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Science, industry, and the German *Bildungsbürgertum*

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The most prominent German physicist of the second half of the nineteenth century, Hermann (von) Helmholtz (1821–1894), was also a representative of the *Bildungsbürgertum* – Germany's educated elite which sought to gain social prestige and political influence through intellectual superiority. Having received a humanistic education at a gymnasium and having studied at university, members of the *Bildungsbürgertum* envisioned a more powerful German nation that was also a bearer of culture and a model of individual freedom. David Cahan's new biography of Helmholtz shows impressively how Helmholtz became a leading scientist who created a bridge between modern science and the classical ideals of the *Bildungsbürgertum*.[1] In his *Aesthetics, Industry, and Science*, Norton Wise also portrays Helmholtz as a member of the *Bildungsbürgertum*, but he does so in the broader context of a cultural history that aims to capture entanglements of aesthetics, neohumanism, industry and science.[2]

Bildungsbürgertum, a term introduced in the twentieth century (see below), is an ambiguous term with both social and cultural meanings. The members of the nineteenth-century *Bildungsbürgertum* belonged to the middle classes; they included professors – mostly of theology, law, medicine, philosophy and the humanities – teachers, parsons, lawyers, physicians, writers, artists, high-level state officials, and also a number of scientists. The *Bildungsbürgertum* cultivated aesthetic and humanistic ideals and argued for humanistic education, including knowledge about Greek and Latin, ancient art and philosophy, classical German literature, music, painting and theatre. Helmholtz was a typical *Bildungsbürger* in the full sense of the term, both with respect to his social background and his cultural ideals and accomplishments. His father was a philosopher and teacher at the Potsdam Gymnasium, who made clear to his son that it was a man's *Bildung* and inner intellectual life that distinguished him. He had also

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[1]David Cahan, *Helmholtz: A Life in Science* (Chicago and London: The University of Chicago Press, 2018).
[2]M. Norton Wise, *Aesthetics, Industry, and Science: Hermann von Helmholtz and the Berlin Physical Society* (Chicago and London: The University of Chicago Press, 2018).

attended the Potsdam Gymnasium and then studied medicine. Sharing the values and ideals of the *Bildungsbürgertum,* even late in his scientific life he was still convinced that knowledge of Greek prepared students well for university and gave them 'the fine formation of taste' (quoted in Cahan, *Helmholtz*, p. 657). He also possessed outstanding knowledge of philosophy and the fine arts, and he even linked scientific knowledge with theories of art. The question arises, however, of whether Helmholtz was also a typical nineteenth-century German scientist, which concerns both Cahan's and Wise's book.

David Cahan is well known as *the* expert on Helmholtz and the world he inhabited. During the last thirty years he has published widely on this subject, and his new biography is indeed a cornucopia of stories and facts. Over almost eight hundred pages (plus notes, references and an index), it follows in chronological order Helmholtz's academic career, utilizing all of his scientific, philosophical and popular articles and books, his correspondence, and official documents. It also portrays Helmholtz as an individual – his passions, friendships, marriages, family, state of health, and many additional private items that Cahan conceives of as elements constituting the 'support system for his complex scientific thought and practice' (ibid., p. 4). Although Cahan puts a strong emphasis on the 'intellectually off-scale individual' and the 'scientific genius' (ibid., pp. 3–4), his biography does not heroize Helmholtz; it also portrays him as a poor teacher, a possessive husband, a Prussian with military principles and a man who shared the anti-Semitic resentments of his contemporaries. Characterizing Helmholtz as a *Bildungsbürger*, Cahan also sheds light on his social and cultural environment, even though the book's structure – its mingling of stories about Helmholtz's scientific activities with details about his private life – almost inevitably moves the outstanding individual to the centre of the stage.

Helmholtz grew up in the city of Potsdam, the second residence of the Prussian king and a garrison city. After graduating from the Potsdam Gymnasium, he studied medicine at the Prussian military medical school in Berlin, as his father did not have the means to finance a university education. He became a student of the famous medical professor Johannes Müller and came in close contact with a group of his students who had strong interests in physiology. The members of this group, which included Emil du Bois-Reymond and Ernst Brücke, called themselves 'organic physicists', since they aimed at doing physiology in a new way, based on physical concepts and experiments involving physical apparatuses, precision measurement, and mechanically recorded graphs. In 1842, Helmholtz received a medical degree and subsequently served for five years as an army physician and military surgeon. He also maintained his connections with Müller's circle and began to carry out research on physical and physiological topics, including animal heat and muscle contraction, which he soon extended to studies of the mechanical work done by a muscle. In 1845, he became a member of the newly founded Physical Society of Berlin. In 1847, he read to the Physical Society his memoir *Über die Erhaltung der Kraft* (On the Conservation of Force), in which he elaborated the principles of what later became known as the conservation of energy. As Cahan observes, the essay linked the organic physicists' programme with the long philosophical search for a unifying principle in nature and the more recent physical studies of the correlation of forces.

In 1850, when he was teaching at the Prussian University of Königsberg, Helmholtz reported his discovery of the velocity of the nerve impulse, which was based on his measurements of the time elapsed after a muscle's excitation and its contraction. This report and another one following in 1852 are now famous for their use of mechanically recorded graphs, and in Wise's book they have a prominent place. At the time, however, it was another work that won Helmholtz a broader European reputation. In connection with lectures on physiological optics, he invented the ophthalmoscope, an instrument that produces a magnified image of the retina. In the 1850s, Helmholtz also studied colour theories and elaborated the distinction between additive and subtractive colour mixtures. He incorporated this and other results concerning physiological optics in his three-volume *Handbuch der Physiologischen Optik* (*Handbook of Physiological Optics*, 1856–1867), the first volume of which appeared in 1856, a year after he had moved to the Prussian University of Bonn.

At the University of Bonn, Helmholtz taught anatomy and physiology, including physiological acoustics. He also turned to the scientific analysis of the flow of water, thus joining, as Cahan observes, a long research tradition that interconnected hydrodynamics (physical theory) and hydraulics (engineering practice). His kinematic and mathematical studies in this field showed that he mastered the use of differential equations and, with them, mathematical physics. Borrowing from diverse additional sources, he produced a mathematical theory of the behaviour of fluids in terms of vortex motion. From 1858 until 1871, Helmholtz was professor of physiology at the University of Heidelberg, where he headed a well-equipped institute. In addition to his studies of physiological acoustics and optics, he began to devote more time to strictly physical topics, including hydrodynamics and electrodynamics. The 1860s, Cahan thus observes, were a turning point in Helmholtz's scientific career: his interests shifted from physiology towards physics.

In 1871, Helmholtz was nominated professor of physics at the University of Berlin. During the following two decades, he became not only Germany's most famous physicist but also followed in the footsteps of Alexander von Humboldt as a leading science popularizer, science manager, scientific advisor to the king, and high-society man. His research first focused on the rapidly developing field of electrodynamics, but he soon also conducted research on optics, especially the theory of the microscope (in parallel to Ernst Abbe's work), atmospheric physics, electrical metrology and electrochemistry, which set the stage for chemical thermodynamics. In the 1880s and 1890s, he extended his studies to chemical thermodynamics, monocyclic systems (mechanics) and the principle of least action. In addition, he was scientifically active in the field of psychology. Shortly after his arrival in Berlin, Helmholtz also became a member of a state commission devoted to improving precision technology in industry, the military and the sciences; a member of a committee that promoted scientific mechanics for the advancement of both science and industry; and the chairman of a committee to test guided air travel. Later on, he also served in committees supervising the Meteorological Institute and the Geodetic Institute. He co-founded the Imperial Institute of Physics and Technology (see below), was president of the Berlin Physical Society (from 1878), and co-edited the prestigious journal *Annalen der Physik and Chemie*. His and his wife's salon was a centre of attraction for members of the court, artists, scientists, engineering professors, influential industrialists and high-ranking military men. Hence, it comes as no surprise that Helmholtz was ennobled in 1883.

When Helmholtz returned to Berlin in 1871, the city had become the capital of the unified German empire and a booming industrial centre with burgeoning enterprises such as the electrical engineering company Siemens & Halske and Borsig's machine works. The University of Berlin was rapidly expanding the number of its students, professorships and physical facilities. Helmholtz immediately set out to organize the construction of a new physics institute, which was completed in 1878. The new university building included not only a well-equipped physics institute, whose laboratories were probably unsurpassed among physical laboratories of the time, but also a second chemical institute, a physiological institute, a pharmacological institute and an institute of technology (*Technologie*). Technology and similar useful sciences such as agricultural science and the science of forestry had been taught at the Berlin University since its foundation in 1810.

In the last third of the eighteenth century, the German states also began establishing more specialized schools of forestry and of agriculture as well as mining academies (*Bergakademien*), polytechnical schools, and schools of civil engineering and architecture (such as the *Bauakademie*). This was followed by the foundation of technical universities in the second half of the nineteenth century and technological-scientific research institutions such as the Imperial Institute of Physics and Technology (Physikalisch-Technische Reichsanstalt, founded in 1887), of which Helmholtz was the co-founder (with Werner Siemens) and first president. Cahan, who is the author of an excellent monograph on the Imperial Institute, comments on Helmholtz's commitment to founding the Reichsanstalt: 'Helmholtz wanted to retire from teaching; this was one important reason he helped found the Reichsanstalt and eventually accepted its presidency' (ibid., p. 618).[3] He also emphasizes that Helmholtz was the director of the

[3]David Cahan, *An Institute for an Empire*: *The Physikalisch-Technische Reichsanstalt, 1871–1918* (Cambridge: Cambridge University Press, 1989).

Physical Section of the Reichsanstalt, 'devoted to fundamental ("pure") science,' and not of its Technical Section, 'devoted to applied science' (ibid., p. 619), and that Helmholtz 'hoped to devote the remaining years of his life to doing research in theoretical physics' (ibid., p. 687). In contrast, Cahan also shows that precision measurement was part of both science and technology, and that the *Reichanstalt* was a mixed technological-scientific institution for advancing precision measurement in science as well as in industry and the military.

Even though Helmholtz held theoretical physics in higher esteem than he did technological science, he was far from driving a wedge between these two forms of science. Like the industrialist Werner Siemens, co-founder of the Reichsanstalt, Helmholtz 'was especially concerned about the rapidly emerging field of electrical metrology and about preventing the British and the French from gaining the upper hand in setting electrical standards' (ibid., p. 617). Cahan also points out that Helmholtz was the defining figure in planning and supervising the actual construction of the Reichsanstalt, and that he organized collaboration between the staff of its Physical and Technical Sections with their colleagues at the Berlin University and the Technical University of Berlin (*Technische Hochschule*, founded in 1879). Furthermore, Helmholtz's expertise about precision measurement and instrument making also carried over to other fields of 'applied physics', as Cahan observes in the case of his research on the microscope in the 1870s and his support of Ernst Abbe, who worked with Carl Zeiss, the owner of a mechanical and optical instrument-making firm in Jena. The 'dramatically increasing interaction of physics and technology', Cahn concludes, was a driving force for both Helmholtz and Abbe (ibid., p. 444).

Helmholtz was an exceptional scientist and, in many respects, a *Bildungsbürger*. He not only made a stand for the humanistic education of Germany's scientists and for the pursuit of philosophy, literature, music, painting and theatre, but he also actively interrelated knowledge about science with knowledge about the fine arts. Being convinced 'that beauty is subject to laws and rules dependent on the nature of human intelligence' (quoted in Cahan, *Helmholtz*, p. 271), he argued that there were substantive connections between sensory physiology and the theory of the fine arts. His treatise on *Tonempfindungen* (On the Sensations of Tone, 1863) was a bestseller in the world of music and beyond; Cahan details its content and reception in Germany, France, Britain and America. Likewise, his lectures on physiological optics and painting (1871–1873), which analyse the painter's artistic categories of form, shade, colour and harmony of colour, won him a high reputation among artists and scholars.

Helmholtz's aesthetic principles and his weaving together of scientific knowledge and knowledge about the arts also play a key role in Norton Wise's *Aesthetics, Industry, and Science*. In Wise's cultural history, Helmholtz is presented as the tip of the iceberg of a much broader cultural movement that aspired to systematically link aesthetic and neohumanistic ideals with science as well as with industry. In particular, connections of aesthetics with industry, Wise observes, 'have not usually been considered either together or in their interrelation with natural science' (Wise, p. X). Aesthetics is an important theme not only for the content of Wise's book but also for its design: the book contains an enormous number of beautiful pictures, photographs, diagrams and other illustrations, many of which are rare.

Wise's beautiful and thought-provoking book addresses many issues: the institutional environment of Helmholtz and his scientific allies, including the University of Berlin, Berlin's technological schools, military schools and Schinkel's art museum; neoclassical architecture, sculpture, drawing and painting; the reformed Prussian army; programmes of industrialization and industrial plants; the *Bildungsbürgertum* and the Physical Society of Berlin; Helmholtz's philosophical and physical studies underlying his *Erhaltung der Kraft* and his physics-based physiology; values and ideals such as neohumanism, aesthetics, *Bildung*, liberalism and modernity. The book is structured along these issues but also reflects Wise's view of the relationships between all of them. Each single chapter approaches its subjects from a fresh angle and is rich in information and ideas. For example, chapters two through four provide an excellent overview of Berlin's new technological and military schools, including information about their curricula, teachers and students. Chapter eight details Helmholtz's physiological experiments in the period between 1848 and 1852 along with his new precision instruments and his method of mechanically recorded graphs – issues that are mentioned only briefly in Cahan's biography.[4] Although Wise zooms in on events in Berlin in the period between the 1820s until the 1850s, his book goes well beyond this time period and the strictly local level of Berlin.

In what follows, I focus on two of Wise's arguments concerning the relationships between aesthetics, neohumanism, science and industry. In chapters two and three Wise discusses a number of different institutions including the *Altes Museum*, a new art museum designed by Karl Friedrich Schinkel and opened in 1830, the Berlin University, the Berlin School of Civil Engineering and Architecture (*Bauakademie*) and the Industrial Institute (*Gewerbeinstitut*). At first glance, this arrangement is counter-intuitive, but it is helpful to introduce an important vehicle for Wise's argument concerning interactions between aesthetics, neohumanism and science: the term 'museum'. 'I am especially interested in "museums" *in an expansive sense*' Wise states (ibid., p. 17, my emphasis). There follows discussion of Schinkel's projection of the concept of *Bildung* into architecture and of Berlin's 'museums of science'.

As to 'museums of science', the University of Berlin possessed an anatomical, a zoological, a botanical and a mineralogical collection, which were renamed 'museums' in the years shortly after the university's foundation in 1810.[5] It is

[4]On these experiments, see also Frederic L. Holmes and Kathryn M. Olesko, 'The Images of Precision: Helmholtz and the Graphical Method in Physiology', in *The Values of Precision*, ed. by M. Norton Wise (Princeton, NJ: Princeton University Press, 1995), pp. 198–221.

noteworthy that these scientific collections were renamed museums. The new name clearly created a *terminological* relationship with Schinkel's museum of art. It should be noted, however, that these collections had existed long before the foundation of the Berlin University, either in their entirety or in scattered parts. The anatomical collection was largely identical with the 'anatomical theatre' of the former Military-Surgical School of Berlin (founded in 1723/24); the zoological and botanical collections came from the 'natural cabinet' and other collections of the Royal Academy of Sciences of Berlin as well as from the Royal Botanical Garden supervised by the Academy of Sciences; the mineralogical collection was transferred in its entirety from the state's mining administration and was long shared between the university and the mining administration. Neither the specimens nor their ordering on shelfs and in closets were changed by giving the collections a new name. Moreover, scientific and technological collections of drawings, models and machines existed also at the *Bauakademie* (founded in 1799) and at the Industrial Institute (founded in 1821), and these collections were actually named 'collections'.

With respect to the collected items and design of exhibition, Schinkel's art museum and Berlin's museums of science were very different institutions. What then was their common denominator? Wise considers these institutions as manifestations of the growing importance of the *Bildungsbürgertum* and its united effort to turn its ideals into reality. From this perspective, both Schinkel's art museum and the Berlin University's scientific museums represented the *Bildungsbürgertum's* aesthetic values, inventiveness, and ideal of active self-formation (*Bildung*), and all of them were 'residences of the muses' (ibid., p. 75). Referring to the 'collections' of technical drawings, models and machines the Industrial Institute had access to, Wise also states that 'they played a role similar to what Schinkel proposed for the presentations of works of art at the Altes Museum, as analogues of scientific experiments that looked toward new creations' (ibid., p. 75). Moreover, Wise extends this view to the argument that Berlin's museums of science promoted, or were even the main origin of, the experimental laboratory sciences in Berlin (and beyond). He thus proposes: that 'it is in relation to the museum that we need to see the emergence of experimental laboratory science on a broad scale'; that the 'pressure for experimental laboratory research and measurement grew within the museums'; that the 'museums were, so to speak, the culture medium for experimentation' (ibid., p. 33, 35); and that the Industrial Institute's collections 'illustrate the way in which museums (as residences of the muses) gave birth to laboratories and collecting to experiments' (ibid., p. 75).

It should be noted in this context that 'laboratories' began to proliferate in the sixteenth century and that chemistry had been an experimental laboratory

[5]Heinz-Elmar Tenorth (ed.), *Geschichte der Universität unter den Linden, 1810–2010, Genese der Disziplinen: die Konstitution der Universität* (Berlin: Akademie Verlag, 2012).

science long before the nineteenth century. Until the late eighteenth century, the term laboratory referred almost exclusively to houses or rooms where chemical operations were performed.[6] For carrying out chemical analyses and other kinds of chemical operations, chemists needed specific equipment, including large furnaces, that could not be moved around and was thus located permanently at one specific site: the 'laboratory'. Hence, Berlin was a city of laboratories and experimental laboratory science long before the founding of its university (1810) and of Schinkel's art museum (1825–1830).[7] The Berlin University had access to the large chemical laboratory of the Royal Prussian Academy of Sciences, which had been established in 1753–1754 and renovated under Martin Heinrich Klaproth's supervision in 1801–1802. There was an arrangement between the university and the academy that the university's 'first professors' of chemistry (first Klaproth, then Eilhard Mitscherlich) used the laboratory both for their research and their teaching. In its early years the university had another, much smaller, laboratory used by the chemist and professor of botany Heinrich Friedrich Link. The chemist and professor of technology at the Berlin University, Sigismund Friedrich Hermbstaedt, had a large laboratory house at his disposal, built in 1802 and financed by the state. From 1774, the mining administration possessed a laboratory, which was also used for chemical-mineralogical analysis and experimental studies of materials. The Royal Prussian Porcelain Manufactory, established in 1763, had a laboratory where Alexander von Humboldt and Klaproth had carried out chemical experiments in the 1780s. There were also more than twenty private laboratories located in Berlin's apothecary shops, many of which had long been sites of chemical analysis and experimentation. For example, the most renowned German chemist of the late eighteenth century, Klaproth, performed many of his precise chemical analyses and discoveries of new mineralogical substances in the laboratory that belonged to his apothecary shop. In the nineteenth century, the Industrial Institute had access to three 'laboratories', and these were chemical laboratories as well. Furthermore, in 1845 the university professor of chemistry, technology and physics Gustav Magnus opened the first physical laboratory in Berlin.

It is perhaps no coincidence that Magnus was also a chemist and thus familiar with the advantages that a laboratory offered for sustained experimentation. By contrast, we have no evidence that Magnus's physical laboratory depended on the Berlin University's anatomical, botanical, zoological and mineralogical museums. Nor do we have evidence that the chemical laboratories associated with the Industrial Institute depended on collections of technical drawings, mechanical models and machines. If we go further back in history, there was at best occasional interaction between Berlin's chemical laboratories and its

[6]Pamela H. Smith, 'Laboratories,' in *The Cambridge History of Science*, Vol. 3*: Early Modern Science,* ed. by Katharine Park and Lorraine Daston (Cambridge: Cambridge University Press, 2006), 290–305; Ursula Klein, 'The Laboratory Challenge: Some Revisions of the Standard Picture of Early Modern Experimentation,' *Isis* 99, no. 4 (2008), 769–82.
[7]Ursula Klein, *Technoscience in History: Prussia, 1750–1850* (Cambridge: MIT Press, in press).

natural history collections. The material culture of chemical laboratories differed clearly from that of natural-historical and anatomical collections, and chemists got the substances for their experiments not from scientific collections but from merchants, apothecaries and mining officials or, alternatively, via scientific exchange systems. Furthermore, neither the collections of the Industrial Institute nor the mineralogical, zoological and botanical museums of the Berlin University were themselves sites of experimentation. An exception is the anatomical museum, where Johannes Müller did his dissections and occasionally carried out physiological experiments as well (ibid., pp. 204–05).[8] All of this brings into question Wise's argument that 'the pursuit of experimental science emerged from within the museum' (ibid., p. XV) – and with it the argument that neohumanistic ideals and aesthetic values played a significant role for the emergence of the experimental laboratory sciences more broadly.

We now come to Wise's argument that aesthetics and Berlin's industry were somehow interrelated. The chapter that comes closest to this issue is chapter six, concerned with the Physical Society of Berlin. The Physical Society was founded in 1845 by a group of six scientists, among them Helmholtz's friend Emil du Bois-Reymond. As Wise points out, its main goal was the promotion of instrument-based experimental knowledge, mainly through the publication of its journal *Fortschritte der Physik*. In its early years, the Physical Society was a socially diverse group, including not only scientists but also aristocrats, state officials, military engineers and, more importantly for Wise's argument, entrepreneurs, instrument makers and two industrialists (Siemens and Halske). We have seen above that Helmholtz's Imperial Institute of Physics and Technology connected research in science with research in technology. The Physical Society is yet another example of a German institution whose scientists and technical experts came together to pursue shared goals. Wise is the first historian to identify almost all of the Physical Society's sixty-one members (in the first two years after its foundation), including the practical men of more humble social origins. He provides impressive examples of how the society's scientists and instrument makers cooperated in reviewing and writing papers for the society's journal *Fortschritte*.

The fact that there was a group of more than twenty instrument makers, industrialists and entrepreneurs (concerned with artificial mineral water, wine, agriculture, pharmacy, china and *Galvanoplastik*) among the society's early members naturally leads to the question of what these practitioners did on a daily basis, and whether they created connections between science and industry. As the practitioners, like the scientists, were interested in new instruments and instrument-based experimentation, it is plausible to assume that they transferred related knowledge to their own business. But Wise goes a step further. He also contends that the Physical Society was 'guided by neoclassical aesthetics and the

[8]See also Laura Otis, *Müller's Lab* (Oxford: Oxford University Press, 2007).

neohumanist educational ideal of *Bildung* as self-realization' (ibid., p. X). And he seems to presuppose that the society's instrument makers, entrepreneurs and industrialists also shared the aesthetic and neohumanistic ideals of its leading scientists, such as du Bois-Reymond and Helmholtz. Hence, he argues that the society's practical members implemented aesthetics in Berlin's industry. Both parts of the argument are questionable, but let us first consider the second part. As evidence, Wise mentions *Galvanoplastik* (galvanic forming or sculpture), which was produced by one society member (ibid., p. 217) and was also a topic of reviews in the Society's journal *Fortschritte*. *Galvanoplastik*, Wise asserts, is an example that goes 'directly to the character of the Society' (ibid., p. 220). Clearly, Wise has a point here, but how far can this example be generalized? What is the evidence that Berlin's industrialists such as Borsig, Siemens and Halke established a type of industry that was marked by aesthetic values (and neohumanistic ideals?) and thus differed significantly from the industry in Manchester capitalism?

As to the assumption that the Physical Society's instrument makers, entrepreneurs and industrialists actually accepted du Bois-Reymond's and Helmholtz's ideals of *Bildung*, a closer look at the meaning of the terms *Bildung* and *Bildungsbürgertum* might be helpful. The two terms play a crucial role not only in Wise's cultural-history approach to nineteenth-century German science but also in Cahan's biography. In the middle of the nineteenth century many engineers and technical experts who had graduated at the new scientific-technological schools claimed to possess *Bildung*. But their interpretation of what *Bildung* meant was not identical with the traditional humanistic concept of *Bildung*, which began to proliferate in the eighteenth century; nor was it identical with the nineteenth-century neohumanistic concept of *Bildung* in the sense of knowledge-based 'self-realization', 'cultivated self', and 'active self formation' (Wise's translations). Rather, it referred to the combination of 'theory and practice' at the new technological schools and thus also included specialized training (*spezielle Fachausbildung*) and '*praktische Bildung*' (practical knowledge).[9] By the end of the century the meaning of *Bildung* had been extended even further, which caused the author of the entry *Bildung* in Meyer's *Konversationslexikon* (1890) to complain that *Bildung* 'is a preferred catchword of our period that shares with the majority of favourite words the fate that its contours, as is the case with a worn coin, has become blurred and its meaning ambiguous'. This view contributes to some doubt that the practical men among the members of the Berlin Physical Society actually shared Helmholtz's and du Bois-Reymond's neohumanistic educational ideal of *Bildung*.

The term *Bildungsbürgertum* was introduced in the early twentieth century, in a period when the traditional knowledge economy had undergone deep changes.[10] In

[9]Klein, *Technoscience in History*.
[10]Berlin-Brandenburgische Akademie der Wissenschaften (ed.), *DWDS – Digitales Wörterbuch der deutschen Sprache. Das Wortauskunftssystem zur deutschen Sprache in Geschichte und Gegenwart*, https://www.dwds.de/wb/Bildungsbürgertum.

addition to the *Bildungsbürgertum*, the highly specialized empirical scientists as well as the engineers and technical experts (*Techniker*) educated and trained at Germany's technical universities were now recognized as a new academic elite. The social prestige of this new elite relied no longer on the canon of humanistic *Bildung* but rather on school-based scientific and technological knowledge as well as on technical knowledge directly acquired in practice. As the historian Jürgen Kocka has pointed out, in the eyes of the *Bildungsbürgertum*, engineers and *Techniker* had a low social prestige because of their low *Bildung* in the sense of lack of humanistic *Allgemeinbildung* (general knowledge).[11] The term *Bildungsbürgertum* thus served not least the goal of demarcating the humanistically educated elite from the new, competing elite of academically trained scientific experts and engineers. As a matter of fact, the use of the term *Bildungsbürgertum* has never been extended to all educated middle class men and women; it has rather served to actively exclude the engineers and industrialists as well as the allegedly narrow-minded scientific experts and empirical scientists. Hence, a great number of nineteenth-century German scientists – among them many chemists, mineralogists, botanists, geologists and meteorologists – do not fit into the twentieth-century category of *Bildungsbürger*. Frequenting the society of technological scientists, engineers and industrialists, these scientists had more pragmatic, down-to-earth goals and interests than the *Bildungsbürger* scientists, and there is no evidence that they implemented aesthetic and neohumanistic ideals into their science.[12]

In their different approaches, Wise's and Cahan's books are complementary works that greatly illuminate Prussian and German science, which was long standing in the shadow of British and French science. The two books also contribute significantly to our understanding of the fact that at the end of the nineteenth century Germany had become a leading industrial and scientific nation. Cahan's book is a biography in the context of German *Bildungsbürger* science. Wise's book is a cultural history of ideas and institutions, with special attention also to the towering figure of Helmholtz. Both Wise and Cahan show compellingly that Helmholtz was an iconic figure who became a model as German *Bildungsbürger* scientist. Helmholtz is not least an interesting figure because he was a *Bildungsbürger* scientist, who, unlike the twentieth-century *Bildungsbürgertum*, had close contact with instrument makers, engineers and industrialists, and shared their goal of (ultimate) practical utility of science.

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No potential conflict of interest was reported by the author(s).

[11]Jürgen Kocka, *Unternehmensverwaltung und Angestelltengesellschaft am Beispiel Siemens 1847–1914* (Stuttgart: Klett 1969), pp. 167–68.

[12]Klein, *Technoscience in History*. See also Kathryn M. Olesko, 'Germany,' in *The Cambridge History of Science, Vol. 8, Modern Science in National, Transnational, and Global Context*, ed. by Hugh Richard Slotten, Ronald L. Numbers, and David N. Livingstone (Cambridge: Cambridge University Press, in press).