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Education and research: the development of German physics in the nineteenth century: part two

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Abstract

At the beginning of the nineteenth century, Heidelberg, Königsberg and Göttingen were the main universities in Germany territory, but thanks to the work and convictions of Wilhelm von Humboldt, Berlin became established as a new academic centre. The University of Berlin opened officially in 1810 and, within a few decades, had become central to the education and training system of the whole of Germany, successfully attracting students, researchers and teachers. Research in science was one of the qualifying points of the education and training system of Germany and the new University of Berlin, which included teachers such as Hermann von Helmholtz and Heinrich Hertz, among others.

Keywords Education · Physics · Prussia · Humboldt · Germany · Helmholtz · Gymnasium · Seminars · Research · University

Berlin is currently one of the most dynamic cities in Europe. With over three and a half million inhabitants, the German capital has become increasingly established in tourism and culture. In addition to a vast network of museums and over forty theatres, it hosts seventy institutions devoted to scientific research, four public universities and twelve private ones with over a hundred thousand students and more than fifty thousand applications each year.[1] Moreover, the Academy of Sciences founded by Leibniz in 1700, the Max Planck Gesellschaft (a public research body funded by the federal government), and the Deutsche Gesellschaft für Geowissenschaft (which promotes geology in research and education) are all based in Berlin.

At the turn of the nineteenth century, Berlin was instead a city with less than two hundred thousand inhabitants,[2] which had recently suffered from famines and sieges during the Napoleonic wars. It was peripheral and expensive for anyone who wanted to move there. In the same period, there were 35 universities in the German States (more than half of them bound to close within a few years), and just under half of the students were enrolled in Halle, Leipzig, Jena and Göttingen.

Already by the end of the eighteenth century, the University of Gottingen, founded in 1737, was considered to be at the forefront for teaching and learning, with high-level professors and students destined to hold important roles in both academic and government fields. Known in all German States for its great university library and the liberal spirit of its environment, during the nineteenth century Göttingen profited from new railway connections that allowed it to free itself from its agricultural origins, but it also experienced periods of controversy. For example, in 1837 the university was faced with a dramatic decline in enrolments following the events that involved seven renowned teachers (*die Göttinger Sieben*) who, due to their liberal ideas and protest against the repeal of the Constitution, were driven out by the university. Among these were the brothers Jakob and Wilhelm Grimm and the physicist Wilhelm Eduard Weber. However, over the years the university became the point of reference for the study of natural sciences and mathematics:

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[1] https://www.morgenpost.de/berlin/article208057005/Berliner-Unis-beliebt-wie-nie-Zahl-der-Bewerbungen-steigt.html.

[2] https://www.berlin.de/berlin-im-ueberblick/en/history/the-royal-capital/.

from Carl Friedrich Gauss to Bernhard Riemann up to Johann Peter Gustav Lejeune Dirichlet, many of the most famous and important mathematicians of the time were teachers at Göttingen, while Weber held one of the chairs in physics.[3]

In addition to Göttingen, other universities played a strategic role in the development of education and knowledge in Germany, most notably Heidelberg and Königsberg. The former, founded in the fourteenth century, is the oldest German university and, just like Göttingen, was known in the nineteenth century for its democratic and liberal spirit. Robert Bunsen, Hermann von Helmholtz and Gustav Kirchhoff are just some of the teachers who embodied what, at the time, was defined *Heidelberger Spirit*.[4] Königsberg, on the other hand, founded in 1544 by Albert I, Duke of Prussia, hosted an exceptional number of students who became particularly well-known over time: from Immanuel Kant to Hermann Minkowski, up to Franz Ernst Neumann. A centre for astronomical research was also established in Königsberg, thanks to the efforts of Friedrich Wilhelm Bessel, and in 1834 a seminar on mathematics and physics was founded, inspired by that of philology. Carl Jacobi and Franz Neumann, professors of mathematics, and of physics and mineralogy, respectively, promoted this new teaching institution destined to spread in a few years in the main German universities and to radically change the conception of teaching and of the very profession of the teacher, who had to combine educational activities with research.

At the time, few thought that Berlin could become a reference for academic education and research in the following decades. The Prussian Academy of Sciences was defined by the advisors of the King of Prussia *corpus mysticum et mortuum*, a meeting place for learned veterans eager to satisfy their own vanity. Friedrich Schleiermacher, theologian and philosopher, rector of the University of Berlin between 1815 and 1816, believed that there were many locations more attractive than Berlin for both students and teachers [10]. Inspired by the ideas of Fichte and Schleiermacher. It was Wilhelm von Humboldt, an official of the Ministry of the Interior of the Prussian government, responsible for the Office of Education, who promoted the most important educational reforms as well as the foundation of a large university in Berlin. The goal of knowledge was to "encourage [the students] to take into account the fundamental laws of science in their way of thinking" [10]; see also [7]. A student of philology at the University of Göttingen, Wilhelm von Humboldt personally wrote to King Frederick William III to present the reasons for a new institution for high-level education in Berlin: the academies, institutes, collections, and major libraries present in Berlin, at the time inadequately valorised, were elements that made the Prussian capital a place of great opportunity [9]. The University of Berlin—with just 256 students and 52 members of the academic staff,[5] including 36 professors and 11 *Privatdozenten*—was opened at the beginning of the winter term of 1810 without special ceremonies. As Humboldt conceived it, it was to be a university that protected freedom of learning (*Lernfreiheit*) and freedom to teach (*Lehrfreiheit*), without a military-style organisation and discipline or an encyclopedic-like education as required by the French model [5]. Humboldt was deeply aware of his own role, of the achievements and the changes taking place, and already in 1810 he said:

> I believe that I can rightly claim that the teaching system in this state has received new impetus from me, and that although I have only been in office for a year, many signs of my administrative work will remain. Something which affects me personally more directly than anything else is the establishment of a new university here in Berlin.[6]

Humboldt's model envisioned that the new university would have state-owned land to ensure financial independence, but this project was abandoned by his successor to the government offices. The approach of students to scientific research through workshops and seminars took place slowly. While until that moment the educational model in Europe to be imitated had been the French one, in the new century it was France itself that sent government representatives to Germany to learn about the progress of German education. Scholars were increasingly attracted to the University of Berlin and the Prussian model: no fewer than 800 physicists and chemists from Great Britain and America obtained a doctorate in Germany during the nineteenth century. Alexander von Humboldt himself, a naturalist and a botanist, the younger brother of Wilhelm and later a private counsellor of the crown, returned to Berlin after 20 years in Paris and many research trips to South America and exercised his influence to promote research and careers of young researchers in natural sciences: by the beginning of the 1830s, Germany had overtaken France in the field of natural sciences. The results obtained in research were fundamental for academic careers and also guaranteed the possibility of a social improvement [9]. Teachers' salaries increased, allowing academics to devote themselves exclusively to university work, and starting in the 1850s German universities were transformed into research institutes. This "research imperative" brought on some innovations: the teachers were obligated

[3] http://www.uni-goettingen.de/en/266241.html.

[4] https://www.physik.uni-heidelberg.de/ueberuns/historisches?lang=en.

[5] https://www.hu-berlin.de/en/about/history/huben_html.

[6] https://www.hu-berlin.de/en/about/history/huben_html.

to new, original results; universities began to provide facilities (libraries, seminars, laboratories) to support research; teaching was revised to introduce students to experimental methodologies; and Prussian teachers joined the *Wissenschaftsideologie* [11].

More than two hundred years after its foundation, the University of Berlin, now the Humboldt-Universität, is today considered one of the most prestigious universities in the world. Over the years a total of 29 Nobel prize winners have studied there. It has hosted many of the greatest German thinkers of the last two centuries, from the philosophers Georg Wilhelm Friedrich Hegel and Arthur Schopenhauer to the founders of the Marxist theory Karl Marx and Friedrich Engels, and to Chancellor Otto von Bismarck. Many physicists have studied, taught and worked in its workshops: from Franz Neumann to Gustav Kirchhoff, from Heinrich Gustav Magnus to Rudolf Clausius, Hermann von Helmholtz, Heinrich Rudolf Hertz, Wilhelm Wien, Albert Abraham Michelson, Gustav Hertz, James Franck, Albert Einstein and Max Planck, just to name a few.

Among all, one of the personalities that indelibly marks the nineteenth century of German physics is Hermann von Helmholtz. Born in Potsdam, he studied in the Gymnasium of his hometown, became soon interested in physics and hoped to study it at university level. Because of the uneasy financial conditions of his family, the young Hermann would have been able to continue his university studies only if he had received a scholarship, but this was available for just a few disciplines supported by the State. Urged by his father, in 1837 he began to study at the Royal Friedrich-Wilhelm Institute of Medicine and Surgery in Berlin, obtaining governmental financial support, on the condition, however, that he serve as an army surgeon in the Prussian army for 10 years after his graduation. In Berlin, Helmholtz had the opportunity to take further courses, including those in physiology and chemistry. Curiously, he did not attend courses in mathematics, although later he became known above all for his contributions in this discipline. He taught himself from the works of Pierre-Simon Laplace, Jean Baptiste Biot and Daniel Bernoulli, as well as works on philosophy, especially by Kant. After his graduation he served in a military regiment in Potsdam, but continued to do research, especially to prove that the functioning of the muscles followed physical and chemical principles and that, had "vital forces" of some other nature existed, then perpetual motion would have been possible.

In that period, between 1842 and 1848, Helmholtz travelled often to Berlin to work in Magnus's laboratory (see the first part of this paper [2]) and to study in his library. During these trips he corresponded with Emil du Bois-Reymond and Ernst Brücke, two of Johannes Peter Müller's students. In 1848 he joined the Physikalische Gesellschaft zu Berlin, founded by du Bois-Reymond, and also joined by Brücke and Werner von Siemens, to support experimental physics condemning "vitalism". The ideas developed in that period were published in his 1847 essay *Über die Erhaltung der Kraft*, in which he states the law of conservation of energy, even if—as can be seen from the title—Helmholtz uses the word *Kraft*, "force", as commonly done at the time: we will have to wait 1880 to see an explicit mention of conservation of energy. The text refers to physical and philosophical arguments and to the works by Sadi Carnot, Benoît Paul Émile Clapeyron, Joule and others. The importance of this theory was immediately evident, so much so that, the following year, Helmholtz was exempted from his duties as an army surgeon and was able to accept the chair of Physiology in Königsberg, which he obtained thanks to the intervention of Alexander von Humboldt. Here he published important works in optics and physiological acoustics, but he had a turbulent relationship with Franz Neumann, professor of Physics in the same university, who challenged him about the priority of some of his ideas [6].

Helmholtz requested and obtained a transfer to Bonn, where he occupied the vacant chair of anatomy and physiology and published an important work on the motion of ideal fluids, treated mathematically with topological methods. However, there were problems here too: the chair also included the teaching of anatomy and the Minister of Education received several complaints due to the alleged incompetence shown by Helmholtz in this area. The scientist reacted harshly to these criticisms, which he believed came from traditionalists reluctant to accept his mechanistic approach, so in 1858 he accepted the offer of a chair in Heidelberg with the promise of setting up a new institute of physiology.

In 1866 he moved increasingly closer to physics, abandoning physiology; when the chair of physics in Berlin became vacant, he applied for it, as did Kirchhoff, who was considered more reliable as a teacher. Kirchhoff, however, refused and in 1871 the position was assigned to Helmholtz, who was able to negotiate the salary and obtain the construction of a new institute of physics. From then on he worked in electrodynamics, discussing the compatibility of Weber's theory with conservation of energy and starting a heated debate that ended without winners, with the acceptance in the 1880s of Maxwell's electromagnetic theory.

At the time when Helmholtz published his first major research work on electrodynamics, no theory in this field had received unanimous approval. Neumann's law of potential, Weber's expression of the distance action between moving charges, and Maxwell's ether theory were approaches that had nothing in common except for the analysis of a closed circuit as the experimental basis. For open circuits these three laws did not lead to acceptable results, and moreover Helmholtz verified that non-physical instabilities could appear in Weber's theory, so it could not be considered satisfactory. The dispute between the two scientists went on for about 10 years. The theories proposed by Weber were the result of overcoming enormous difficulties common to all scientists in conceiving the propagation of electrodynamic action. Indeed, already in the 1820s, Ampère had imagined electrodynamic action as a mechanical stimulation of adjacent layers of electric fluid, despite his elementary laws being formally based on the theory of distance action. In a 1845 letter to Weber, Gauss proposed the idea of the propagation of electrodynamic action over time. Weber agreed with Gauss's solution and, a year later, introduced the idea of a medium among moving charges, which would be fundamental to the theory of electrodynamic interaction. Furthermore, Weber thought that the conduction current should be formed of a current of "positive electricity", which moved in a certain direction, and one of "negative electricity" current, which moved in the opposite direction.

Clausius, among others, criticised this double conduction mechanism and suggested starting from a single "electric fluid", referring to the analogous model of the then known "caloric". The disputes were far from settling down. In 1857, Helmholtz challenged Weber's laws, believing he could have the last word in this regard. He believed, in fact, that in his hypotheses Weber contradicted the law of conservation of "force" (energy), since he had based everything on the action of central forces that depended solely on distance and not on velocity. The disputes continued until 1870, when Helmholtz granted to Weber that, formally, his theory was in accord with the law of conservation of energy, while the structure of the temporal evolution of his laws led to states of particles in motion, with less energy than those at rest. This would have caused instabilities in the current flow. The debate between the two scientists, which also concerned the nature of the mass of electrical corpuscles, carried on until 1880, when the explanation of electromagnetic forces in terms of distance action in the ether gave way to electromagnetic field theory. There was an animated discussion even on the choice of the unit of measurement of electric current: in 1881 Helmholtz proposed using the *ampere* even though, at the time, the term *weber* was widely used for this purpose. Because of their scientific rivalry, Helmholtz could not allow the weber to be made official in honour of a man he so often disagreed with.

Ludwig Boltzmann, Wilhelm Wien and Albert Abraham Michelson were some of Helmholtz's pupils in Berlin. Helmholtz came to entrust Heinrich Hertz—whose remarkable skills he observed from the very first lessons and who was in turn profoundly influenced by Helmholtz's thought throughout his career—with the development of many of his ideas on electromagnetism.[7] Hertz had received a solid and well-rounded education, had studied classical and modern languages, including Arabic, and had arrived in Berlin in 1878 after his studies in engineering at the Technische Hochschule in Munich. When he realised that his interests were different from the studies he had undertaken, he asked his father for support to change his curriculum and devote himself to a life of research. He enrolled in Munich, where he attended courses in physics, astronomy, zoology and mathematics. After a year, Hertz moved to Berlin and became a student of Helmholtz and Kirchhoff. He immediately devoted himself to experimental work and was encouraged to participate in the prize competition organised by the university to solve a problem concerning electrical inertia. Helmholtz, seeing the enthusiasm of the student, reserved an office for him in the faculty and provided him with useful scientific literature, which enabled him to win the first prize. In a letter to his family, Hertz wrote that he had found the area of science in which he felt he could make his contribution. On this occasion Helmholtz sensed Hertz's enormous potential and suggested that he continue doing research, but Hertz preferred to devote himself to his doctorate, which he obtained with honours in 1880, with a work on electromagnetic induction, written in just 3 months.

In the following 3 years Hertz worked in Helmholtz's research group, who in his eyes was the best physicist in the world, and wrote 15 papers on various subjects. He had a great desire to also work as *Privatdozent* and in 1883 he accepted the chair of mathematical physics in Kiel. It was not until 1886 that Hertz started working on the project of the Academy of Sciences of Berlin in which Helmholtz had been trying to involve him since 1879: he developed an experiment to detect the electromagnetic waves that had been theorised by Maxwell, but he did not immediately understand the scope of what he was doing, going so far as to say: "I do not think that the wireless waves I have discovered will have any practical application".[8]

Fame brought him many offers from many universities, including Berlin, but he preferred to accept the chair in Bonn that had become vacant following Clausius's death in 1888. Unfortunately, in those days Hertz had already begun to suffer from physical disorders that would soon be associated with a malignancy that caused his death at the early age of 37. But his experimental activity had already given unexpected results in 1887: he had noticed that the electric discharge between two metallic spheres became brighter when one of the two spheres was illuminated with ultraviolet light. Hertz spoke to his assistant, Philipp Lenard, about a "completely new and extremely mysterious phenomenon".[9]

7 http://www-history.mcs.st-and.ac.uk/Biographies/Hertz_Heinrich.html.

8 http://www-history.mcs.st-and.ac.uk/Biographies/Hertz_Heinrich.html.

9 For more about this, see [1, 3, 12].

The premises for the new century were good. Many opportunities for research and theoretical studies were born. The story of the “mysterious effect” would lead to Einstein’s Nobel prize in 1921 thanks to his explanation of what we now call “photoelectric effect”. There were many fields of research, and many scientists able to overturn the convictions of the time. One of these was Max Planck, at the cutting edge of 20th-century science. Although not fully convinced of the teaching abilities of Helmholtz and Kirchhoff, his teachers in Berlin, he found inspiration in Rudolf Clausius, in his “lucid style and in his illuminating clarity of reasoning” [8] and elaborated quantum theory, which allowed physics to take giant steps and earned him the Nobel prize in 1918 [4].

At the end of a life spent promoting knowledge, Planck stated that

> A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it [8, pp. 33–34].

German physics, and not only, was finding its identity.

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