Introduction

In 1887 a private philanthropist and the imperial German government combined resources to establish an institution, the Physikalisch-Technische Reichsanstalt – in English, the Imperial Institute of Physics and Technology – which was to represent the best of both pure science and industrial technology. The Reichsanstalt's scientific studies, like that on blackbody radiation, which helped usher in the new quantum physics; its institutional commitment to physical metrology, for example in the development of electrical standards needed by science and industry; and its testing and certification work on scientific instruments, measuring apparatus, and materials – these and other activities demonstrated some of the intellectual and social benefits that science and technology could contribute to modern society and to the modern nation-state. By the turn of the century, the Reichsanstalt stood at the forefront of institutional innovation in science and technology, uniting diverse practitioners and representatives of physics, technology, industry, and the state. For many in the scientific, technological, and industrial worlds, the Reichsanstalt in Berlin came to symbolize, in another sphere, the young German Reich's newly acquired political power and authority. The Reichsanstalt was an institute for an empire.

Success soon brought imitators. In 1898, barely a decade after the Reichsanstalt's founding, the mathematician Felix Klein, with the aid and support of the Prussian Kultusministerium (Ministry of Culture) and a group of German industrialists, established the Göttinger Vereinigung zur Förderung der angewandten Mathematik und Physik (Göttingen Association for the Advancement of Applied Mathematics and Physics). Like the Reichsanstalt, it helped unite and advance physics and technology; but unlike the Reichsanstalt, it also trained advanced students in these disciplines.[1]

German chemists also viewed the Reichsanstalt as a model institution for advancing their discipline. During the early years of the twentieth century, several leading German academic chemists – including Emil Fischer, Walther Nernst, and Wilhelm Ostwald – and chemical firms – with representatives from the chemical giants Agfa, BASF, and Bayer – espoused the idea of a Chemisch-Technische Reichsanstalt (Imperial Institute of Chemistry and Technology) that they hoped would do for academic and industrial chemistry what the Physikalisch-Technische Reichsanstalt was already doing for physics and its allied industries. The proposed Chemische Reichsanstalt was established in 1921. In 1910, however, it formed the core idea of a proposal that led to the establishment of the most prestigious scientific institutes in twentieth-century Germany: the Kaiser-Wilhelm-Gesellschaft (Kaiser William Society), founded in 1911 and known since 1946 as the Max-Planck-Gesellschaft zur Förderung der Wissenschaften (Max Planck Society for the Advancement of the Sciences). Not surprisingly, the Gesellschaft's first three constituent institutes were devoted to chemistry.[2]

The Reichsanstalt had imitators abroad as well as at home. In 1895, Douglas Galton, the reigning president of the British Association for the Advancement of Science, began promoting an idea suggested in 1891 by Oliver Lodge: the construction of a British national physical laboratory to help advance measuring physics and precision instrumentation, just as the new German Reichsanstalt was doing. Galton complained that British scientists had to resort to assistance from Paris and Berlin in order to standardize their precision instruments. To make Britain more independent in metrological matters and to help advance science-based industry there, he called for "the extension of the Kew Observatory, in order to develop it on the model of the Reichsanstalt," going so far as to display detailed construction plans of the Reichsanstalt and to analyze its organization.[3] Galton and a stellar crew of British scientists – including Lord Rayleigh, Joseph Lister, Henry Roscoe, and Michael Foster – called for a scientific institution "which should do for the United Kingdom that which the Reichsanstalt did for Germany."[4] By 1898 British scientists and industrialists had persuaded the Treasury to approve their plans; a year later the new National Physical Laboratory in Teddington began operations.[5]

American scientists, engineers, and manufacturers were also well acquainted with the Reichsanstalt's achievements in standardization and in conducting research in science-based technology aimed at helping industry.[6] In 1897, Henry Pritchett, the director of the American government's five-man Office of Standard Weights and Measures, hired a physicist, Samuel W. Stratton, to review the office's work "and to recommend . . . a plan for its enlargement into a more efficient bureau of standards, which might perform in some measure for this country the work carried on by the Reichsanstalt in Germany."[7] Pritchett and Stratton's campaign for an American equivalent of the Reichsanstalt found strong support from physicists, among others. George Ellery Hale, astrophysicist and scientific empire builder, advised Stratton that American engineering industries required an American standards and testing laboratory that would provide the same sort of "guarantee of excellence furnished by the authority of the Reichsanstalt."[8] Hale's distinguished colleague, Joseph S. Ames, professor of physics at The Johns Hopkins University, argued similarly that both American science and American industry would receive untold benefits from an American institute like the Reichsanstalt. Ames claimed that "everyone" agreed "that the tremendous advance in all branches of manufactures in Germany, in the last ten years, is due largely, if not entirely, to the work of the Reichsanstalt."[9] Pritchett and Stratton soon found that, in addition to the warm support of physicists like Hale and Ames, they also had the backing of major congressional and government figures. In 1901, their efforts came to fruition: The United States Congress established a National Bureau of Standards. Less than a year later, the bureau's first president, Samuel W. Stratton, was in Berlin, as *Science* magazine reported, "studying the Reichsanstalt with a view to the buildings to be erected at Washington for the newly established Bureau of Standards."[10]

The Reichsanstalt retained its preeminence at least until the outbreak of the First World War, providing the model, further, for Japan's Institute of Physical and Chemical Research.[11] But by 1914 the compliment of imitation had turned into the threat of competition. The National Physical Laboratory and the Bureau of Standards as well as other institutional circumstances within Germany challenged the Reichsanstalt's hegemony in metrology and its previously unmatched research opportunities.[12]

The Reichsanstalt's scientific and technological accomplishments, its importance for German industry, society, and the state, and its role in inducing others to establish complementary or similar institutions in Germany and abroad make it a natural object for historical study. Yet apart from a number of studies of the Reichsanstalt's origins,[13] and apart from three celebratory chronicles by the Reichsanstalt itself and by its post-World War II successor, the Bundesanstalt,[14] there has been to date no scholarly study of the Reichsanstalt in Imperial Germany.[15] Two reasons help explain this historiographical gap: First, Allied bombing of Berlin during World War II destroyed about 40 percent of the Reichsanstalt's buildings, whose contents would doubtless have greatly aided any would-be historian.[16] Valuable Reichsanstalt archival materials were also lost due to combat in Berlin.[17] Second, the sheer size of the institution and the volume of its activities make it difficult to organize the study of the Reichsanstalt. In short, documentary source material and a thematic approach are needed for a scholarly and manageable history of the Reichsanstalt in imperial Germany.

The present study of the Reichsanstalt is the evolutionary product of two previous studies that addressed these needs. In the first, a doctoral dissertation, I located and organized a good deal of previously unexploited documentary source material.[18] Three sets of archival holdings proved particularly valuable for that (and this) study. At the Siemens Museum in Munich, I found materials on Werner von Siemens and, even more important, copies of the minutes of the meetings of the Reichsanstalt's Board of Directors (Kuratorium), minutes that had been destroyed or lost during the bombing of Berlin in World War II. At the Zentrales Staatsarchiv in Potsdam (in the German Democratic Republic), I found extensive Reichsanstalt materials, particularly concerning personnel matters. Finally, access to Reichsanstalt materials in the archive of the Physikalisch-Technische Bundesanstalt-Institut Berlin (Federal Institute of Physics and Technology, Berlin) proved to be equally vital. In the second of my two predecessor studies, this one intended for a German-reading audience on the occasion of the Reichsanstalt's centennial, I had an opportunity to rework my doctoral dissertation, paying less attention to day-to-day details and attempting to discern general trends and drawing more general conclusions.[19] In the present study I have further revised my empirical findings and, more important, have attempted to elaborate more fully themes that were relatively undeveloped or merely implicit in my previous work.

The present study of the Physikalisch-Technische Reichsanstalt in imperial Germany seeks to provide an understanding of the workings and results of this model scientific institute for the new German Reich and the means by which the Reich helped advance, and at times hindered, the enterprises of science and technology. In so doing, it pursues two interrelated themes: the institutionalization of science (and technology) and measurement as the "essence" of the Reichsanstalt. In examining the first of these, it analyzes not only how the Reichsanstalt was founded but also how it developed both internally and in relation to other scientific and political institutions. In addressing the second of these, it argues that the common element of the Reichsanstalt's diverse contributions to the German scientific, industrial, and political communities was the creation of measuring methods, instruments, standards, and data. It was its commitment to advancing the art and science of physical measurement that gave the institution its character and coherence. Whether Reichsanstalt scientists and technicians were helping at a given moment to form new ideas about the nature of radiation or to establish safety standards for boilers, they were engaged in the field of physical metrology – the creation or improvement of measuring methods and instruments and the actual making of measurements.

The Reichsanstalt originated and functioned in multiple contexts: at once political, scientific, and industrial. Chapter 1 discusses several of the social roles of physics and technology in imperial Germany, including instruction in physical measurement, aid to science-based industries (above all the optical and electrical), and the enhanced cohesiveness of German political life through the establishment of nation-wide physical units and standards. Moreover, it discusses the need for state support of new physics institutes and shows the revolutionary change that took place in the institutional bases of physics between 1865 and 1918. In so doing, it sets the stage for the emergence of the Reichsanstalt after 1871 and for one of the central, intractable problems that confronted the Institute after 1900: competition from academic physics institutes.

Chapter 2 pursues the theme of institutionalization by arguing that during the process of the Reichsanstalt's establishment in the 1880s a struggle occurred between two groups of individuals over the future institute's purposes and course. In particular, it shows that the industrial scientist Werner von Siemens – the central figure in the Reichsanstalt's founding – and his scientist allies were interested principally in building an institute devoted to pure scientific research, yet one that would also address the long- and short-term needs of technology. Siemens and his allies wanted something more than an institution devoted to the more immediate needs of technology; they wanted a state-supported, nonteaching physics research institution, one that would fill what they perceived to be certain shortcomings of German academic science. By contrast, Siemens's adversaries – instrumentmakers, professors of engineering, and interested professional associations of engineers and artisans – wanted an institute that would more directly pursue work that was immediately relevant to their interests. The struggle between these two groups resulted in a rift in the Institute's foundations, a rift that was to be only partially overcome and that deeply marked the Institute's subsequent development.

Chapter 3 also pursues the theme of institutionalization, now by relating how Hermann von Helmholtz, Germany's foremost scientist during the last third of the nineteenth century, built the new Institute. It shows how he used his understanding of the needs of physics, technology, and the state and his widespread contacts in German scientific life to take the Institute through its "heroic" period (1887-1894). The aging but still charismatic Helmholtz began the process of shaping an institutional structure that could flourish without him – by, among other devices, establishing a governing board of directors, developing formal rules of authority within a hierarchically ordered institute, and securing loyal organs of publication. Chapter 3 argues that there was a causal relationship between the buildup of the workspaces under Helmholtz and the pace and type of work done at the Institute during his reign. The need and desire first to construct buildings for scientific research delayed pure scientific research under Helmholtz, while the need to show its adversaries that it could contribute to German industry led the Institute to occupy available rooms at the nearby Technische Hochschule Charlottenburg in order to achieve some immediate technological results of use to industry.

When he died in 1894, Helmholtz left behind a small, partially completed institute, a nascent scientific bureaucracy. His successor, Friedrich Kohlrausch, completed the institutionalization of the Reichsanstalt and oversaw its development into a full-scale bureaucracy. Chapter 4 shows that Kohlrausch's presidency (1895-1905) brought unprecedented growth to the Reichsanstalt, making it a scientific institute sui generis and one of the first institutional embodiments of Big Science.

Chapter 4 also presents a discussion of the Institute's most dramatic scientific results: its measurements of blackbody radiation, work that served as the experimental foundations of Max Planck's new quantum theory and that helped bring the Reichsanstalt's Willy Wien as well as Planck the Nobel Prize in physics for 1911 and 1918, respectively. Building on Hans Kangro's outstanding historical study of the background to and experimental foundations of Planck's law of blackbody radiation,[20] Chapter 4 argues, against Kangro, that the practical needs of the German illumination industry – better temperature measurements and better understanding of the economy of heat and light radiation – provided the institutional justification and motivation for the Reichsanstalt's blackbody work. To be sure, individual Reichsanstalt physicists were principally concerned with finding (as Kangro and others have so well shown) a spectral-energy distribution law for blackbody radiation. But they worked in an institute that faced multiple, complex demands and that supplied the finest material resources then available for conducting physical measurements. In short, Chapter 4 argues that utilitarian as well as purely scientific interests led to the Reichsanstalt's blackbody-radiation work and that a full appreciation of the timing and setting of the origins of quantum physics requires attention to both types of interests.

At the same time, Chapter 4 discloses that scientific and industrial interests at the Reichsanstalt sometimes clashed with one another. In particular, the ever increasing demands of the electrical industry for more testing work by the Reichsanstalt and for the right to run electrical streetcars in front of it threatened to, and in part did, damage the Reichsanstalt's capacity to conduct scientific research. Conversely, industry's unwillingness to allow the Reichsanstalt full control over the implementation of legal electrical standards and the testing of electrical meters further contributed to a sometimes antagonistic relationship between the industry and the Reichsanstalt.

By 1905, when Emil Warburg succeeded Kohlrausch as the Reichsanstalt's third president, the Reichsanstalt stood at the height of its scientific fame. It had become the world's foremost center for physical measurement – for both scientific and industrial purposes. It had also become a large scientific bureaucracy, greatly in need of reform. Chapter 5 analyzes the nature and causes of a series of institutional problems facing the Reichsanstalt after 1905, along with Warburg's attempted reforms.

The outstanding and paradoxical symptom of these problems was that, despite its contributions to blackbody-radiation work between 1893 and 1901, by the start of Warburg's presidency (1905-1922) the Reichsanstalt was but little engaged in pursuing topics at the forefront of contemporary research in pure physics. The very successes of its leading scientists during the 1890s enabled many of them to leave the Reichsanstalt for academic positions at the new physics institutes of the German universities and the older, expanded institutes of the Technische Hochschulen (institutes of technology). After 1900, the expanded research facilities of German academic institutes and the greater attractions of academic life for a number of Reichsanstalt physicists meant that academic physics institutes could now more than compete with the Reichsanstalt in conducting physical research. As Chapter 5 shows, in comparison with academic institutions the Reichsanstalt offered its scientists inadequate professional rewards and opportunities. Moreover, the enormous testing burdens on the Reichsanstalt constantly forced its scientists to forgo research in pure physics and to concentrate instead on research for industry or on conducting merely routine testing work. Largely as a consequence of these two forces – the increased research capacities of academic institutes and the enormous testing burdens on the Reichsanstalt's resources – the Reichsanstalt had evolved from the original vision into an institution devoted to the one area of physics that the academic institutes could not sufficiently address and that industry increasingly required: measuring physics.

Warburg sought to overcome the Reichsanstalt's institutional inadequacies and to meet the demands of contemporary science and technology through a series of reforms, ranging from a search for increased financial support to a major internal restructuring of the Institute. But Warburg's reforms had barely any opportunity to be tested. The outbreak of World War I made a shambles of his reforming efforts, crippling the Institute simultaneously with the demise of the Reich itself.

In pursuing the two themes of institutionalization and measurement, I have attempted to combine a chronological and analytical approach to the Reichsanstalt's history during Germany's imperial era. Like all institutional historians, I have had to confront the problem of faithfully relating the institution's achievements without letting the study degenerate into a mere catalogue of personnel and events. Indeed, in the case at hand the sheer number of scientists and technicians employed at the Reichsanstalt – about 150 – and the innumerable observations, experiments, tests, and other scientific activities conducted by them between 1887 and 1918 prohibit any linear, year-by-year chronology. In order to deal with this methodological problem, I have focused my analysis of the Reichsanstalt's scientific and technical work on three years – 1893, 1903, and 1913 – which typify its work under each of its first three presidents: Helmholtz, Kohlrausch, and Warburg. By adopting this cross-sectional mode of analysis I have avoided, I hope, some of the common pitfalls of institutional history and provided a sense of both continuity and change at the Reichsanstalt. However, I have not hesitated to abandon this format when reporting important results that were achieved in other years or that stretched over a number of years, as in the case of blackbody radiation. Readers interested in learning more about the Reichsanstalt's activities in the intervening years can consult the Institute's (nearly) annual reports (*Tätigkeitsberichte*), which appeared in the *Zeitschrift für Instrumentenkunde* and which form the basis of this study's discussion of the Reichsanstalt's work.

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Physics and Empire

"The Flag of Science"

On 19 January 1871, Alexandre Regnault, a young but already highly acclaimed Parisian artist, was killed by a Prussian bullet at the battle of Buzenval during the Franco-Prussian War. The battle was a decisive one for France and for the new German Reich, founded only the day before in the Hall of Mirrors at Versailles, where the Germans had recently set up their military headquarters. It sealed the fate of Paris, and soon brought an armistice and the surrender of France to Germany, leaving only the Parisians to destroy one another during the coming months. It sealed the fate, too, of the young artist's father, Henri Victor Regnault, one of France's leading scientists, a physicist known particularly for his creation of new heat-measuring methods, instruments, and data.

After his son's funeral, Regnault sought refuge in his laboratory at the nearby Sèvres porcelain works, of which he was director. Thanks to an agreement that he had reached with the Prussian crown prince, his barricaded laboratory in occupied Sèvres stood under official protection, and entrance to it was expressly prohibited. Upon entering the laboratory, however, Regnault discovered that all of his precision instruments and apparatus – thermometers, barometers, manometers, balances, and so on – had been smashed to pieces or bent beyond repair and that his manuscripts and data-recording notebooks, containing the results of a decade's worth of the painstaking empirical research for which he was so renowned, had been burned. Not a lock had been forced nor a window broken by the Prussian soldier who had entered the superbly equipped laboratory and destroyed its contents. The destruction, Regnault declared, was the work "of a true connoisseur."[1] The victimized physicist never recovered from this double catastrophe: