for a few months he occupied himself in its correction. He sought for a secondary effect that would compensate for the diversion from the linear relation. One possibility was to use a temporary magnet, i.e. an object that becomes a magnet in the presence of a magnetic force but loses it immediately after the force is removed. The electromagnetic coil would induce such a temporary magnetism in proportion with the strength of a current, so the magnetic effect would be of second order, as needed. Yet, his initial attempts to add a small soft iron horseshoe led to results opposite to those desired. Dropping the iron did not help either, as the meter continued to have an error in a direction opposite to the one predicted by theory. Aron tried other means but to no avail. Then he "accidentally found out" that the steel magnet in the bob was not hard enough. He replaced the magnet to one of a harder steel and found that "the temporary magnetism of this very hard steel is exactly adequate to produce uniformity [*Gleichmässigkeit*], better of which I could not wish [*wie ich sie nicht besser wünschen konnte*]." In his laboratory's test, results of which he cited in the publication, the precision was of 2 to 1000, when the meter was used for a relatively wide range (1:24 between minimum and maximum current). In other words, Aron found that the theory was inadequate since it considered only permanent magnetism. Fortunately to his technological aims, the induced temporary magnetism (not considered by the theory) exactly compensated the difference between the theory and the linear rule required for the usefulness of the electricity meter.⁶⁴

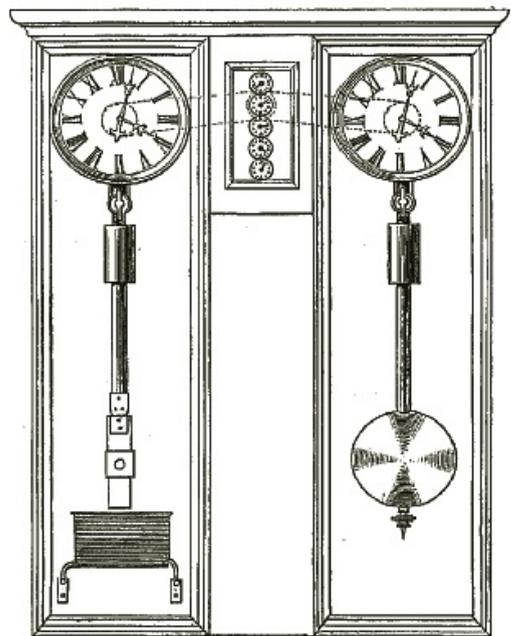


Figure 2: A pendulum meter with differential mechanism. The right pendulum is a normal clock, The left is modified by the electric current (source, Aron (ref. 61)).

63 The second approximation (second order Taylor series) gives: $N = n(1 + \frac{J}{2C} - \frac{j^2}{8C^2})$, which leads to $2C(N - n) = Q(1 - \frac{J}{4C})$. So the diversion from the linear rule is $J/4C$. Although C can be

modified according to the current one wants to measure, it cannot be too large, since at that case the meter would not be sensitive enough in low currents. Aron found that for a desirable range (1 to 24 in current) the diversion is of 2.5%. Ibid., 484-5.

64 Ibid., Aron described his effort and success to reach precision in this paper, which is based on a lecture from November 1884. Interestingly in the patent, which he filed on June 15th, he mentioned only the first order (linear) approximation, without a clue to its limits. Hermann Aron, "Elektricitäts-Zähler," German patent DE30207, filed 15-6-1884, issued 1885. However, Aron had probably already worked on this problem then, since he said he had worked on the problem for a long time, and by the end of July he had a precise instrument (he mentioned measurements from that date at the lecture).

Aron detected the initial error of his meters theoretically by rigorously applying the known laws of the mutual action of permanent and electromagnets. Thus, articulated scientific knowledge led to a search for a correcting effect. Physical theory could also suggest the kind of an effect sought. However, scientific theory was hardly instructive in finding the means to produce the desired temporary magnetic force. The solution was specific for a particular design. In order to reach it, Aron had to return to trial and error method. He could not rely on theory in determining the exact design of new models, which differ in particularities of magnet design.⁶⁵ This is a good example of the interplay between theory and practice and the benefit of their combination in such knowledge-based technologies. The theory was needed to point out the problem, the practice for its particular solutions.⁶⁶ Aron's trial and error search was common in technological design. As often in design, it consumed much time and efforts. Still such a pursuit was not completely remote from the practice of the physical laboratory, where one often works hard to improve one's apparatus or locate a problem.⁶⁷

So, in November 1884 after a year of development Aron presented new precise electricity meters for both current and energy to his colleagues in the Electro-technology association. As he said in concluding his lecture, the future of his invention was unclear. Its high precision and wide range of current strengths, as well as the relative simplicity of its use and the clarity of its reading (at least in the differential mechanism models) were clear advantages, which eventually led to its success. Indeed, Aron's meter won experts' attention and approval. For example, the French journal *Lumière électrique* described Aron's meter twice within two months. Excusing the duplication, the reporter referred to a major reason that Aron had for optimism. "Indeed," he wrote, "given the rapid development of the electric industry and its applications, which multiple from day to day, the question of an electricity meter . . . is of extreme importance from a practical point of view."⁶⁸ Public electric distribution to home and business in the cities had just begun. With the development of the electric incandescence light bulb, and the system of generation and distribution of electricity needed for its successful introduction, from 1882 public central stations were constructed all over Northern America and Western-central Europe. These electrical systems needed a convenient and reliable electricity meters for charging customers according to their consumption, (other method of charging,

65 In the electric-energy-meter (watt-meter) the static electromagnetic coil should encircle the pendulum's bob, and iron is put inside the pendulum's coil (*ibid.*, 486-7). Later models had different designs like two magnets in a U shape in the pendulum (in meters from 1897 and ca. 1900). I thank Thomas Schraven for the information on these meters which he personally inspected (personal communication 22.1.08).

66 A similar combination, albeit by two persons, was helpful in the historical reconstruction of Aron's work. See appendix 1.

67 E.g. after a second examination Eduard Riecke and Voigt found that shellac on their condenser was responsible for the discrepancy between their measurements of piezoelectric constants and those of the Curies, Katzir, *Beginnings of Piezoelectricity* (ref. 17), 195.

68 B. Marinovitch, "A propos d'un nouveau compteur d'électricité," *La Lumière électrique* 15 (1885): 83-90, quote on 83, a previous description in Hugo Michaelis, "Chronique de l'étranger - Allemagne," *La Lumière électrique* 14 (1884): 219-221, on 220. Other examples: in a series of articles on electricity meters in 1888, Hospitalier in France found Aron's charge meter "a very simple and highly practical instrument" (p. 391) while the energy meter "is certainly the simplest watt-hour-meter currently known," (p. 454), E. Hospitalier, "Les compteurs d'énergie électrique," *l'électricien* 12 (1888): 273-276, 289-293, 307-311, 328-330, 340-343, 360-363, 390-393, 403-408, 418-425, 450-454, 469-471, 498-504, 551-554. While suggesting his own electricity meter in 1887, Siemens considered Aron's as the only current good system to measure electric consumption, Werner Siemens, "Ueber Elektrizitätsmesser für Stromlieferungs-Anlagen," *ETZ* 8 (1887): 269-271.

e.g. flat rates, were considered problematic by consumers and companies alike).⁶⁹ Contemporary meters, however, did not satisfy many. They had problems of precision, reliability, range of current measured etc. Probably the most exact device before Aron's was of Edison. Yet, Edison's electrolytic meter could not be read on the site. A company technician had to take its electrode to the station where its weight was measured. It is no wonder that this opaque and costly process was not popular by customers and electric suppliers.⁷⁰

Notwithstanding the potential of Aron's invention, at late 1884 a few obstacles could lay along the way to commercial success. A working prototype is not yet a workable commercial device. The meter had not been examined in practice. Industrial production of the device (even by artisans, let alone in a factory) hides its own potential problems that may harm the function of an instrument (especially a delicate one like the meter with its sensitivity to the material used). Due to its special function the meter had to be protected against attempts to manually change its reading. The device had also disadvantages in comparison to other suggestion. Its price was probably the gravest. Since Aron's meter consisted two pendulum clock mechanisms plus an electromagnetic part, it was relatively expensive.⁷¹ Possible improvements in competitor devices, and the invention of new ones posed another threat on the success of Aron's device. This threat was more visible since the distribution of electricity from central stations was at its beginning, and the market was only emerging. Due to the novelty of the market, Aron could not count on mass selling in a short time. Berlin had its first central station opened only in August 1885, three years after the first stations, which supplied electricity to a tiny number of New York or London buildings.⁷²

5b. business moves

In autumn 1885, a year after he had presented his electricity meters, Aron was waiting for the decision of Berlin's municipal commission between his and Edison's meters. The commission decided that the electrical distributor of the city would use Aron's device; consequently, Berlin's "Städtische Elektrizitätswerke" bought 100 meters until the end of the year, the first that Aron sold.⁷³

69 Due to the lack of good meters some stations charged by number of lamps (which were also provided by the company). On the current meters see Aron, "neuen Elektrizitätzähler," (ref. 61) the references in note 68 and C. N. Brown, "Charging for Electricity in the Early Years of Electricity Supply," *Iee Proceedings. Part A, Physical Science: Measurement and Instrumentation, Management and Education Reviews* 32 (1985): 513-524.

70 On the meters see Brown, *ibid.*, especially 515. Graeme J. N. Gooday, *the Morals of Measurement: Accuracy, Irony, and Trust in Late Victorian Electrical Practice* (Cambridge: Cambridge University Press, 2004), 232-39 for the professional and public attitude.

71 Hirst recalled that in spring 1887 Aron "offered a price of £15 each meter, and it turned out the cost was only £6 [120 marks]." Hugo Hirst, "The History of the General Electric Company Up to 1900 - Part 2," *GEC Review* 14, no. 2 (1999): 147-157, on 148. From the estimations of the total costs of meters by Edison's staff it seems that they estimated a meter in about £1. Edison papers, Menlo Park notebooks # 112, p. 261 (11.8.1880), #129 p. 109 (undated, 1880), #172, p. 83 (undated, 1880) (<http://edison.rutgers.edu>). The cost of Aron's meter was more than twice the monthly average salary in German industry, Berghahn, *Imperial Germany* (ref. 35), 302. An electric lamp costed about 1.5 marks.

72 Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore, MD: Johns Hopkins University Press, 1983), on Berlin 72-73. In September 1884 Berlin's electric utility company constructed a small lighting plant for one block.

73 B. Weinstein, "Bericht über die von Elektrotechnischen Vereine zu Ehren der internationalen Telegraphen-Konferenz am 3. September veranstaltete Ausstellung," *ETZ* 6 (1885): 409, 456 (on waiting for the decision); Hermann Aron, "Ueber Elektrizitätzähler für elektrische Centralstationen," in *Die*

Yet, it seems that in autumn 1885 and probably later, Aron's plans were unclear. At an industrial exhibition in September he showed another invention - an electromechanical clock, which he patented in December 1884, while other commercial companies presented his meters. Aron continued to work on improvements in the clock during 1885. Like his meters, Aron's clock employed the uniform oscillation of the pendulum. In his clock Aron replaced the regular mechanical escapement (which moves the clock's wheels and gives an impulse to the pendulum) with an electromechanical escapement. Thereby he eliminated the need to transform motion between the gear and the pendulum, which was a source of errors. In addition he got rid of the need to wind the clock, which was powered by a battery.⁷⁴ The similarity in the mechanism, if not in the purposes and markets, suggests that the electric clock was originated in the electricity meter, which was, technically, a modified clock. Some electric clocks, like the popular Hipp Clock, even employed an electromagnet below the pendulum, as in Aron's meter, although for a different function. Moreover, the need to compare the readings of his electricity meters to reliable clocks raised Aron's interest in time keeping. In particular he employed clocks from systems of master-secondary clocks. In these systems secondary clocks are synchronized to a precise master clock, like the one in Berlin's observatory. These systems used electric signalling and electromechanical methods (similar to those applied by Aron) to ensure that the distance secondary clocks follow the rate of a master clock. The application of electromechanical means to the pendulum clock in order to achieve higher precision, to facilitate use or to connect different clocks was well known at the time.⁷⁵

Aron's patent and communications in 1884 to 1886 display his interest in the invention and improvement of technological devices and methods. In addition to the electric clock and the meters, he filed patents on protecting electromagnets from electromagnetic induction (most probably a followup of his work with them in the clocks and to a lesser extent in meters), and a patent on a primary mercury alkaline battery. In the *Elektrotechnische Verein* he presented a system of clock synchronization of his invention, in which he "employed the same principles [of his electrometers], even if to a different aim."⁷⁶ His patent on the dry mercury cell, like his meter, reveals Aron's taste

Versorgung von Städten mit elektrischem Strom. Nach Berichten elektrotechnischer Firmen über die von ihnen verwendeten Systeme, ed. Friedrich Uppenborn (Berlin: Springer, 1891), 17-26, (on selling 25).

74 In Aron's design the pendulum causes the closing of an electric circuit, which includes an electromagnet on an armature. The produced magnetic force pushes the armature, which thereby simultaneously moves the gear and gives impulse to the pendulum. Hermann Aron, "Elektrische Uhr," German patent 16-12-1884, issued 1885, to which Aron filed to supplements in July and October 1885 (DE34215 and DE34998), Weinstein, *ibid.*, 455-56.

75 Hermann Aron, "Ueber eine neue elektrische Uhrenregulirung," *ETZ* 7 (1886): 353-360," on their use in his earlier work on 355. On electric clocks Michel Viredaz, "Electric Clocks," <http://homepage.bluewin.ch/electric-clocks/> and Roger Stevenson, "Mechanical and Electrical Clocks," in *Greenwich Time and the Discovery of the Longitude*, ed. Derek Howse (Oxford: Oxford university press, 1980), 205-219, on 213-19.

76 Aron's system was based on advancing or retarding an out-of-phase pendulum of 'slave' (secondary) clocks by the changed of vibration period caused by electromagnetic coil. Small levers in the slave and master clocks moved in the phase of the pendulum and closed the electric circuits in the slave clocks in a way that only current in the direction needed to correct the error passed through each coil. Aron examined the system in his laboratory from January to August 1886, before he presented it. (Aron, *ibid.*,) However, it seems that this system did not become commercial. From the mid 1890s, Aron's company commercially constructed a different system of clock synchronization. *Fhmfundzwanzig Jahre Elektrizitäts-Zähler-Fabrikation: Den Freunden unseres Unternehmens aus Anlass des 25 jährigen Bestehens unseren Firma* (Charlottenburg: H. Aron Elektrizitätszähler-Fabrik G.M.B.H., 1909).

for expensive devices that satisfy high demands.⁷⁷ Apparently, economy was not central in his considerations. Indeed, it seems that Aron did not have clear business plans for exploiting his inventions. With the want of better historical evidence, this seemed true also for the most promising of them - that of the electricity meter. On the technical side, Aron improved his models and continued selling them from late 1885. However, he probably did not raise capital to construct a production facility or to prepare stock of meters. His expenses were modest: the rent of one industrial room and probably only after the first orders a small staff for manual production. Small loans, if at all needed, were offered for such purposes by German banks.⁷⁸ According to later recollections of his acquaintances, only in late 1887 the demand for his meters and pressure of friends drove Aron to raise capital and to build his production factory. His friends also financed his company. From that year for about half a decade he showed less interest in technical questions that were unconnected to the meters. So, at least according to later memories, Aron was pushed to the role of an entrepreneur.⁷⁹

77 Aron referred to the high cost of his mercury oxide - zinc alkaline battery as its disadvantage in comparison to the common copper-zinc alkaline battery. Alkalies enable a dry batter, which, unlike other batteries in use in the nineteenth century, could in principle be closed in a box and did not require maintenance - a considerable advantage as a consumer device. Aron pointed also at the advantages of its device: its higher voltage (1.3v versus 0.7v) and the fact that it does not spontaneously discharges (i.e., that it has a much longer shelf life). Its latter property was crucial to Samuel Ruben's successful introduction of a battery on the same principles during the second World War. Since the army's (carbon-zinc) battery suffered from very short shelf life in hot and humid climates (as in the Northern African and Pacific theatres). Costs were less important for the military. While Aron's battery "proved unmanageable in practice," Ruben constructed a useful device. This initial market for the battery led to investments first in the details of efficient design and then to in its mass production and improvements in design, which were important incentives for its commercialization for the civil market after the war, when it gained a considerable special market, until the ban on the sale of mercury elements for environmental reasons. Quotation from E. J. Wade, *Secondary Batteries: Their Theory, Construction and Use* (London: The Electrician printing, 1902), 133, Hermann Aron, "Galvanisches Element," German patent DE38220, filed 30-6-1886, issued 1886, Eric S. Hintz, "Portable Power: Inventor Samuel Ruben and the Birth of Duracell," *Technology and Culture* (forthcoming); Samuel Ruben, "Alkaline Primary Cell," USA patent US2473546, filed 23-1-1943, issued 1949; Schallenberg, *Bottled Energy* (ref. 49), 324-27.

78 German banks were a central source of investments in industry in Germany. Although the 1880s were part of what contemporary saw as a great depression, modern historians prefer to see it as a period of retarded growth of uneven changes in different economic sectors and times. The electric industry knew much growth and the early 1880s saw a general economic improvement. Berghahn, *Imperial Germany* (ref. 35), 11-15; on the banks: Gustav Stolper, continued by Karl Hüser and Kunt Borchardt, *The German Economy 1870 to the Present*, tr. Toni Stolper (London: Weidenfeld and Nicolson, 1967), 25-27.

79 Although the only direct reports on Aron's business moves were given many years after the events in accordance with a stereotype of a scientist's engagement with the material world, they cannot be dismissed. Eugen Goldstein and Hugo Hirst knew Aron at the time. Although the latter's recollections do not agree in all details with other sources, there is no reason to reject the main story that Hirst recalled. According to Eugen Goldstein a schoolfriend of considerable means had to force Aron to receive capital for his company. Hirst a representative of a London company, recalled that in April 1887 Aron's "laboratory, offices and staff were confined to a room . . . no bigger than the private office of an average G.E.C [Hirst's British firm] manager." Hirst ordered 24 meters, an order that took Aron a few months to deliver. However, the meters gained the approval of leading British men of science and engineering and Hirst ordered additional 150 meters. Aron "received him and his orders with a helpless smile as he did not knowhow he could meet the situation. He had neither works, nor money to start works, nor any intention of stating works. . . Mr. Hirst suggested that he would be prepared to order 500 . . . This offer proved

Table 2: number of electricity meters sold by Aron's company

year	1885	1886	1887	1888	1889	1890	Jan- Jul 1891
no. of meters sold	100	325	853	1570	2194	4236	3770

Total number sold:

until 7.1891	until 1895	until 1897
13048	35000	65000

source: Aron, "Elektricitätszähler für Centralstationen" (ref. 73), 25, and *ETZ* from 1895, 1897

He was not an Edison type of inventor-entrepreneur quick to look for the capital that would enable commercial exploitation of his invention.

Nevertheless, Aron successfully filled the role of inventor-entrepreneur and company manager. From 1887 his sells and business grew quickly and impressively (table 2). Aron's electricity meter won first prizes in international contests and exhibitions. Positive technical reports led central stations in Europe, and specially in Germany to adopt it. By 1893 it was the most widespread meter in Germany, and very common in other European countries, but probably not across the Atlantic.⁸⁰ Aron's company did not rely only on the quality of its product and its improvements but also on business moves like the foundation of sister companies and factories in Paris (1890), London (1893) and Vienna-Budapest (1897).⁸¹ Aron did not stick only to his original technological ideas. When the cheaper motor-electricity meter became precise enough for small consumers, his company began to produce motor-meter of Aron's design, while designating its pendulum-meters to users for whom precision was more important. The pendulum-electric meter was the basis of growth of the company but it produced also meters for other ends (e.g. taxi, gas) and systems of synchronized electric clocks. By 1909 Aron directed an impressive cluster of companies with more than one thousand employees

sufficiently tempting to Professor Aron, who after some consideration and consultation with some of his friends (from whom he got financial assistance), decided to accept the order and set to work to execute it." A few times Hirst mentioned that Aron had claimed that "he was not a businessman." Apparently Hirst exaggerated the drama and his personal role in it. Aron started selling his meters before the second half of 1887 and he produced more than 150 meters already in 1886. Still, the figures of his sells, the agreement with Goldstein's account and Aron's engagement with many other technical questions at that period, suggest that Aron did not invest in a production facility before 1887. Anno., "Professor Aron and the G.E.C," *The Magnet Magazine* 2 (1913): 216-227, quotations on 218, 219-20; Goldstein, "Aus vergangenen Tagen," (ref. 8).

80 25 Jahre Fabrikation (ref. 76) mentions central prizes. For contemporary views and reports of use see E. Hospitalier, "Concours de compteurs d'énergie électrique," *La nature* 19 (1891): 21-25; Felix Auerbach, "Beziehungen des Magnetismus zu anderen Erscheinungen," in *Handbuch der Physik*, ed. Adolph Winkelmann (Breslau: Eduard Trewendt, 1895), 233-296, 249; Anon., "Aron's electric meter," *Science* 14 (1889): 123.

81 Aron asked his brother Maurice to become a general manger of his English firm. Maurice, two years senior from Aron, immigrated to Australia in 1864 and to England in 1891 (perhaps to represent Aron's interests there), (personal communication with Michael Aron, Maurice's great grandson). This move resembles the strategy of Werner Siemens who nominated his brother Wilhelm (later William) to direct the British branch of their firm.

and an authorized capital of five million marks.⁸²

Aron's technological achievements, the meter and to a lesser extent the clocks, shaped the structure of his company, which virtually specialized in a one and later two products. This kind of specialization was not very common in the early electrical industry, which attracted various kinds of entrepreneurs. It seems to characterize companies based on a specific technological expertise. In other cases, entrepreneurs in small and medium size companies (like Aron's) were tempted to spread their chances between a few products. Take for an example "Jakob Einstein & co. Elektrotechnische Fabrik," which was studied thanks to the later fame of Albert the nephew of Jakob, the technical head of his firm. In 1891 Einstein's company was important enough to appear in the Frankfurt electrical exhibition with twenty other companies, among them Aron's Elektrizitätzähler Fabrik. At the exhibition Einstein presented a dynamo of the company's design (by Jakob with collaboration of other inventors), several arc-lamps and an electricity meter. Contrary to Peyson's claim, Einstein's meter (invented with Kornprobst) was not based on comparing clocks. The company supplied electricity to several public buildings with their own devices. The company attempted to sell these various devices and to construct central electric stations, which it did in two Italian cities. In the non-specialized field of electric power, giants like AEG and Siemens had obvious advantages. Many companies like Einstein's, did not survive.⁸³ Aron, on the other hand, found a niche in which his device was superior to others. This niche was successful since the electricity meter was not imbedded within a full system, but was needed in all. It could work with many different systems of electric distribution, and with relatively simple modifications could be made compatible to different networks (different voltage, distribution system, kind of current and its frequency). Patent laws protected Aron's devices and thus helped to maintain its superior technological position in this niche.⁸⁴ This was not self-evident since "before July 1877, when the new patent law came into force, there was no effective patent protection in Germany." While in many cases patent laws served big corporations, in others (like this one) they enabled the development of new firms with a modest capital.⁸⁵ Indeed, the electricity meter did not require an expensive and long development phase, a fact of considerable

82 25 Jahre Fabrikation (ref. 76), Manfred Aron, "Rede" (ref. 13), 6. This was a small firm in comparison with giants like AEG with a capital 104 million marks in 1910, or Schuckert (the third largest in Germany) with 60 million in 1900. Yet, the fifth largest company in 1907 had 14 millions, W. E. Mosse, *Jews in the German Economy: the German-Jewish Economic Élite 1820-1935* (Oxford: Clarendon press, 1987), 248). Moreover, only four French electric firms (including utility companies) had more capital than Aron's company, Fox and Guagnini, *Laboratories, Workshops and Sites* (ref. 45), 178, 181. In 1907 only 3,452 individuals in Prussia had capital of over two million marks (Berghahn, *Imperial Germany* (ref. 35), 303).

83 Pyenson, "Audacious Enterprise" (ref. 35), p. 40. Sebastian Kornprobst and Firma J.Einstein & CO., "Neuerung an Elektrischen Mess- Und Anzeigevorrichtungen," German patent DED53846, filed 21-11-1889, issued 1890. In the first decade of the twentieth century Jakob Einstein was the manager (*Direktor* or *Geschäftsführer*) of Aron's Viennese company, Nicolaus Hettler, "Die elektronische Firma J. Einstein u. Cie in München, 1876-1894" Ph.D. Dissertation, University of Stuttgart, 1996. p. 181.

84 Indeed AEG and others tried to abolish Aron's patents in order to enable them domination also in this niche, Manfred Aron, "Rede" (ref. 13), 5.

85 Henk van den Belt and Arie Rip, "The Nelson-Winter-Dosi Model and Synthetic Dye Chemistry," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. W. E. Bijker, T. P. Hughes, and T. J. Pinch (Cambridge, MA: MIT Press, 1987), 135-158, on 150. On the importance of the patent law in creation of research laboratories in the German dyestuff industry see Ernst Homburg, "The Emergence of Research Laboratories in the Dyestuffs Industry, 1870-1900," *British Journal for the History of Science* 25 (1992): 91-111.

importance with Aron's lack of an initial business plan and capital. In that the meter differed from the storage batteries. The latter was also a niche technology, which required the full attention of companies in order to succeed. However, it also required capital for development and cooperation with either central electric stations or traction companies for the inclusion of the batteries within their systems, as these were its only significant potential uses.⁸⁶ That Aron found a niche especially suitable to the growth of a firm based on knowledge, rather than capital or connections (not that he could do totally without them), was to a considerable degree a fortune incident.⁸⁷

To maintain the advanced technological position of his meters, Aron made many improvements in the device (e.g. better agreement between the two pendulums) and modifications according to developments in methods of electricity distribution (e.g. 3, and 5 wires systems, alternate current). These and the management of the company required much time and effort. With the success of the company since circa 1888 they explain why Aron turned most of his attention to his factory. Aron's move to industry at that point, without a real position at the university, seems an obvious choice. Gradually and incompletely Aron left the academic world. He last published in a journal of physics in 1883. While he continued to publish in the electrotechnical journal, his last communication there on a subject other than his meters was in 1886, and was also related to an invention of his (clock synchronization). For a few years his teaching had not been affected by his new interests. Until 1890 he kept about the same load and kind of courses at the university. Then he reduced them to one weekly hour, and left the institution in 1895.⁸⁸ He continued teaching physics at the artillery and engineering school until his retirement in 1910. Apparently the connection with physics was important for him (clearly he did not need the extra salary), yet he turned his creative power to technological research. This included meters of various kind (not only of electricity), electric clocks and in his last years metal filaments for incandescent lamps.

6. The factors that led Aron to the electricity meter

The success of the electricity meter and the need to keep improving it explain why Aron devoted most of his time and efforts to industry. But what led him to the electricity meter? The answer is found in his research on the storage battery, where Aron found an immediate need for an electricity meter. To estimate the batteries' efficiency he had to measure the electric charge they produced. Since the voltage and thus the current from a battery was often changing during discharging, the readings of a galvanometer, which gives the instantaneous current, was problematic. In 1882 Aron employed an electrolytic electricity meter of the type suggested by Edison. Then he got a first person experience with the cumbersome process of its reading. The need to weight its plate for each measurement was tiresome also in the laboratory, when one needed to make many measurements (14 in one of Aron's experiments).⁸⁹ Moreover, these meters were not very precise, especially for small amounts of electric charge often needed in the laboratory (even if not in the particular experiments of

86 Schallenberg, *Bottled Energy* (ref. 49), 61 and passim.

87 It was not completely an incident since the need to invest much time and money in small gradual improvements in the storage batteries was probably a factor in turning Aron's attention to other issues.

88 His courses from summer 1890 were given without payment, the last four of which were either on electric machines or electric measurements *Verzeichnis der Vorlesungen der Berlin Universität*. His 1886 paper included a description of his own scheme of clock synchronization. The last paper that did not describe a device of his own was on the efficiency of storage batteries in 1884.

89 Aron, "Theorie der Akkumulatoren" (ref. 48), 105-06. On Edison's and other meters see Brown, "Charging of Electricity" (ref. 69),

Aron). Other contemporary electricity meters fared no better. So, Aron felt himself the need for a precise and comfortable meter. Scientists often invented and usually also produced laboratory instruments. Measurement instruments were central among them. In this activity they worked much like engineers.⁹⁰ In this context Aron's attempt to construct a reliable electricity meter was not extraordinary, but the design of a commercial device was less common. At an early stage he probably recognized that the device has a real potential for the future consumers of central electric stations. He designed the meter for a general rather than scientific use, although he mentioned that it can be used also for the latter.⁹¹

Aron probably found the inspiration for the electricity pendulum meter in an exercise common at physics laboratories and classrooms. The pendulum, the forces and the variables that affect its period were well known in the world of physics. At Neumann's school, to which Aron belonged, it became the central pedagogic example. As Neumann explained:

Next to the balance, the pendulum is the most important physical instrument. It offers the means to measure forces, to express intervals of length and time and to study these. It serves as well to measure gravity and to study its properties Not only gravity, but also magnetic, electrical, torsional, and frictional forces are measured with the pendulum.

The pendulum served teaching physical theories and more importantly theoretical and experimental techniques, which were to serve the student in later original research. In particular the students were taught how to reach precision in the laboratory: methods of error reduction by the experimental protocol and by the mathematical analysis. Comprehensive mathematical account of all known and accidental sources of errors was considered as the best means to experimental precision and to a valid assessment of theoretical claim. Aron surely knew the example from his studies and plausibly also from his teaching. Indeed, in presenting his invention he described the high exactness reached by careful reduction of errors in the pendulum, which serve to measure the slight differences in the earth's gravitational force.⁹²

In the original exercise, forces other than gravitation were interferences, sources of error, which should be eliminated by changes of design or by a calculation of their effect. In the new context, the magnetic force becomes the effect to be measured, and its mathematical expression the way to know its magnitude. The aim was different but the mathematical theory was the same and the manual experimental knowledge required similar. Even Aron's method of calculation and comparison of his

90 For example, about the same time Jacques and Pierre Curie designed a device that can be used to measure electric charge (in static case) or pressure based on their discovery of piezoelectricity. Unlike Aron, the Curies did not construct the instrument, but collaborated with Bourbouze an instrument maker (Katzir, *Beginnings of Piezoelectricity* (ref. 26), 23). Among the physicists who invented and improve electrical measuring instruments were Gustav Fechner, Jean Gaugain, Gustav Hankel, Hermann von Helmholtz, Gabriel Lippmann, William Thomson, Wilhelm Weber and Gustav Wiedemann.

91 The currents and voltages for which he designed and tested his meters are those of the commercial users of electricity for light. A differential mechanism is quite dispensable for a laboratory, where one can easily compare the meter to a regular clock. On the high precision that allows scientific use see Aron, "neuen Elektrizitätszähler" (ref. 61), 486.

92 Ibid., 483-4. On precision in Neumann's school and the use of the pendulum following Bessel's second pendulum, see Olesko, *Physics as a Calling* (ref. 23), especially 146-49, Neumann's quotation their on 146. Kirchhoff discussed pendulums including a physical pendulum in his 1876 textbook of mechanics, which Aron surely knew well as a student of Kirchhoff and teacher of physics. It is also plausible that Aron studied the example in Kirchhoff's experimental seminar. Gustav Kirchhoff, *Vorlesungen über mathematische Physik, Mechanik*, 2^{ed} edition (Leipzig, 1877), 78-84.

meter with an ordinary clock was similar to Neumann's method. Both based comparisons on the number of vibrations.⁹³ Moreover, the meticulous effort to gain precision by detailed examination of the apparatus on all its material and theoretical sides, which was a lesson of the scientific exercise, was central in Aron's development of a precise and reliable instrument. As common in Neumann school, mathematical analysis led Aron's effort to reach precision (i.e. the mathematical calculation of the potential error preceded its measurement). This effort was probably the central factor that made Aron's meter practical, while William Ayrton and John Perry's similar suggestion of an electricity meter based on modified clocks was not.⁹⁴

The two English engineering professors filed a patent in 1882. However, they left no record of either an experimental examination similar to Aron's, or a mathematical analysis beyond the first approximation.⁹⁵ Like Aron, Ayrton and Perry had a thorough scientific background. Yet, Ayrton is famous in his later advocacy of simple laboratory exercises for engineers, which aimed at acquaintance with the instruments and the physical concepts but not with the implementation of methods of careful error analysis and correction like those advocated in Neumann's school.⁹⁶ Nevertheless, Like Aron, they tried to exploit scientific principles for technological ends. In both designs, one can see a preference to use one simple theoretical principle rather than a compensation of a few effects, even if Aron realized the need for a correction to the principal effect. This preference characterizes design based on scientific laws.⁹⁷

93 Olesko, *ibid.*, 148, Aron, "neuen Elektrizitätszähler" (ref. 61), 484-6.

94 In the published version of his lecture on the meter Aron claimed that he had been informed about Ayrton and Perry's meter only following his lecture. Years later, he told the same to his son. There is no ground to doubt his claim, *ibid.*, 488.

95 William Ayrton and John Perry suggested two different electricity meters, one based on a motor and the other on a clock (by spring or pendulum) modified by a magnetic force due to the current. In their patent they elaborated on the former, and gave only a general description of the latter. Only others described it with some details. Although in 1883 Perry mentioned experience with their clock meter, it does not seem that it was fully practical, and it clearly did not go beyond the experimental stage. In selling his meters in England, Aron reached an agreement with Ayrton and Perry (although they probably did not renew their patent) (an advertisement from 1899 reproduced in Hirst, "History of the General Electric Company" (ref. 71) 149). This and the failure of an effort by AEG and other German companies to abolish Aron's patent rights by using the Englishmen's patent support the conclusion that the latter's meter did not work in practice. Although they were less careful than Aron with the electricity meter, in general they did pursue precision in their technical and scientific work. William Eduard Ayrton and John Perry, "Registering the Amount of Work Given Electrically to Any Part of an Electric Circuit in a Given Time," GB patent 2642 (application number) 5-6-1882; James N. Shoolbred, "On the Measurement of Electricity for Commercial Purposes," *Journal of the Society of Telegraph-engineers and Electricians* 12 (1883): 84-123, on 101-03, 109-13 (Perry's comments); Brown, "Charging of Electricity" (ref. 69), 516, On the legal procedure in Germany, Manfred Aron, "Rede" (ref. 13), 5.

96 Ayrton's claim that his student determined the mechanical equivalent of heat using direct reading electric instruments arose fierce controversy and resistance in England. Its opponents, like the members of Neumann school, required knowledge of theory of the instrument from their students, (like that of the pendulum). Graeme Gooday, "The Morals of Energy Metering: Constructing and Deconstructing the Precision of the Victorian Electrical Engineer's Ammeter and Voltmeter," in *The Values of Precision*, ed. M. N. Wise (Princeton, NJ: Princeton University Press, 1995), 239-282.

97 The engineer-physicists William Ayrton and John Perry were respectively the professors for physics (later termed electrical engineering) and mechanical engineering at Finsbury technical college in London. They collaborate in many scientific researchers, studies of technology (telegraphy) and patents.

While Aron's experience in science inspired his invention of the electricity meter, scientific knowledge instructed his important 1891 patent on the measuring of electricity in a three-phase system of electric distribution. As Aron noticed, the use of three electricity meters one in each branch of the phase system would not give the total consumption. By an elegant algebraic deduction based on the laws of electric power in a three-phase system and Kirchhoff's well known current and voltage laws, Aron showed that in order to calculate the total energy consumption one can measure the electric current and voltage in two branches (designed to this purpose). Moreover, the measurement can be performed by one and the same electricity meter. The electricity meter should be modified accordingly. Aron showed how this can be done with his own pendulum meter, and with two other kinds of meters. The patent claim was independent of the kind of meter in use. So, companies which used three phase current had either to buy Aron's meter, or pay royalties, or to use an inferior system as AEG and Schuckert did.⁹⁸ Aron's priority in this case originated beyond his technical competence from the reputation that he had already gained in the field. The promoters of the first large three-phase system constructed for Frankfurt's international exhibition asked Aron to design the required meter. This was somewhat in a variance with the ideal type of inventor-entrepreneur, who identifies and defines technological problems himself.⁹⁹ The exhibition was a triumph for the three-phase system and set a standard for its equipment.¹⁰⁰ Aron's three-phase meter was a minor even if important ingredient in the success of the system, but a major factor in the expansion of Aron's company.

Aron's patent was the subject of a priority dispute with Hans Behn-Eschenburg, who claimed to suggest the same circuit for measuring the energy consumption independently. Behn-Eschenburg was an assistant of Heinrich F. Weber, at the physical institute of the ETH in Zürich, when Weber was asked to develop measurement technology for the Frankfurt electric exhibition, simultaneously with Aron. Apparently, his assistant took the challenge. Like Aron, Behn-Eschenburg had a thorough knowledge of physics and mathematics, which he studied at the universities of Berlin and Zürich, where he submitted a dissertation on an electric dynamometer in 1889.¹⁰¹ Aron was the first to implement the ideas in practice. Yet, both inventors employed their scientific proficiency for the sake of a specific technological goal.¹⁰² Although by 1891 Kirchhoff's laws were common knowledge

Electrical measuring devices were central among the latter. In their research on science and electrical technology Ayrton and Perry resemble Aron. However, unlike him they continued to work on both realms. Graeme J. N. Gooday, "Ayrton, William Edward (1847–1908)," "Perry, John (1850–1920)," in *Oxford Dictionary of National Biography*, (Oxford: Oxford University Press, 2004), [<http://www.oxforddnb.com/view/article/30509>, accessed 17 Nov 2006].

98 The alternative methods were considerably less exact, F. Wallmüller, *Der Elektrizitätszähler in Theorie und Praxis* (Berlin: Norden, 1935), 417.

99 Hofmann, "Aron" (ref. 59), 799. On inventor-entrepreneur see Hughes, *Network of Power* (ref. 72), 19.

100 On the exhibition, Hughes, *ibid.*, 131-135.

101 Apparently the technological mission that Weber took shaped the career of his assistant. In 1892 Behn-Eschenburg left physics for the Swiss electric company, Maschinenfabrik Oerlikon, where he later became chief electrician and general technical director. He made this move in an earlier stage of his career than Aron. A. Traber, "In memoriam: Hans Behn Eschenburg," *Bulletin des Schweizerischen Elektrotechnischen Vereins* 29 (1938): 420-421.

102 Aron thought that Behn-Eschenburg reached his solution by 'reverse engineering' from a three-phase electricity meter made by Aron, to which he had access before he made his claim. Yet, Behn-Eschenburg's background in theory and the fact that the technological problem that occupied both minds does not have many good solutions make the assumption of simultaneous discovery more plausible.

among electrical engineers, the laws of alternating currents were less familiar (they were based on partial differential equation, a more difficult mathematical subject). Moreover, Kirchhoff formulated his laws in a scientific study of electricity based on physical assumptions and mathematical methods. When the laws were introduced in 1845, they were regarded as a nontrivial consequence of Ohm's law and assumptions.¹⁰³ Thus, scientific knowledge was crucial for Aron's two most important patents (the pendulum meter and the three-phase circuit) and therefore to the success of his firm. The weight of these two patents in the development of Aron-Elektrizitätszähler-Fabrik casts doubt on the significance of König's finding that university graduates were only a small minority among the leading technical personnel of the electric industry of the time. Even if Aron had been the only university graduate in his firm, the company was based on knowledge and expertise that originated in scientific research and education. In this sense it was a "science-based industry." Whether that was the case for other factories in the electrical industry at the time should be examined. Yet at any case, the small number of university graduates does not show that they were insignificant in transferring scientific knowledge to industry. On the contrast, Aron's case suggests that scientific education was instructive to electrical technological innovation.

Aron's need to measure electrical charge in his research on storage batteries and his thorough knowledge of the pendulum provide the plausible motivation and inspiration for the electricity meter. They do not explain his choice to develop a commercial rather than a laboratory device. Part of the explanation lies in the obvious wide potential use of electricity meters in the growing electric distribution systems. This had at least two attractions at the time. One was the possible financial gain. Another was to place one's own invention to the benefit of others, which was tightly linked to a pride in one's design and its advantages over others. Yet beyond these attractions lied Aron's earlier decision to invent and improve commercial technology. This brings us back to his research on the storage battery, his first known effort to invent and develop a commercial technology, and the factors that drew him to it.

7. The factors that led to the study of the storage battery

The general interest among scientists and all other kinds 'electricians' in the novel electric power technology at the late 1870s provides a partial answer to the question of why Aron began a research on storage batteries. Scientists' curiosity about electric power seems to follow their long engagement with electricity, which preceded that of engineers. Electromagnetism was a central field of physics in the nineteenth century; aspects of it also interested chemists. Discoveries in the physics laboratory enabled the technological utilization of electric current from the battery to the dynamo. Moreover, scientists and not only scientists, understood the working principles of practical devices by the laws of physics. And therefore regarded their training as relevant to the new technologies, whether for their estimation and judging, or, for their improvement by advice or, less often, by themselves.¹⁰⁴ As mentioned above for the case of the telephone, scientists also study practical instruments to examine

Manfred Aron, "Rede" (ref. 13), 5-6; Hofmann, "Aron" (ref. 59), 799.

103 Kirchhoff formulated the laws as a student in Neumann's seminar. L. Rosenfeld, "Kirchhoff, Gustav Robert," in *Dictionary of Scientific Biography*, ed. Charles C. Gillispie (New York, Charles Scribner's Sons, 1970), vol. 7, 379-382, on 380; Gustav Kirchhoff, "Ueber den Durchgang eines elektrischen Stromes durch eine Ebene, insbesondere durch eine kreisförmige," *AP 64* (1845): 497-514.

104 Scientists' preference of the role of reviewers can be seen in their participation in many committees to examine different machines, methods and suggestions (a role of the French *Académie* since the 17th century) and in associations like the Electro-technological. On the other hand, their direct involvement in inventing and improving instruments, except those they needed in their own laboratories, was much more limited.

the validity of theories about nature. In addition, they showed sheer curiosity in the mechanisms of these technologies, which they were in a better position to understand than laymen.

Electric circuits of high current and voltage became feasible with the development, beginning of 1866, of the powerful dynamo, replacing the much weaker (primary) batteries, which had been the major source of electric energy till then. This opened new possibilities of electric motors for machine and traction and of electric light. In particular, the incandescent light bulb promoted high expectations and attracted the attention of quite a few individuals and groups including Joseph Swan and Thomas Edison, who by 1878 and 1879 had working filament lamps. Indeed, the incandescent lamp became the most important factor in the electrification of Western cities in the nineteenth century. Paris's 1881 electrical exhibition "stimulated intense commercial and technological interest and competition." Yet, by 1878-79 experts in fields close to the new technology, like telegraphy, electro-metallurgy and electromagnetism, had already displayed intense interest in electric power technology. The foundation of Berlin's *Elektrotechnische Verein* and its journal in 1879 resulted from this interest, as were the foundations of similar journals and associations (or changes of name and scope of others) all over Europe and the US. The commercial potential of the new technology was also recognized before 1881. Electricity was the central technology at Berlin's general industrial exhibition of 1879. Its main attraction was Siemens & Halske's small electric train running within the fair, and city streets were lightened by electric arc lamps.¹⁰⁵ Aron surely did not need the exhibition to be informed. His participation in the *Elektrotechnische Verein* shows that he, like other physicists, was well aware and curious about the developments.

The introduction of the dynamo, which supplies high amounts of electric energy suggested a novel need for a technology to store this energy. Although, in retrospect it is clear that the expectations from the storage battery were higher than its actual performance, in the early 1880s it "attract[ed] almost as much attention and investment as the incandescent lamp itself."¹⁰⁶ Aron surely considered a few particular potential uses of batteries, but regarded the question also from a general perspective. According to him, "[t]he challenge to store up energy, available for any purpose as it is desirable, and handy as possible in any time and place, is among the most important challenges of technology [*Technik*]." Aron's emphasis on energy as the basic concept reflects his thinking as a physicist, albeit on a general technological question. Apparently, also his attempt to suggest an efficient use of available energy fits the thinking of a scientist more than that of a technologist, who ideally would prefer economical or energetic considerations. Edison expressed such a priority and the objection to the batteries concisely: "I have never yet been able to learn of a 1000 horsepower of storage

105 Fox and Guagnini, *Laboratories, Workshops and Sites* (ref. 45), quote on 69. Still a preexistent interest of a large group of experts was necessary for the construction of the exhibition. Fabienne Cardot, "L'exposition de 1881," in *Histoire générale de l'électricité en France*, Vol 1, François Caron and Fabienne Cardot (ed.) (Paris: 1991): 18-33; Sigfrid von Weiher, *Berlins Weg zur Elektropolis: Technik- und Industriegeschichte an der Spree*, 2nd ed. (Göttingen: Musterschmidt, 1987), 82-83; Hughes, *Network of Power* (ref. 72), 31-37. The enthusiasm that William Thomson showed from 1878 (but not earlier) for electric power (including storage batteries) is a good example for dating the growing interest, Smith and Wise, *Energy and Empire* (ref. 1), 712-15.

106 In the central station a storage battery could enable the operation of the dynamo (and the steam engines that move them) in their efficient (high) capacity. The batteries could then discharge in high peak hours and save thereby the construction of additional dynamos, or replace the generators in off-peak hours (and the need to attend them). Batteries, unlike dynamos, were mobile, so they could deliver electricity to small places (while wire networks were very expensive). More promisingly, they might move electric trams, especially when upper wires were objected on a few grounds. Schallenberg, *Bottled Energy* (ref. 49), 48-51, quote on 59.

[batteries] than can be bought as *cheap* as 1000 hp of boiler and dynamos” (italics added).¹⁰⁷

In his history of the storage battery Schallenberg identified three individuals who independently developed methods for constructing a secondary battery for storing a high amount of energy. The three shared a scientific technological education and experience in engineering, and more importantly in electrochemical or electroplating technology. Their experience in the latter technologies was instructive for their inventions. According to his own testimony, Aron should be added to these independent developers of the storage battery.¹⁰⁸ Unlike, the other pioneers, he did not have an experience in technology. However, he did have an experience with the scientific study of electrochemistry. As an assistant of Paalzow in 1872-3, Aron took part in a research on the electromotive force of liquids. This research provided Aron with an intimate knowledge of metallic and acid solutions and their behaviour in different conditions and settings. These were solutions of a similar kind (some of them even the same) as used in the storage battery. Aron’s experience in Paalzow’s laboratory gave him not only articulated theoretical rules of electrochemical phenomena, but also a know-how of such phenomena and the experimental methods used in their study, a few of which he applied in the technological research. Aron’s “physical examination” of the storage battery continued Paalzow’s approach in studying the relations between metals and solutions.¹⁰⁹ Paalzow, applied the results of his investigation to explain the behaviour of the Daniell cell, the popular contemporary primary battery at the laboratories. Yet, clarification of a mechanism observed in a technological device was not Paalzow primary aim. His main goal was the relation between chemical and contact sources of electric current and voltage differences. His results supported the assumption that chemical reactions are responsible for an electric current between fluids. A second scientific issue was the relation between electric and thermal currents, issues connected to Paalzow’s previous research on conductivity.¹¹⁰

Whatever were the specific questions, the electrochemical relations among solutions and between them and metals were well known to Aron. His familiarity surely led to some interest in them in later years. Whether that led him also to consider the potential usefulness of the storage battery (which is an electrochemical device) or whether his interest in the storage battery originated in another source, Aron’s experience with electrochemistry seems essential to his decision to carry a research for its

107 Aron, “sekundären Elemente” (ref. 54), 222. The quotation of Edison from Schallenberg, *Bottled Energy* (ref. 49), 174. Edison’s view, which was shared by other ‘electricians’ was grounded, among other reasons, in severe technical problems in the performance of storage batteries, *ibid.*, 67-69.

108 Schallenberg mentions in addition to Camille Faure in France (who had the priority) the Americans Charles Brush and Nathaniel Keith. Keith suggested a different method of formation, but its goal and result were very similar to those of Faure and Brush (*ibid.*, 51-57). Aron claimed that he examined Faure’s method independently but was not satisfied with the results. Faure’s success inspired his further work on the subject. Still it did not stimulate him to consider the problem, and in this sense Aron should be considered with the three pioneers. (Aron, “Theorie der Akkumulatoren” (ref. 48), 58-59). In view of the potential of the storage battery and the shortcomings of Planté’s accumulators it is possible that others examined similar method, probably unsuccessfully.

109 Among the less common methods that Aron applied was a measurement of changes in the specific weight of the solution as an indication of the chemical reaction that took place. This kind of measurements, which appear also in Paalzow’s research, made Aron’s approach “physical.” A. Paalzow, “Ueber die elektromotorische Kraft von Flüssigkeitsketten,” *AP Jubelbandes* (1874): 643-49.

110 For batteries, Paalzow’s findings suggested that chemical reactions are responsible for undesired secondary currents, while contact electricity explains the operating voltage. This information was potentially instrumental for designing batteries. However it was only one among a few aims of the research, *ibid.* On Paalzow earlier research see Rubens, “Paalzow,” (ref. 32) .

improvement. Apparently, Aron thought that his knowledge of and experience with electrochemistry would help him to solve the central shortcomings of the storage battery. In that he showed a belief in the usefulness of scientific knowledge and methods in the development of technology. This view was shared by most of his colleagues and many other contemporaries, as expressed, for example, by the *Elektortechnische Verein* and the foundation of the *Physikalisch-Technische Reichsanstalt* (eventually in 1887).¹¹¹ Regardless the truth value of such a view, the belief that scientific knowledge can instruct technological development was a major force beyond Aron's attempt to implement science in improving the battery, and consequently in his move to technological research.

To summarise, Aron's move to the research on the batteries is explained by the general interest in the technologies of power electricity, and the promise of the batteries in this realm, and more specifically by his experience with and knowledge of electrochemistry gained in his scientific study of the field, which was coupled with the belief in the value of scientific approach in developing technologies. This explains why Aron thought that he could succeed in developing a technology and his choice of the storage battery. His curiosity and ingenuity kept his interest in the field. However, this does not explain his choice to dedicate his time and effort to the design of commercial technology.

8. Main reasons for Aron's transition to technology

We are now in a position to identify the main factors that led Aron to technology and industry. One reason for Aron to look outside academic physics was his low prospects to get a university professorship. He had good reasons to view his Jewishness as a serious obstacle for getting a position. This might have reduced his motivation to publish. At any case, His modest list of publications could not provide much help.¹¹² Although evidently Aron had a chance to get a secondary position in physics, it is possible that at the early 1880s he saw higher chances in the novel discipline of electrical engineers, whose early teachers came from physics. In 1885 Siemens suggested Aron as one among a few candidates for such a professorship.¹¹³ Such prospects might encourage Aron to carry research on electrical technology.¹¹⁴

More important than the 'negative' factor that pushed Aron out of physics were a few important 'positive' factors that pulled him to the study and development of technology. The prevalent interest of physicists in the novel technology of electric power, which Aron shared was one of them. Curiosity about novel techniques and devices was only one, albeit important component. Enthusiasm for the technology and its prospects for society, sometimes mixed with private interest, and the latter alone were others. This interest was intensified in Berlin, where the newly established *Elektortechnische Verein* symbolized the nexus of science, technology and industry. Information,

111 The benefit of scientific research to technology and economy was a central theme among the promoters of an institute that unite physics and technology, David Cahan, *An Institute for an Empire: The Physikalisch-Technische Reichsanstalt, 1871 - 1918* (Cambridge: Cambridge University Press, 1989), 29-39.

112 That Aron published little probably relates to his rapid changes of interests, as described by Goldstein, "Aus vergangenen Tagen," (ref. 8).

113 Siemens however did not know about Aron's knowledge of mechanics although he regarded him as a competent physicist and mathematician. Werner Siemens to Professor Bach, 9.2.1885, in Siemens's archive 2/Li 546. I thank the archive for providing me a copy of the letter.

114 One cannot know if the request of an extraordinary professorship for Aron would have received more sympathetic response if Aron had focussed on research in physics from 1880.

questions and problems flowed between the different participants in this nexus. Aron was at one of the junctions in his activities in the association, in addition to his teaching positions. Personal meetings and visits, scientific and technical lectures at Berlin's scientific academy, the physical society, the electrotechnical association or any other venue, and of course the technical and scientific literature all provided knowledge and opportunities to encounter new questions and path of research. In a later phase, the acquaintance with industrialists and their staff facilitated Aron's move not only to inventions but also to industry. The establishment of a commercial company was more respectable in this milieu than it might have been in a German university town. When an industrialist like Werner Siemens was respected not only on his fortune but also on his contribution to technology and even science, *Privatdozent's* research and development of commercial technology was culturally acceptable. In addition, the connections between science and technology in Berlin enabled Aron to move gradually. The graduality was important because the lower risk that it entailed and the psychological connection that Aron kept with the scientific establishment.

Probably the most important factor in Aron's turn to technology was the relevant experience that he gathered in his study, research and teaching of physics. Scientific practice provided Aron not only with articulated rules about nature (which he employed in technological research and development) but also with specific techniques, attitudes, tacit knowledge and experience with laboratory and practical devices,¹¹⁵ all of them crucial to his early study of practical instruments. Electrochemistry of solutions and methods of their study were central in his first extensive technological research on the storage battery. The pedagogical exercise on the pendulum and its period inspired his successful electrometers.

Aron's background in the Jewish low-bourgeoisie on its mercantile culture (and the inclination for entrepreneurship of Jews of higher means) might suggest that he was more inclined to entrepreneurship than his colleagues, who usually came from the idealistic culture of the German high-bourgeoisie. Although such an hypothesis is seductive, the evidence does not support it. There is no evidence that Aron had connections with businessmen or manufactures beyond those that he gathered through his scientific career. In particular his family and his guardian (mentioned as a shochet) do not seem to suggest such connections.¹¹⁶ To the extent that Jewish entrepreneurship in Germany at the time had typical characteristics, Aron did not share them.¹¹⁷ At an early stage Aron seemed to adopt the idealistic values of the higher educated German (or Jewish-German) bourgeoisie to which he joined at the Gymnasium: he moved to reform Judaism, showed German patriotism and displayed an interest in humanistic Culture. Moreover, his early engagement with invention and industry does not reveal any "business spirit," but rather naivety and only partial, almost insufficient, attention to financial matters. His earlier abandonment of medical studies, which promised a secure income, for the uncertainties of physics clearly does not reveal a 'practical' interest in future income. There is no indication for a significant change in his attitude later. As Goldstein wrote, "in the prime of his life [*kräftigsten Mannesalter*] this remarkable man [Aron] wished [*wünschte sich*] either to be

115 The division between a laboratory and practical device is not so clear. For example the storage battery had both roles.

116 For a mention of the occupation of his guardian see Aron's registration in Heidelberg (ref. 15).

117 Mosse, *Jews in German Economy* (ref. 46), ch. 4 "Entrepreneurial activities," 96-171.

Notwithstanding figures like Emil Rathenau, Jews were not conspicuous in German electric technology of the time, neither as entrepreneur (like Rathenau) or engineers. Unlike the chemical industry, the electrical industry was not connected to earlier trades or manufactures in which Jews traditionally worked. Anthony S. Travis, "From Color Makers to Chemists: A Jewish Profession Elevated," *Jahrbuch des Simon-Dubnow-Instituts* 3 (2004): 199-219.

a professor of mathematics at a small German university or - somewhere a dramaturg [literary manager] of Shakespearian plays.”¹¹⁸

Aron’s personality probably played a role in his transition to technology. Following Isaiah Berlin’s distinction, Aron was “a fox,” who interested in many subjects and questions, moving, as Goldstein told us, rapidly from one issue to the other, and “pursu[ing] many ends.” His fox personality facilitated Aron’s transition in two central ways: he had wide knowledge, which includes the interesting questions in various subjects; and more importantly, he was open to different kinds of questions, scientific, but also technological (and according to a few stories also literary),¹¹⁹ without being occupied with one big project.¹²⁰

Conclusions

Aron’s origins in a modest Jewish family clearly affected his career. It caused him to begin his Gymnasium studies late. His chances to get a professorship were viewed as lower due to his Jewishness. His origins probably also played an actual part against his nomination. Aron had somewhat stronger connections with Jewish than with non-Jewish junior scientists. Nevertheless it is difficult to point at a direct influence of Aron’s Jewishness on the subjects that he chose or on the manner by which he approached them. These are traced to Aron’s education within the German University system regardless of his origins. That should not be a surprise, since previous studies did not show a strong discrimination against Jews as students, but only at the higher stages of their academic career. By decreasing Aron’s chances of academic career in physics, his Jewishness indirectly influenced research directions. However, since it is difficult to estimate its contribution for pushing Aron out of academic physics, it is even more speculative to estimate the contribution of his origins on the special trajectory of his career. At least part of the difficulty is methodological. That Jews were statistically discriminated is insufficient to show that a particular Jew was discriminated. It clearly cannot allow us to draw a non hypothetical causal connection between his Jewishness and plausible consequences of the assumed discrimination.

The technological devices that Aron developed, successful or not, depended crucially on his scientific expertise. The knowledge and experience that he had acquired in the physical laboratory and in its theoretical analysis were necessary (albeit insufficient) for his secondary battery and the electricity meter. Above his application of scientific theories and rules, in these inventions Aron drew on experimental and theoretical “know-how” from his scientific research. In other words his experience as an experimental and theoretical researcher and as a teacher provided him examples, methods and intimate knowledge of phenomena and artifacts, on which his technological breakthroughs relied. Science is more than well-elaborated theories and a list of empirical findings.

118 Goldstein, “Aus vergangenen Tagen,” (ref. 8) 41; on Aron’s expressions of German Patriotism Manfred Aron, “Rede” (ref. 13).

119 Theilhaber, (“Messer der magischen Kraft” (ref. 15)) reports about a lecture of Aron on Hamlet while he was a student in Heidelberg, a story which he attributes to the memories of Aron’s friend from that period. I could not support the story, beyond Aron’s interest in Shakespear.

120 Isaiah Berlin, *the Hedgehog and the Fox* (New York, NY: Simon & Schuster, 1953), 1. Aron’s studied in physics did not follow any unified principle, either by their subject matter, not by the methods for achieving the results. In addition to the testimony of Goldstein one can look at Aron’s rapid response to Helmholtz’s paper on the telephone. Interestingly, Edison, the inventor-entrepreneur of electric power technology par excellence, was a hedgehog. Hughes, *Network of Power*, (ref. 72), 18. This characteristic, however, does not seem to be explained by our knowledge of Aron’s upbringing, education, context etc.

The practice of science and its ethos of precision played a more important role in Aron's devices. These, more than the theories which Aron employed, made his electrometers industry "science based" in a very concrete sense.¹²¹

That Aron could employ results and technique from his scientific study in the design of practical devices is not self evident. Rather, it points at a deep connection between the objects and subjects of inquiry of science and technology at the time. This connection is not a mere coincidence. Late nineteenth century electric technology was based on effects and laws discovered in the scientific research on electricity and magnetism (usually with technological development lagging a few decades beyond the scientific findings). On the other hand, technology provided questions and useful devices for the scientific study. At least since the 17th century artificial devices and process were considered as a subject of scientific understanding. For example the interest in the electrochemistry of solutions was connected with their use in batteries. At a deeper and more practical level technological and scientific research shared methods and means of experiment and theory alike. Indeed, Aron's successful application of scientific methods and the similarity between his and other works on storage batteries and electricity meters suggest that contemporary advanced technology drew much on the practice of science.

The deep connection between science and technology did not mean that all important differences disappeared. On the contrary, Aron's career shows that science and technology were distinguished intellectually and institutionally. Knowledge was its own aim in Aron's research until 1880; his education and teaching were designed to train the students to conduct an open-ended research aimed at knowledge rather than at a particular result. A nice illustration for the difference between a technological and scientific research is provided by Aron's theory of the microphone. This theory was directed at examining the validity of Helmholtz's explanation of hearing rather than at rules that would help improving microphones. Solving technological problems and improving design became goals only later with Aron's transition. At that stage Aron used earlier results, methods and objects. Yet the aim of design (in a general sense of the term) moulded the research that was no longer directed at open questions but at possible solutions for technological problems. In the institutional level, Aron communicated on technology in journals devoted to that subject (besides actual devices and patents), while he published on physical theory in physics journals and taught it in his regular courses.¹²² While the institutional settings of physical research at the universities or other institutes of learning were much different from those of technological development at the industry (and the engineering professor provided another setting), one could cross the lines between them. At the late nineteenth century when engineers, inventors and industrialists recognized the technological potential of scientific research and when physicists showed an interest in electric technology, the cultural gap between scientists and engineers was not wide and could be passed even in Germany with its 'purist' *Bildung* tradition.

121 This contradicts (at least for this case) König's claim that the electric industry at the time did not enjoy contemporary scientific knowledge. König, "Industry-based Science" (ref. 4). Of course, in more general and indirect manner all electrical industry relied on the findings of electrostatic, electrochemistry and electromagnetism in eighteenth and early nineteenth natural philosophy.

122 From 1893 Aron taught courses on electric technology. Unlike regular courses these were free of charge and consisted of only one weekly hour.

Appendix - Theory and practice in reconstructing Aron's research

The historical reconstruction of Aron's early electricity meters well illustrates the power of the combination of theory and practice. The theory that Aron presented in his paper shows clearly that on its own the pendulum's permanent magnetism would not give a linear effect as needed for a useful meter. Therefore, Aron used a compensation effect. However, it was not clear to me at first which compensating effect Aron used. Since Aron had tried the use of a horseshoe magnet (or steel to be magnetised), I asked Dr. Thomas Schraven, an antiquarian and historian of electric clocks and meters, to look at his specimens of Aron's meter for horseshoe or similar additional magnets. Schraven did not find second magnets in the meters. A more careful reading of Aron's text showed me that Aron dismissed his attempt to use a horseshoe steel as a second magnet, and instead used a secondary magnetism of the permanent magnet. Meanwhile, however, Schraven found two later meters in which magnets were formed in a U shape with brass in the middle. These specially shaped magnets reveal the significance of second order effect for an accurate meter and the need to compensate for them by different designs in different models.¹²³

So, the theoretical analysis alone would have revealed neither how Aron compensated for second order effects (which appears in the text), nor that different models required different design for such an effect (which one can find only by viewing the artifacts). On the other hand, only the analysis (with my help) led Schraven to look closely at the design of the magnets in specimens that he had known for many years. Moreover, that Aron had to look for a compensating effect and consequently the role of special shapes of the magnets are understandable only by the theoretical analysis. Of course, Aron carried both the practical and theoretical parts by himself.

123 Correspondence between the author and Thomas Schraven, 13.12.2007-23.1.2008.

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Abstract:

This paper examines the unusual move of Hermann Aron from academic physics to the direction of his own industrial firm in Imperial Germany. Aron carried out a research on physics and in 1876 became a lecturer at Berlin University. However, seven years later he founded a company for the development and production of an electricity meter of his own invention, which in 25 years had more than 1,000 employees in four countries. Aron gave up research in physics and later academic teaching and dedicated his efforts to technological design and to his firm.

Why did Aron move from physics to inventions and industry? What did enable his success in the latter field? The answers for these questions are sought here through an intellectual and professional biographical study of Aron from his student days until his move to industry was completed around 1891. Aron's low prospects to get a professorship in physics, which were reduced by his Jewish origins (whose role in his career is discussed *inter alia*) formed one factor in pushing him towards the study of electric technology, a new field with wider possibilities. However, a few 'positive' factors that pulled him to the study and development of electric technology were more important. These included physicists' general curiosity of and enthusiasm for the new electric technology. The interest was especially intense in Berlin as a centre of science and industry, and a nexus for scientists, engineers and industrialists with ample opportunities for formal and informal meetings. In addition, part of the technological questions that Aron examined was closely related to knowledge acquired in his research and teaching of physics. This knowledge included rules and data but also specific techniques, attitudes, tacit knowledge and experience in the laboratory. In particular, experience in science provided an inspiration for the design of his successful electricity meter, and physical theory the key to further crucial improvement in the technology. The role of scientific experience in Aron's development of technology and in its success points not only at the possible practical application of physics but more significantly at the deep relationships between the objects of the physical sciences and (electric) technology at the late nineteenth century. Yet, despite the mutual (but not symmetric) influence of science and technology they were clearly distinct intellectually (i.e. by the kind of questions and aims of research) and institutionally.