Technological Entrepreneurship from Patenting to Commercializing: A Survey of Late Nineteenth and Early Twentieth Century Physics Lecturers

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Abstract

Only a few late nineteenth and early twentieth century academic physicists sought to develop, produce and market technical inventions. This paper examines a few pre-World War I scientists from the German speaking world who committed to 'full blown entrepreneurship' and compares them to others who invented and patented but did not pursue a business enterprise. It shows that the turn to entrepreneurship required a combination of intellectual, technical, social and individual factors. Connections between their scientific research and teaching and new technological fields related to science opened possibilities and allowed scientists to exploit their laboratory and theoretical expertise to develop devices and methods. The marketability of these inventions was a central factor in moving them to industrial career. This turn resulted from pushes within the academia and pulls towards industry: low professional prospects and financial difficulties in the university and/or attractive offers by industrialists.

Key words

Science-technology relationships; invention; Leo Arons; Carl Auer von Welsbach; Ferdinand Braun, Ernst Abbe; Hermann Aron

Introduction

Ernst Abbe was a partner at the famous optical manufacture 'Carl Zeiss' of Jena and an extraordinary professor of physics. Hermann Aron taught physics in Berlin University when he established an electricity-meter firm that would employ more than 1,000 workers. Ferdinand Braun, a physics professor in Stuttgart, was a founding partner in a few large radio companies that eventually merged into Telefunken, which dominated the field in Germany for many decades. Abbe, Aron and Braun were exceptions among natural scientists teaching at institutes of higher education in the late nineteenth and the early twentieth century. Only few academic physicists and inorganic chemists embarked on an enterprise of developing, producing and marketing technical inventions and improvements. Becoming such a 'full blown' entrepreneur, to employ the terms suggested in the introduction to this collection, was a hazardous endeavour, which required investing and risking time, money and often also prestige.[1]

Moreover, apparently many contemporaries regarded direct involvement in business as unsuitable for an academic scientist. Indeed, in a few cases the engagement with commercial work eventually led the scientists not only into industry but also outside the academic institutes. No similar obstacles hindered scientists from filing patents. This kind of practice did not require substantial investments; it carried much lower risk, mainly of losing time and limited amounts of money, and seemed to be ethically acceptable.

Inventing and patenting, thus, was quite a common practice for academics. Despite important differences between patenting and full-blown entrepreneurship, the two practices were connected. Both patenting and full-blown entrepreneurs engaged with invention, and employed patents to secure their rights on their innovations. Patents were crucial for most of the full-blown entrepreneurs, as they were their most valuable asset in establishing or joining a company. Most of them began their engagement with technology through patenting, before they engaged in industrial, production and commercial aspects of the technology.[2] In a few cases they began with consulting, which led them to inventions and patenting.

This article examines how and why academic scientists embarked on commercial – full blown entrepreneurships. To this end it begins with a more general discussion of the attitude towards invention and patenting and two examples of scientists who invested time in invention and securing profit but did not embark on a commercial or industrial enterprise. These examples will help to understand the obstacles that discouraged or halted their further move towards commercial activity as well as the reasons that led others to full-blown entrepreneurship. The factors that facilitated or hindered their move shed fresh light on the relationships between the physical sciences and technology in the period. In particular, they point at the relevance of academic teaching and research in the sciences for developing technologies before the rise of the 'entrepreneurial university'.[3] The rare cases of full-blown entrepreneurship indicate connections between the scientific and technological enterprises of the period, but also, as will be shown below, differences in their aims and attitudes that kept them distinct. The fact that patenting was common while full blown entrepreneurship was not shows that scientists, in varying ways, adopted only some practices common in industry, This suggests that any simplistic view of science and technology at the time as either merged or being two unrelated enterprises could not account for the historical phenomena. Science and technology were separate social – epistemological realms, albeit with important areas of contact, exchange and overlaps.

I analyse here those who began their career as researchers in physics and inorganic chemistry (and not those who arrived in higher education from industry) and later turned to develop commercial products. The examples of full-blown entrepreneurs are drawn from pre-World War I Germany, and include all the clear cases that I have been able to identify in the secondary literature.[4] Two representative examples of patenting scientists are taken from my studies of interwar United States. The choice of examples from two places is made only for convenience on the assumption of a similarity between them. Following the new unified law of 1877, patents became central for industry and business in Germany, as they had already been earlier in the Anglo-Saxon world,[5] and continued to be also after World War I. I do not imply that patenting was an American phenomenon while entrepreneurialism was a German one. American academic researchers developed commercial enterprises and some of their German colleagues patented without becoming entrepreneurs.[6]

Moreover, despite differences between the two periods and places, the physical sciences in both shared the same 'disciplinary regime', to use Shinn's terms. In both cases, research topics followed mostly the inner criteria, questions and developments of established disciplines.[7] Technology influenced the research in the disciplines from the outside. In particular, it provided topics for research by pointing at unexplained phenomena and areas of interest for further development. Still the main point of reference for the scientists were their peers in the same discipline. Engaging in invention and development of technologies, scientists-entrepreneurs overstepped their discipline's borders, moving to a 'transitory regime,' i.e. 'the circulation of scientists from a disciplinary framework into an entrepreneurial environment, and the subsequent migration back to the disciplinary referent.' Within this regime, '[t]he practitioner identifies himself with the discipline and strategically seeks to be linked to it.'[8] Although the numbers are small, the examples below suggest that often the requirements of full-blown entrepreneurship did not allow scientists to follow such a strategy and that the industrial activities diverted them from science. Still the scientists-entrepreneur made considerable efforts to keep academic affiliation and fashioned themselves first as scientists, rather than as a successful inventor and a businessman. These ties to disciplinary science indicate that historians need to explain the reason for overstepping its boundaries.

Inventing and patenting by academic scientists

The second wave of the industrial revolution of the second half of the nineteenth century made academic pursuits closer to the interests of industry in fields like chemistry and electricity and led to an expansion of engineering schools.[9] The research of university scientists in these disciplines often related to topics of technological development, and a number of them employed their knowledge in inventing devices and methods for laboratory and commercial use. The findings on Britain by Anna Guagnini in this collection and by Stathis Arapostathis and Graeme Gooday suggest that many of them filed patents for their inventions. This was especially common in fields of engineering and organic chemistry, wherein the disciplinary teaching and research were closest to the industrial technologies. Patenting was quite common also in electricity, and continued to be so with the development of wireless and electronics. In addition, scientists often filed patents for scientific instruments that they developed for diverse experimental field of study. While a few of these patents led to considerable profit, like William Thomson's quadrant electrometer, the great majority did not. If the instruments did not reach use beyond the laboratory (and they rarely did), even relatively successful devices did not yield high revenue.[10] This suggests that financial profit was not the main reason for patenting: scientists filed patents on their devices also for protecting them against contesting patents and for establishing their priority, and thus prestige among their peers.

Though it was quite common and legitimate to file patents for scientific instruments, patenting some other kinds of results of scientific research was against the ethical norms that prevailed among academics. John L. Heilbron and Robert Seidel claim that in the early 1930s the physicist Ernest Lawrence, one of the first to pursue 'big science', 'shared the inhibitions of the academic scientists against securing a personal financial interest in his discoveries or inventions.'[11] The common view in the British and American scientific and technical press opposed research pursued in the hope of gaining financial benefits. Yet, Heilbron and Seidel's claim is a rather sweeping one: in fact, the norms did not bar all kinds of financial gains. Apparently physicists (and probably also other scientists) made a distinction between discoveries and experimental designs on the one hand and inventions on the other hand. The former, to which much of Lawrence's innovations belonged, were regarded inappropriate for patents, as they entailed an exclusive right of use, against the scientific ethos of open information and examination. In similar fashion, when physicist Leo Szilard applied for patents on his scientific findings he was warned that 'it is not customary to take out patents on scientific discoveries.'[12] Many physicists, however, filed patents on inventions that followed from their research but which they regarded either as not an integral part of the scientific research itself or related to special instruments developed in support of their work. Many more judged this kind of patenting pattern favourably.

Invention did not occupy a central place even in the work of most academic scientists who did seek to translate research into practical devices. They were, so to say, occasional inventors.[13] Most of them did not become entrepreneurs, as their involvement in technology remained marginal and rare. They followed three main paths to invention: improving or inventing laboratory devices; exploiting new findings for practical applications; and working for a limited period on a technological problem for a private or governmental request. Improvement of experimental methods and scientific instruments and the invention of new ones followed from the engagement with them in the laboratory and was (and still is) regarded as an important part of scientific practice. In inventing new devices and methods, scientists also exploited experimental and more rarely theoretical findings conceived as part of disciplinary research. While scientific instruments were most common among the inventions, they also included technologies of more general use, like crystal frequency control and a new kind of gas lamp, which are discussed below. This kind of occasional inventor is inherent to work of natural scientists due to the connection between aspects of their research subjects and practical technologies.

This connection was also a main reason for requesting scientists' help in developing existing and new technologies. Military-related projects, especially those connected to war-emergency, are the most famous cases in which scientists engaged in technological developments and inventions for a limited period. Still, commercial companies and entrepreneurs also asked to use the technical expertise of scientists for limited projects, often, as discussed in this special issue as consultants. Experience as occasional inventors facilitated the move of some academics, discussed below, to full-blown entrepreneurship. Yet their enterprise did not necessarily follow these inventions. Moreover, some academics began to embark upon commercial work on the basis of a study of technology, i.e., research and development aimed clearly at new methods and devices.

Patenting scientists

Walter Cady (1874-1974), an occasional inventor who exploited his scientific findings for practical inventions, is one example of a patenting scientist. After earning a PhD in Berlin, Cady joined the physics department of Wesleyan University, Connecticut, in 1902. There he devised his own laboratory equipment, a practice that led him to design several new devices. He published on a machine that he invented for compounding sine waves for use as a teaching aid (which he did not patent), and filed a patent on a wire connector.[14] Both activities fit the characteristics of occasional inventors of the first kind. His work on them suggests that Cady had an interest in devising instruments, and perhaps also in financial gains, but they were far from making him an entrepreneur. His involvement with technology increased dramatically in 1917. When the United States entered World War I Cady joined the research on submarine detection methods. He worked most of the time at his university laboratory, while being part of a group spread out at a several sites that studied and developed piezoelectric transducers for producing and receiving ultrasonic waves—the system we know today as sonar. In essence, Cady's role was similar to that of a scientific employee in a commercial laboratory.

In the aftermath of the war, Cady returned to scientific research, but on a new subject: the piezoelectric vibrators on which he had worked during the war. He discovered that these crystals display a very strong, abrupt and stable electric effect when they are in mechanical resonance. Recognizing that the new effect could be useful for measuring frequencies, within a few weeks he began devising methods that allowed using the crystals as frequency meters. It took him a year to file a patent on such methods. This invention was similar to his earlier improvement of laboratory devices in offering a measurement instrument useful in his specific area of physics.

Still, unlike his former inventions, his meters originated from a discovery of a surprising effect that he had discovered in a research about a physical phenomenon rather than from an effort to improve his laboratory instruments. Moreover, Cady realized that the new method had a large potential beyond the laboratory, as it could be useful in the quickly expanding field of wireless telecommunication. He, therefore, presented it to a few colleagues including acquaintances at the research department of AT&T (the predecessor of Bell Labs). The industrial physicists expressed limited interest in the method as such, but they encouraged Cady to go beyond measurement devices and design methods for controlling the frequency of electronic oscillations, a highly useful property for the rising electronic-telecommunication field. Intrigued by the possible wide applications of such a device (currently produced in billions annually), Cady invented a few circuits for crystal frequency control and filed another patent.[15]

Cady recalled that he 'applied for the patents from motives of prestige and profit,' hoping to collect royalties from AT&T and many other users.[16] The reality, however, did not match his hopes, not because the method was not used—it was—but due to litigation on the frequency control patent from AT&T. The corporation claimed rights on the method on the basis of an earlier patent filed by one of its employees. Unable to defend himself from the attack of the giant corporation, the inventor sold the patent to another corporation – RCA for $50,000, a handsome sum, although it was still low in relation to the widespread use and economic value of the invention.[17] Though the encounter with AT&T discouraged Cady from making inventions his main occupation and from becoming a full-blown entrepreneur, it seems that he had not planned on pursuing such a course from the beginning. For him patenting was secondary to his scientific research and teaching, which remained his main professional identity and prime interest. He received more appreciation by making himself a leading figure in the study of piezoelectricity, which expanded in size and importance and attracted further study and findings following the discovery of resonance.

With the development of crystal frequency control, scientific experimentation and findings continued to produce knowledge relevant for practical improvements of the resonators and their use. Cady contributed to such technological advancements mainly as a consultant for a few military and commercial projects, leading to about a dozen additional patents in the next 15 years. Apparently, he earned fees and some revenue from these endeavours, but the sums were not very high.[18] His engagement in extramural activities beyond the university remained limited. He neither opened his own company nor joined other commercial enterprises. Maintaining his academic position as his primary occupation, he preferred keeping scientific investigation at the core of his work.[19]

Cady presented his resonators and methods to a few colleagues including George Pierce (1872-1956), who spent his entire career at Harvard, from a graduate student in physics to a full professor. Like Cady, during the war he worked on submarine detection, but unlike Cady, focusing on passive ways to receive the noise made by submarines. Pierce was not only impressed with Cady's method but was also inspired to examine alternative methods of using the resonators, resulting in simpler frequency control circuits in 1923. Pierce's invention originated from his interest in frequency control as a technology of general use for radio, rather than from a scientific study (as was the case with Cady) or from a laboratory method. The initiative to improve the technology seems to have been Pierce's own, rather than a response to an external call like that of the military or a commercial company. Pierce had a long active interest in radio technology and electric oscillations. Much of his research was related to technological questions, like electric characteristics of telephone receiver, and rectifying methods for radio waves. The latter led to about ten patents, making patenting his secondary occupation.

His experience with patenting, which he effectively secured with his patent attorney David Rinse (who later also worked with Cady) and his contacts with industry probably prepared him for the struggle to enforce his much more lucrative patent of crystal frequency control. Unlike Cady, Pierce received high revenue from selling royalties of his piezoelectric patent, which was followed by a series of related ones. A few years later he invented another successful oscillator, based on magnetism for which he actively developed many applications. Before 1935, he filed about 40 additional patents, an effort which largely supplanted his academic publication after World War I. Pierce became wealthy through his patents, some of which he exploited vigorously, and usually successfully, in the face of interference suits by large corporations.'[20] By then inventing and patenting were no longer only an occasional endeavour for him, but his central occupation, Such effort included actively seeking to exploit his inventions technologically (by finding commercial uses for them) and thenby licencing and selling his patents. Still, this practice did not include risking his own capital or forming a company.

Full blown entrepreneurs

Cady and Pierce represent two kinds of inventors: for the former, his own scientific findings were the sources of inventions; for the latter the basis was his involvement in practical technology. Like Cady's earlier inventions, Leo Arons's 1892 invention of a mercury lamp derived from research on laboratory techniques and instruments. In his experimental research on electric discharge in gas, he found a method for producing intensive illumination when the space between the electrodes of an 'arc lamp' was filled with mercury, and used it to study spectral lines of specific substances. He further worked on the improvement of this lamp and its stabilization and reached agreement with a commercial company, Muencke, for its production and marketing as a scientific instrument. Arons (1860 – 1919) was a Privatdozent for physics at Berlin University, i.e. a lecturer who earned only fees directly from the students, with aspiration and a plausible chance to receive a better position. With these prospects, he did not engage in developing the lamp for uses beyond the laboratory, refraining from overstepping disciplinary borders.

Apparently, he changed his attitude only due to two events of different kinds. In in 1899 he lost his modest teaching position due to his social-democratic political activity and he subsequently failed to secure a professorship in Switzerland. About the same time an American engineer, Peter Cooper-Hewitt, developed a cheaper and simpler commercial mercury-vapour lamp based on Arons's ideas. In 1903, Arons narrowly failed in his attempt to enter the German Reichstag, consequently he lessened his political activity and devoted more time to pursue other interests.[21] In the following year he approached the American company General Electric and the German firm Allgemeine Elektrizitätsgesellschaft. The companies jointly financed a laboratory and assistants that he directed for making his mercury lamp commercially viable; in 1906 they introduced the new 'Arons's mercury-vapour lamp' to commercial users who needed a strong light source, resulting in a profitable share of the market. Soon thereafter Arons terminated his employment at the two companies, despite not yet being able to have a teaching post. Since he initiated the enterprise with the electric companies he might be considered a full-blown entrepreneur, yet unlike the ideal type he did not take a commercial risk by establishing his own company, but joined extant and strong corporations on a limited time contract.[22] His move to entrepreneurship hinged on his early engagement with patents, and his initial patent rights. Securing these rights was a quite common practice within the disciplinary regime. Still he moved to the transitory regime of further research in technology only following his failure to secure an academic career. In the late nineteenth and early twentieth centuries low prospects in the academia seemed to be a major reason for embarking on a technological enterprise.

Similar factors drove his elder colleague, bearer of a similar name, Hermann Aron (1845 – 1913) to full-blown entrepreneurship. Yet, his inventions originated from research and development directed towards improving technologies of general use (like Pierce), rather than from the improvement of laboratory instruments (like Arons) or from his own scientific findings (like Cady). Not that his scientific background was irrelevant. On the contrary, Aron chose practical problems in which his knowledge of physics and chemistry and his theoretical and experimental expertise seemed conducive to finding solutions. Like Arons, Aron first pursued an academic career. He received a PhD in theoretical physics in 1873 and began teaching the subject at a military engineering school, submitted an experimental *Habilitation* (a second dissertation granting the right to teach) three years later and started to teach as a *Privatdozent* at Berlin University. Yet, by 1880 his prospects of getting a regular academic position in physics did not seem high.[23] He moved to a 'transitory regime' pursuing mostly research on technology and continuing teaching at both institutes and publishing little in physics.

His work in technology followed two directions: a general study of issues at the forefront of current technology and research and development for improving devices.[24] Apparently, Aron had hopes for a regular academic position in physics or in the new discipline of electric engineering, but he also pursued options of making inventions an important source of income. He published his findings on technology in the *Elektrotechnische Zeitschrift* - a new professional journal devoted to electrical technology. The association for electrical technology (*Elektrotechnische Verein)*, publisher of the journal and of which Aron was a founding member, established an intermediate space between research in physics and academic engineering on the one hand, and industry and work on practical devices on the other. It legitimized the kind of work that Aron carried out on technology including general research and the development of particular techniques. Its members regarded those who profited from science-based industries (like Werner Siemens) as respected members of scholarly circles.

For three years, the young physicist explored different technical ideas in fields mostly related to the burgeoning interest in electric power technology. Prominent among them was the storage battery. Aron's research and development led to a new working storage battery as well as some publications but did not reach technological nor financial success. He gained success later with his innovative electricity meter of 1884. Electricity meters became important for the new companies distributing electricity from central stations. Aron found an inspiration for his invention of a pendulum-based electricity meter in scientific practice: an experimental and theoretical exercise in exact measurements. His device was more accurate than any other electricity meter, and therefore was adopted by a few power supply distributors, such as Berlin's utility.

After this invention, Aron left the modest facilities of the university in which he had been working. He established a company for the production and marketing of the new meters, engaging with their improvements, employing his scientific knowledge, and managing the company. Aron probably did not need to raise much capital because initially the production remained on a small scale, but he nevertheless became an entrepreneur and industrialist. Even with this success, he still hoped for a university position; but in the same time period, his last attempt for promotion at the university was rejected. With the commercial success from late 1885, the technological and business needs of his company took up almost all his time. In twenty five years, his business grew to employ more than 1000 workers in four countries. Still, Aron continued teaching physics at the university for a few years, and at the military school until his retirement age. Apparently, the physicist-turned-industrialist cherished the connection to the academy and physics. Personal and institutional connections in Berlin, the center of German electric industry and of research, helped him to maintain links to the academic world. Still, Aron turned from academic science to technology and industry. For him, the transitory regime was a step in a definitive passage from the academy to industry. The transition was not back to science but to a new career in industry.[25]

The chemist Carl Auer von Welsbach (1858 – 1929) was another successful scientist-entrepreneur who found difficulties to attain an academic position. In 1882, after receiving his PhD in Heidelberg, Auer returned to Vienna as an unpaid assistant at Adolf Lieben's chemical laboratory, where he continued his research on the discovery (that is. the separation and identification) of rare earth elements. He used spectral light methods in which a flame heated and thereby excited the chemical substance, which consequently emitted light at characteristic wavelengths. Comparing the emitted spectrum with spectra of known substances one could isolate and identify an unknown element. The heating of the specimen in the experimental apparatus resembled the way carbon-cotton mantle was heated in a regular gas lamp. Though the aims were quite different, both devices released light.

As Auer experiemented with substances that released strong lines in the visible spectrum, this work stimulated his 1885 invention of a new gas mantle that produced light by emanating of spectral lines, rather than by incandesce, as was common with gas lighting. The new mantle was consequently more energy efficient, i.e. lighting more powerfully while burning less gas. According to the chemist Wolf J. Müller 'Spectroscopy drove him to the discovery, which made the chemist Auer a successful industrialist and organizer.' [26] Thus, Auer's initial invention was similar in kind to Cady's. He followed the results of scientific experiments to develop a new practical device. Unlike Cady, however, he did not rely on an original discovery but on an effect known to quite a few researchers, namely that some substances release visible light after being heated. Moreover, he had to depart from his scientific research on rare earths to develop a lighting mantle, moving at an early stage in the development of his invention into a transitory regime. Auer, like Cady, had to carry out research and development to attain a working device.

As with the other entrepreneurs discussed here, Auer filed a patent on his invention. Since the market and the potential benefits of the invention were clear, he soon sold his right of use to a German firm for a handsome amount. He used the revenue to embark on a wider technological and business enterprise. He expanded his research and development efforts, leaving the university laboratory and with it his academic career, and hiring Lieben's assistant Ludwig Haitinger (who continued working in the university laboratory). In 1887, Auer established a company with an English partner and acquired a factory for producing his gas lamps. At this stage he turned into an industrialist and inventor. The fact that he did not have an official academic position probably eased the process.

Like Aron, he continued to develop his devices, yet he also relied on the expertise and ingenuity of his employees. In 1890, for example, Haitinger invented an improved lamp mantle with the addition of Thoriumoxide, which replaced Auer's invention. Auer himself continued with research and development. In a new laboratory (established in

1895) he examined possible metallic replacement of carbon in the filaments for electric lamp, leading to his highly profitable invention of an osmium filament lamp in 1898. Like Aron, too, Auer was immersed in research on technology and managing his complex industrial business and hence he drifted away from academic science. Nevertheless, science continued to play a central role in the strategies of their respective companies. Recent developments in scientific research and scientific analysis of their technological problems served them in innovating devices and methods, like the osmium lamp (Auer) and a highly profitable method for a three-phase electricity meter (Aron). Moreover Auer, like Aron, did not fully leave the scientific world: he returned for varied periods of research on the rare earths, published his findings in scientific journals and even discovered two further elements in 1906.[27]

Quite unlike the previous two entrepreneurs, Ferdinand Braun (1850 – 1918) turned his attention to industrial technology only following an external request. His research and career led him neither to a study related to specific technological questions nor to entrepreneurship. Braun conducted a successful career in physics, holding some professorships before being appointed to the prestigious chair of experimental physics in Strasbourg in 1895 at the age of 45. During his career, Braun modified and invented a few laboratory instruments, including (in 1897) the oscilloscope for which he is known today. Yet, these instruments had a very specific and limited market. A year later, and without an apparent connection to the oscilloscope, a group of wireless entrepreneurs organized by Albert Zobel, which included industrialists and investors, consulted Braun about the potential of an invention that was expected to circumvent Marconi's system.

The reason they approached Braun rather than another physicist was their contingent connection with him; two members of the group, Fritz Nies and Albert Gümbel, who lived in Strasbourg, reached him through a common acquaintance. The investors clearly deemed Braun's scientific expertise in electricity as useful for the new technological enterprise. The physics professor expressed the opinion that the suggested invention was worthless (as it was not independent from Marconi's patent). Although he had not studied the field before, Braun was intrigued by the new possibilities of wireless communication and the funds that the group collected for its development. Within a few weeks, he invented and patented a new transmitter based on different principles, improved it towards the end of the year, and embarked on a study of wireless communication for which he later received the Nobel Prize together with Marconi.

Braun did not limit himself to the technical side, but became a partner in the new enterprise. In order to protect his reputation, he asked for his role to not become known to the public before the system would show clear technical success (in this case, transmission over more than 100 km). However, despite passing this test, Braun's technology was found inferior to Marconi's. Due to these technical shortcomings and to business-related issues, the company went through a few changes and mergers, which reduced Braun's role. In 1904, following the formation of the Telefunken company and the transition of its research and development center to Berlin (previously Braun conducted an important part of his research in Strasbourg) and as a result of disagreements within the company, Braun returned to research in physics, practically ending his entrepreneurial adventure. Unlike Arons, Aron and Auer, he could return to his secure academic position (which he had never left), thus reverting from the transitory to the disciplinary regime. The risk that Braun took was smaller than those of the other commercial entrepreneurs discussed here. He joined an enterprise that was initiated by others without investing his own capital and he kept his academic position. He risked his reputation, but even that cautiously, in return for expectation of high revenues. Eventually, his profits were not so high, but still substantial. At least for a few years they were a few times higher than his professorial salary.[28] Yet the move still required a willingness to be engaged in technological development rather than in science, and moreover to engage in business, which was quite different from the usual view of a German *Gelehrte*.[29]

Another famous academic entrepreneur who did not initiate his enterprise was Ernst Abbe (1840 – 1905). Yet, Abbe's case resembles Aron's and Auer's more than Braun's. Like the former he lacked a secure position. Earning his living as a *Privatdozent* for physics and mathematics in Jena, he had to turn to an external source of income. In 1866, 'when financial difficulties forced Abbe to consider finding additional income to supplement his lecturing fees, Abbe began working for [Carl] Zeiss optical instrument company as an academic consultant.[30] In the first years, he designed and used measuring devices for the Zeiss company, employing his experience in the physics laboratory. He did not file patents, which had no legal status in Thuringia.[31] Zeiss employed the new measuring devices to develop an improved line of microscopes. Abbe and Zeiss developed, to use Terry Shinn's terms, a 'research technology' that could be used for various scientific ends and that would later find also commercial uses.[32]

The scientific clientele of the instruments required a theoretical explanation of their properties for their use and purchase. To provide such an explanation Abbe carried out research and published articles. His examination of the optical instruments and justifications of their use were crucial for their success. The close connection between this industry-related research and academic research allowed Abbe to advance his university and entrepreneurial careers simultaneously. In 1870, he was promoted to extraordinary professor at Jena university. At Zeiss, he continued to develop new microscopes, defend their use and convince scientists in various fields to use them. Recognizing the importance of Abbe's scientific-technical contribution and entrepreneurial activities, in 1875 Carl Zeiss made him a silent partner and a co-director of the company.[33] Thus, like Aron and Auer, Abbe made a life-career in the industry. Like Auer, he also hired other scientists to carry out research and development. Most important among them was Otto Schott, who had earned a PhD in chemistry in 1875 in Jena. Four years later he approached Abbe with ideas for producing optical glass 'on scientific basis,' which he envisioned after he returned to his hometown Witten. The new optical glass that Schott developed for the company in the early 1880s was a great commercial success. Consequently, Schott also became a partner in a subsidiary company.[34]

Although Abbe became a successful businessman, he saw a tension between the pursuit of financial profit and the scientific pursuit of knowledge. His reservations can be seen in his request to remain a silent, rather than open, partner in the company (but the company did enjoy his reputation as its scientific expert). This choice resembles Braun's. Yet unlike Braun, Abbe did not worry about a technical failure that would cast doubt on his expertise. His concern was that his reputation as a disinterested scientist could be called to question due to his strong involvement with a commercial enterprise and therefore he did not publicize his business role even after the technology proved successful. He kept a distance from the commercial aspects of the enterprise. Moreover, he seemed to have more general reservations about the profit motive in industrial capitalism. He therefore decided to transfer his share in the company to a special fund, whose aim was (and still is) fostering scientific research and caring for the welfare of its workers. Abbe managed to convince Schott and Zeiss's heir to donate also their shares.[35]

Discussion and conclusions

The academic entrepreneurs discussed here built and developed their companies on science-based devices and methods. The operating principles and understanding of the technologies on which their commercial activity was based depended on scientific research and practice. The content of their research and their expertise in teaching proved crucial for the scientists' move into and success in industrial technologies. In the cases examined here, the academic researchers employed expertise that they had acquired through their theoretical and experimental experience as researchers and teachers to attain practical commercial technological aims. Their success to employ their knowledge for practical invention points at the scientific basis of the industries to which they contributed. .[36]

In two cases, those of optical manufacturing (Abbe) and gas lighting (Auer), the scientists-entrepreneurs were central in transforming the respective traditional manufacturing fields into science-based fields.[37] In the other cases, the scientists-entrepreneurs entered new and expanding fields of technology: Aron into electric power stations and lighting; Arons into the second wave of development in electric incandescent lamps, to which Auer later joined; Braun into early electromagnetic radio transmission, a decade after Hertz demonstrated the existence of electro-magnetic waves in the physics laboratory (Lodge and other British academic scientists mentioned in Guagnini's paper in this issue also engaged in this field); and Cady and Pierce contributed to electronics and to the more specific subject of frequency control where they introduced a new technology even without becoming full-blown entrepreneurs.

The new technological fields offered two kinds of opportunities. On the intellectual–technical level these fields included many niches in which the expertise gained within the disciplinary regime was useful for examining and solving technological problems. Radio provides the most conspicuous example as electromagnetic waves were known better to physicists than to telegraph engineers, but also in most other cases the scientists discussed here employed expertise that were rare or non-existent among engineers and professional inventors at the time. Though scientific knowledge did not provide guidance in dealing with some important problems, it was very useful in others and was deemed relevant in still other problem areas.[38] Effects discovered in the laboratory were useful for practical devices in lighting as well as in frequency control. New technological areas suggested commercial opportunities as well since novel fields were dynamic and open to new enterprises. Established companies did not enjoy advantages of existing production lines and factories or distribution channels and loyal clientele in these fields. In such fields that were not yet divided among extant firms, new companies like that of Aron for the electricity meter and successive ones in which Braun was a partner for radio had higher chances of success.

Instruments were central in mediating between scientific practice and practical techniques, and consequently also entrepreneurship, since they were used in both. Leo Arons invented his lamp as an experimental device and turned it later into a commercial appliance. Carl Auer employed principles related to his apparatus for detecting rare earths in devising a new gas lighting lamp. Hermann Aron modified a laboratory experiment used for teaching to form a successful electricity meter.[39] While experimental apparatuses facilitated the move from physics to practical technology, general purpose 'research technologies,' in the sense discussed by Shinn were not central.[40] Only the optical instrument that Abbe developed for Zeiss fits the concept. In the other cases the scientists developed technologies for a wide range of users from households to technicians of large companies.

The move from scientific research to invention was quite smooth when the scientists worked on related questions in their disciplinary studies, as in the cases of Cady's frequency standard and Auer's first gas lamp. In Arons's case, the initial invention of an experimental mercury lamp was even a part of his laboratory disciplinary research. In the other cases the scientists had to turn from their disciplinary to technological research at an earlier stage of their work on their practical inventions. Whether they invested much time and efforts in research and development of technology before or after the crucial invention, the move to a larger scale engagement with development was sharper than a transitory move to invention, and was more difficult for the scientists to take.

It resulted from a combination of causes. One common factor in these examples was the success of an initial invention (such as a gas lamp) or of a later one (like an electricity meter). It was combined with other causes: pulls towards commercial enterprise and pushes from the academy turned the scientists into full blown entrepreneurs. Low chances of getting a regular academic position was the central reason for the move to technology and industry in the cases of Auer von Welsbach, Aron and Arons, and the lack of such a position and resultant financial problems were crucial in the case of Abbe. In contrast, Cady and Pierce, who did not have similar difficulties, did not turn into full blown entrepreneurs despite the success of their invention. A pull rather than a push was important in the case of Braun who followed an attractive offer by a group of businessmen. Yet, a pull was also important to Abbe, whom Zeiss made a business partner in order to increase and extend his role in the firm. Personal particularities and sometimes also contingencies seem central in their move to entrepreneurship. The famous case of William Thomson who pursued a career of inventor, consultant and partner alongside his successful academic career in physics stands as a clear exception in comparison to these examples from the pre-WWI German speaking world.[41]

While full blown entrepreneurship did not fit the ethos of academic science, engagement with technology and enterprise of non-academics was viewed favorably in some circles, which facilitated scientists' acceptance of industrial work. The scientific-technical electric community in Berlin, which connected academics with practicing engineers in industry and the state, encouraged Aron in his research and development of electric technology; it probably helped also Arons, although the latter was not involved in this community to the same degree. Personal contacts with industrialists, businessmen, inventors and middlemen also helped the move to invention and enterprise. The scientific community and organizations also showed tolerance towards research and development for technology and involvement with industry. Auer and Haitinger could continue working at Lieben's university laboratory; Abbe was promoted to an extraordinary professor on his research related to technology that he developed with Zeiss; Braun was able to retain his professorship, while he was working on commercial technology. The tolerance also had a material component; the researchers continued using university facilities while working on their own inventions. This was also the case in Britain, and seemed to be the common practice until after World War II. Judging by present-day norms, one may justify the use of such public resources in the case of non-paid researchers, like Aron and Arons who worked as a *Privatdozenten* or Auer who was an unpaid assistant, as an indirect way of payment. Yet, it seems that, unlike today, practitioners like Cady, Pierce and Braun did not find a need to justify their use of university resources.

Science was central to the technological and commercial success of the entrepreneurs discussed here. It was also central to their identity. They viewed and portrayed themselves first as scientists and only secondary as inventors and entrepreneurs. This provides one reason why they put considerable efforts to maintain connections with the scientific establishment and academia. It was also a way to bestow scientific and academic authority on their commercial products. Aron and Abbe continued teaching at institutes of higher education even when the salary they earned for those jobs was virtually negligible relative to their income from their companies. Auer carried out scientific research on which he published in the proceedings of the Vienna Academy and *Monatshefte für Chemie*. Their autobiographical comments and the biographies written by their friends often describe them as preferring basic scientific research on technology and industry. Braun 'sometimes longed to be back in his laboratory doing pure research.' Aron 'wished either to be a professor of mathematics at a small German university or – somewhere a dramaturge of Shakespearian plays.' Cady was 'not a professional inventor' only a 'physicist.' Arons similarly 'would not be happy to be introduced as the inventor of the mercury lamp' but as a physicist. This, I argue, should not be dismissed as merely self-fashioning according to the higher cultural value that science was accorded. Combined with their practice, the rhetoric reflects also their passion for science and their belief in its crucial role for technological innovation.[42]

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[1]Guagnini's survey of the British case and my own search of German speaking academics point at less than a dozen full blown entrepreneurs among the physicists in each country in the four decades before the First World War. I do not regard academic-inventors, like Walther Nernst, who actively looked for companies that would develop and produce their inventions, but neither established a company not went into partnership, as full-blown entrepreneurs. Kormos Barkan, *Walther Nernst and the transition to modern physical science*.

[2] For example, out of the four main examples of full-blown entrepreneurship by academic scientists mentioned in Guagnini's article three fits this move from patenting (William Thomson, Silvanus Thompson and the partners Barr and Stroud. It fits less the path of Lodge, although he also used his patents. I exclude the case of Fleming Jenkin since he had begun his commercial activity before he became a university teacher). See also the cases discussed in this article.

[3] Etzkowitch, "Research groups as 'quasi-firms'"

[4]Here I discuss five cases of academic physicists and chemical physicists who became full blown entrepreneurs in the German speaking world in the decades before the First World War. There are probably few further examples (probably of less successful entrepreneurs) that I have not recognized in my survey.

[5] Maestrejuan, "Inventors, Firms, and the Market for Technology during the Kaiserreich, 1877–1914."

[6] On American entrepreneurs see Morris, "Commerce and Academe."

[7] In the terms used by Marcovich and Shinn for example, this was a transitory science and technology regime. Marcovich and Shinn, "Regimes of Science Production." On the different regimes of science and the distinction between science and technology at the time, see also the introduction to this collection and Mirowski, *Science-mart*, 87-92.

[8]Ibid., 47, 49.

[9] Fox and Guagnini, *Laboratories, Workshops and Sites.*

[10]Smith and Wise, *Energy and Empire*, 705. Inventing and patenting scientific instruments was common also among scientists who were not engaged in devices and invention beyond the

laboratory like Jacques and Pierre Curie, Katzir, *Beginnings of Piezoelectricity*, 23. For the use of patents to protect a scientific method see for example Urey in a letter from 3 May 1933, cited in Heilbron and Seidel, *Lawrence and his Laboratory*, 112.

[11] Heilbron and Seidel, *Lawrence and his Laboratory*, 111

[12]Heilbron and Seidel, *Lawrence and his Laboratory*, 112.

[13]Shaul Katzir, "Scientists as occasional inventors," a talk at the *Society for the History of Technology, 50th Conference*, (Lisbon, October 2008).

[14]Cady, "Saving Ancestors," 1963; Cady, "A Machine for Compounding Sine Curves,"; Cady, Wire-connector, US1093972 patent, filed 11.7.1913; McGahey, "Harnessing Nature's Timekeeper," 47–49.

[15]Katzir, "War and Peacetime Research on the Road to Crystal Frequency Control"; Katzir, "From Ultrasonic to Frequency Standards."

[16] Cady, "Problems Confronting the Independent Inventor," manuscript of a talk 6.8.1963, in AIP archives, 1

[17] By purchasing power 50,000 USD of the late 1920s worth about 650,000$ of 2015. It was probably about ten years of Cady's salary. McGahey, "Harnessing Nature's Timekeeper," 59. David B. Potts, *Wesleyan University, 1910–1970*, 136, 190.

[18] Unfortunately, the sources here, as in other cases described below, do not provide figures for revenue from patents and companies and salaries (needed for comparison). I refer to more precise data when is provided.

[19] Katzir, "War and Peacetime Research on the Road to Crystal Frequency Control."

[20]Quote from Süsskind, "Pierce, George Washington," 605; Saunders and Hunt, "George Washington Pierce."

[21] Arons came from a wealthy banking family and could easily support himself with his own capital.

[22]Wolff, "Die Quecksilberdampflampe von Leo Arons". Arons, "Ueber einen Quecksilberlichtbogen"; Wolff, "Leo Arons —Physiker und Sozialist.".

[23] That Aron was a Jew reduced his chances to get a position and might have motivated him to pursue a career in technology. Katzir, "Aron's Electricity Meters," 476, 479. Katzir, "From Academic Physics to Invention and Industry," 13. This was probably not the case with Arons, whose political activity as a social democrat stood as a center of a public controversy.

[24]Unlike Pierce, who had a secured academic position, Aron could not stop publishing. Yet, the work on technology drifted him away from his expertise in theoretical physics.

[25]Katzir, "Hermann Aron's Electricity Meters"; Katzir, "Scientific Practice for Technology"; Katzir, "From Academic Physics to Invention and Industry."

[26]D'Ans, "Carl Freiherr Auer von Welsbach," A59–92; Müller, "Carl Auer von Welsbach."

[27] The two elements: ytterbium and lutetium, were separated and identified independently by Georges Urbain and Charles James. Adunka, "Carl Auer von Welsbach" 24-26; id. " Carl Auer von Welsbach und die Geschichte der von ihm gegründeten Fabrik in Atzgersdor."

[28] Braun began getting substantial amount after the establishment of Telekom in 1903, which promised him ¼% of the company's capital annually. In 1913 (which might have been the last year in which he received money from the company) he received 34,000 RM from the company, while his university salary was of 9,000 plus 1,500 RM "supplement", Hars, *Ferdinand Braun,* 117, 167-9, 214-5.

[29]Kurylo and Susskind, *Ferdinand Braun*; Hars, *Ferdinand Braun,* 130-181.

[30] Feffer, "Ernst Abbe, Carl Zeiss, and the Transformation of Microscopical Optic," 38.

[31] Maestrejuan, "Inventors, Firms, and the Market for Technology during the Kaiserreich, 1877–1914," 20. Abbe could still patent his inventions in other states.

[32] Shinn *Research-Technology and Cultural Change*, 1–40.

[33] Feffer, "Microscopes to Munitions," 113.

[34] Feffer, "Microscopes to Munitions".

[35] Cahan, "The Zeiss Werke and the Ultramicroscope."

[36] 'Science based industry' means here an industry whose techniques depend among others on scientific empirical and technological findings made before the development of the particular methods. This does neither deny a contribution (usually crucial) of traditional techniques and technological research and development nor a flow of knowledge from technology into science.

[37]Microscopes manufacturing was clearly a field based on artisan techniques. Feffer, "Microscopes to Munitions."Arguably, gas lighting was based on scientific knowledge in its early stages, but that was no longer the case in Auer's time.

[38] Hong, *Wireless: From Marconi's Black Box to the Audion*.

[39] The role of instrument as mediators between science and technology has been pointed out among others in Hong, "Historiographical Layers in the Relationship between Science and Technology."

[40] Shinn, *Research-Technology and Cultural Change*.

[41] As seen in Guagnini's contribution to this volume, Thomson's unique combination of science and entrepreneurship stands out also in the British context, with a closer case of William Stroud, but the latter eventually left the university for his business. The unique place of Thomson makes the attempts to generalize from his case (like that of Marcovich and Shinn) quite problematic.

[42]Jonathan Zenneck quoted in Kurlyo and Susskind, *Ferdinand* Braun, 127; Goldstein (on Aron) “Aus vergangenen Tagen der Berliner Physikalischen Gesellschaft,” 41. Cady’s letter to president of the Academy of Applied Science Robert H. Rines, 25.10.1963 (Cady papers in Archive Center, National Mueum of American History), Arons’ letter to Ludwig Darmstaedter, 29.11.1910, quoted in Wolf, “Aronslampe,” 346.

References

Adunka, Roland. " Carl Auer von Welsbach: Das Lebenswerk eines österreichischen Genies," *Plus lucis* (2000): 24-26.

Adunka, Roland. “ Carl Auer von Welsbach und die Geschichte der von ihm gegründeten Fabrik in Atzgersdor” http://www.i-l-g.at/fileadmin/ILG/symposium/2007/Adunka_Welsbach.pdf (accessed 13.6.16)

Arons, Leo. “Ueber einen Quecksilberlichtbogen, ” *Annalen der Physik,* 47 (1892): 767-771.

Cady, Walter G. “A Machine for Compounding Sine Curves,” *Science* 23, no. 597 (1906): 877–81.

Cady, Walter G. “Problems confronting the independent inventor,” a manuscript of a talk 6.8.1963, in AIP archives.

Cady, Walter G. “Saving Ancestors,” 1963 [Unpublished Autobiography].

Cady, Walter G. Wire-connector, US1093972 patent, filed 11.7.1913, and issued April 21, 1914.

Cahan, David. “The Zeiss Werke and the Ultramicroscope: The Creation of a Scientific Instrument in Context.” In *Scientific credibility and technical standards*, edited by Jed Z. Buchwald, 67-117. Dordrecht: Kluwer Academic, 1996

D’Ans, J. “Carl Freiherr Auer von Welsbach,” *Berichte der deutschenchemischen Gesellschaft* 64, no. 5 (1931): A59–92.

Etzkowitz, Henry, “Research Groups as ‘quasi-Firms’: The Invention of the Entrepreneurial University,” *Research Policy*, 32 (2003), 109–21.

Feffer, Stuart M. “Ernst Abbe, Carl Zeiss, and the Transformation of Microscopical Optics.” In *Scientific credibility and Technical Standards in 19th and Early 20th Century Germany and Britain*, edited by Jed Z. Buchwald, 23-66. Dordrecht: Kluwer Academic, 1996.

Feffer, Stuart M. “Microscopes to Munitions: Ernst Abbe, Carl Zeiss, and the Transformation of Technical Optics, 1850-1914” (PhD diss., University of California, Berkeley, 1994).

Fox, Robert and Anna Guagnini. *Workshops, & Sites: Concepts & Practices of Research in Industrial Europe, 1800-1914* (Berkley: Office of the History of Science and Technology, University of California Press, 1999).

Goldstein, Eugen. “Aus vergangenen Tagen der Berliner Physikalischen Gesellschaft,” *Naturwissenschaften* 13 (1925): 39-45.

Hars, Florian. *Ferdinand Braun (1850-1918): ein Wilhelminischer Physiker* . Berlin: Verlag für Geschichte der Naturwissenschaften und der Technik, 1999.

Heilbron, J. L., and Robert W. Seidel. *Lawrence and His Laboratory: A History of the Lawrence Berkeley Laboratory*. Berkeley: University of California Press, 1989.

Hong, Sungook. *Wireless: From Marconi’s Black Box to the Audion*.Cambridge MA: MIT Press, 2001.

Hong, Sungook. “Historiographical Layers in the Relationship between Science and Technology,” *History and Technology* 15, (1999): 289–311.

Katzir, Shaul. "From Academic Physics to Invention and Industry: The Course of Hermann Aron's (1845-1913) Career,",*Preprint, Max Planck Institute for the History of Science*, 370 (2009).

Katzir, Shaul. “From Ultrasonic to Frequency Standards: Walter Cady’s Discovery of the Sharp Resonance of Crystals,” *Archive for History of Exact Sciences* 62 (2008): 469–87.

Katzir, Shaul. “Hermann Aron’s Electricity Meters: Physics and Invention in Late Nineteenth-Century Germany,” *Historical Studies in the Natural Sciences* 39 (2009): 444–81.

Katzir, Shaul. “Scientific Practice for Technology: Hermann Aron’s Development of the Storage Battery,” *History of Science*, 51 (2013): 481-500.

Katzir, Shaul. *The Beginnings of Piezoelectricity: A Study in Mundane Physics*. Boston Studies in the Philosophy of Science.Dordrecht: Springer, 2006).

Katzir, Shaul. “War and Peacetime Research on the Road to Crystal Frequency Control,” *Technology and Culture* 51 (2010): 99–125.

Kormos Barkan, Diana. *Walther Nernst and the Transition to Modern Physical Science*. Cambridge: Cambridge University Press, 1999.

Kurylo, Friedrich and Charles Susskind. *Ferdinand Braun, A Life of the Nobel Prize Winner and Inventor of the Cathode-ray Oscilloscope*. Cambridge Mass.: MIT Press, 1981.

Maestrejuan, Andrea Rene. “Inventors, Firms, and the Market for Technology during the Kaiserreich, 1877–1914.” Ph.D. diss., University of California, Los Angeles, 2009.

Marcovich, Anne, and Terry Shinn. “Regimes of Science Production and Diffusion: Towards a Transverse Organization of Knowledge.” *Scientiae Studia* 10, (2012): 33–64.

McGahey, Christopher Shawn. “Harnessing Nature’s Timekeeper: A History of the Piezoelectric Quartz Crystal Technological Community (1880--1959).” Ph. D. diss., Georgia Institute of Technology, 2009.

Mirowski, Philip. *Science-mart: Privatizing American Science*. Cambridge MA: Harvard University Press, 2011.

Morris, Susan W. “Commerce and Academe: American Universities as Hosts of Entrepreneurial Science, 1880–1920.” In *Knowledge Management and Intellectual Property: Concepts, Actors and Practices from the Past to the Present*, edited by Stathis Arapostathis and Graham Dutfield, 183–99. Northampton, MA: Edward Elgar Pub, 2013.

Müller, Wolf Johannes. “Carl Auer von Welsbach. ” *Deutsches Biographisches Jahrbuch* 11 (1931, for 1929): 360-375.

Potts, David B. *Wesleyan University, 1910–1970: Academic Ambition and Middle-Class America*. Middletown, CT: Wesleyan University Press, 2015.

Saunders, Frederick A., and Frederick V. Hunt. “George Washington Pierce,” *Biographical Memoirs. National Academy of Sciences*, 33 (1959), 351-380.

Shinn Terry. *Research-Technology and Cultural Change : Instrumentation, Genericity, Transversality*. Oxford: The Bardwell Press, 2008.

Smith, Crosbie, and Norton M. Wise. *Energy and Empire: A Biographical Study of Lord Kelvin*. Cambridge UK: Cambridge University Press, 1989.

Süsskind, Charles. "Pierce, George Washington." *Dictionary of Scientific Biography*. Vol. 10. Detroit: Charles Scribner's Sons, 1975. 604-605.

Wolff, Stefan. “Die Quecksilberdampflampe von Leo Arons.” In *Circa 1903: Artefakte in der Gründungszeit des Deutschen Museums*, edited by O. Blumtritt, U. Hashagen and H. Trischler , 329- 346. München: Deutsches Museum, 2003.

Wolff, Stefan. “Leo Arons —Physiker und Sozialist,” *Centaurus* 41, (1999): 183–212.