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The Rise of Academic Laboratory Science: Chemistry and the 'German Model' in the Nineteenth Century

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It is no less true for being a cliché that the practices, cultures, and geography of the laboratory sciences in Europe were transformed during the course of the nineteenth century. One change centers on professionalization of the field. In 1800, the various laboratory sciences could scarcely be described as established academic fields, nor was science a profession per se, one marker of which is the fact that the English word 'scientist' had not yet appeared. By contrast, by 1900 there were well-developed university curricula, officially sanctioned undergraduate and graduate degrees, disciplinary journals, societies, and (most importantly) jobs, inside and outside of academia, in various scientific disciplines. The social and professional norms of academic science had also been transformed, for the 'research mandate' had become firmly established, and, for the laboratory sciences at least, the research group rather than the sole worker was now the operative entity, both for research practice as also for education and training. A third kind of change had to do with the trajectories of science in the leading countries of Europe. French science certainly had the greatest prestige in the year 1800, with Britain and Germany following behind. By the end of the century, Germany had gained a clear overall lead, in the case of chemistry even approaching something like global hegemony.

The following essay treats the causes and contexts of these transformations, with particular attention to the 'German model' of advanced education and research that is thought to have been so influential, and focusing on the branch of science in which that model is usually said to have first

Alan Rocke, *The Rise of Academic Laboratory Science: Chemistry and the 'German Model' in the Nineteenth Century* In: *A Global History of Research Education: Disciplines, Institutions, and Nations, 1840–1950*. Edited by: Ku-ming (Kevin) Chang and Alan Rocke. *History of Universities* XXXIV/1, Oxford University Press (2021).
 DOI: 10.1093/oso/9780192844774.003.0004

appeared, chemistry.[1] To begin, I cite some quantitative measures that suggest the kind of geographic shifts that took place, with particular reference to France and Germany. Christoph Meinel's statistical study of all the papers published by 200 prominent nineteenth-century European chemists is revealing. From 1800 to 1825, only about half as many chemistry articles per year were published in German journals as in French ones. Starting about 1825, however, chemical articles began to appear in Germany at a rate about 25% greater than in France. Between 1850 and 1865 this proportional advantage increased to about 40%. Then in the late 1860s the German rate exploded to more than double that of the French, and in the early 1870s three and a half times more chemical articles were published per year in Germany than in France. Edward Frankland's study of publications during a single calendar year, 1866, is consistent with these numbers. He found that during that year, more than three times as many 'original [chemical] investigations' appeared in German as in French journals, and the British record of publications that year was even worse than the French. Frankland's purpose in conducting the study was to alert the British Parliament to what he, a German-educated academic chemist himself, regarded as a disturbing and ever increasing preeminence of German science.[2]

The rise over the course of the nineteenth century of academic chemical laboratories for teaching and research formed the context for these trends. To put it simply—really too simply, in fact, as we will see—academic laboratories became essential and expected features of university science teaching and research first in a particular country and in a particular branch of science, namely in *German chemistry*; that pattern then spread to other sciences within Germany, and to other countries. How did all this happen?

Origins of the German Model

We need to add complexity to the simple picture we have sketched by summarizing some of the fine research that has been done on this subject over the last generation. The rise of laboratory science in European universities has deep history in eighteenth-century France, whose intellectual

[1] Some of the material that follows is taken more or less directly, but in revised form, from Rocke, *Nationalizing Science: Adolphe Wurtz and the Battle for French Chemistry* (Cambridge, MA, 2001), and from Rocke, 'Origins and Spread of the "Giessen Model" in University Science', *Ambix*, 50 (2003), 90–115.

[2] Christoph Meinel, 'Structural Changes in International Scientific Communication', *Atti del V convegno di storia e fondamenti della chimica* (Perugia, 1993), 47–61; Edward Frankland testimony, 14 February 1871, *First and Second Reports from the Royal [Devonshire] Commission on Scientific Instruction*, British Parliamentary Papers (London, 1872), 25:372.

leaders were inspired in part by Enlightenment ideals of empiricism and utility. In the *ancien rég*ime and especially during the Napoleonic era, preexisting institutions included predecessors of the *grandes écoles* and also of research institutions such as the Collège de France and the *Muséum d'Histoire Naturelle*, and laboratories were provided in some of these institutions. In general, Napoleon designed a system intended to promote centralized state control, and social utility. In a strict sense the French universities actually disappeared, having been functionally replaced by a single bureaucratic entity called the '*Université de France*', and what were called *Facultés*.[3] French academic careers during the nineteenth century labored under a tripartite fragmentation comprising, first, the faculties, the most prestigious of which was the Sorbonne in Paris, all of which were intended strictly as didactic teaching institutions, hence devoid of laboratories; second, the *grandes écoles* devoted to practical training for professions that were of particular interest to the state; and third, research institutions. Such functional fragmentation, along with centralization in Paris and insufficient salaries, led leading savants to accumulate multiple simultaneous positions, the monopolizing practice known as *cumul*.[4]

The transformations with which we are concerned had important roots in the eighteenth-century German lands, as well, especially the important example of the University of Göttingen, founded in 1737 by the Elector of Hanover, who was also King George II of Great Britain. Göttingen benefited from the tie to Enlightenment Britain for an infusion of classical liberal ideas, as well as the unusual freedom allowed to its professors, and the emphasis given to research. That progressive atmosphere contrasted with the parochially corporative, didactic, narrowly professional, and often poverty-stricken character of most of the other 34 universities across the various German states. The irony is that in Britain itself, Oxford and Cambridge were mired in similar hidebound conditions as the German

[3] The Université de France designated France's entire system of secondary and higher education, all bureaucratically centralized in the Ministry of Public Instruction in Paris; the Facultés were the instructional units comprising the various schools of medicine, law, letters & sciences, etc., in the national higher education system run by the Université.

[4] Louis Liard, *L'enseignement supérieur en France* (Paris, 1894); Antoine Prost, *Histoire de l'enseignement en France, 1800–1967* (Paris, 1968); Robert D. Anderson, *Education in France, 1848–1870* (Oxford, 1975); François Leprieur, 'La formation des chimistes français au XIX[e] siècle', *La recherché* 10 (1979), 732–40; Robert Fox and George Weisz (eds.), *The Organization of Science and Technology in France, 1808–1914* (Cambridge, 1980); G. Weisz, *The Emergence of Modern Universities in France, 1863–1914* (Princeton, 1983); R. Fox, 'Science, the University, and the State in Nineteenth-Century France', in G. Geison (ed.), *Professions and the French State, 1700–1900* (Philadelphia, 1984); Harry Paul, *From Knowledge to Power: The Rise of the Science Empire in France, 1860–1939* (Cambridge, 1985); and R. D. Anderson, *European Universities from the Enlightenment to 1914* (Oxford, 2004).

universities; it was to Scotland that Continental reformers looked, especially Edinburgh.[5]

The Napoleonic wars brought a caesura for the German states. Even before liberation, Prussia, under the leadership of Wilhelm von Humboldt, began a movement in higher education by establishing a new university in Berlin. Under the influence of classical liberal ideas as well as Romantic currents of philosophical idealism, this movement advocated professorial research as well as teaching, and mandated a degree of freedom for professors and students that became a watchword for German university life throughout the century. The movement ultimately became known as neohumanism, characterized by conspicuous philhellenism allied to the elevated holistic educational philosophy associated with the pregnant German words '*Bildung*' and '*Wissenschaft*.'[6]

But as much as this new set of ideas was designed deliberately to contrast with the centralized French system of higher education, German neohumanists came to embrace Enlightenment strains in addition to Romantic ones. Especially in the sciences at the new Berlin university, an empiricist epistemology derived from Kant and others, and an experiential pedagogical philosophy derived from Enlightened reformers such as Heinrich Pestalozzi, gradually led newly hired professors there to rely less exclusively on didactic lectures and offered an entrée to seminar- and laboratory-based instruction. This trend can be seen especially with the professorial recruitments by the Prussian *Kultusminister*, Altenstein, after the German states were liberated from French hegemony.[7]

[5] Friedrich Paulsen, *Geschichte des gelehrten Unterrichts auf den deutschen Schulen und Universitäten* (Leipzig, 1885); Paulsen, *Die deutschen Universitäten und das Universitätsstudium* (Berlin, 1902); R. Steven Turner, 'University Reformers and Professorial Scholarship in Germany, 1760–1806', in L. Stone (ed.), *The University in Society*, 2 vols. (Princeton, 1974), ii. 495–531; Charles McClelland, *State, Society, and University in Germany, 1700–1914* (Cambridge, 1980); K.-E. Jeismann and P. Lundgreen (eds.), *Handbuch der deutschen Bildungsgeschichte*, 3, 1800–1870 (Munich, 1987); and Anderson, *European Universities* (2004).

[6] In addition to the sources in the previous note, see also R. Steven Turner, 'The Growth of Professorial Research in Prussia, 1818–1848, Causes and Context', *Historical Studies in the Physical Sciences* 3 (1971), 137–82; Turner, 'The *Bildungsbürgertum* and the Learned Professions in Prussia, 1770–1830: The Origins of a Class', *Social History* 13 (1980), 105–35; Turner, 'The Prussian Professoriate and the Research Imperative', in H. N. Jahnke and M. Otte (eds.), *Epistemological and Social Problems of the Sciences in the Early Nineteenth Century* (Dordrecht, 1981), 109–21; and Turner, 'Universitäten', in Jeismann and Lundgreen (eds.), *Handbuch*, 221–49.

[7] Karl vom Stein zum Altenstein hired for the new university in Berlin (among others) Eilhard Mitscherlich, Heinrich Rose, Gustav Rose, Johann Christian Poggendorff, Heinrich Dove, and Gustav Magnus. He also attempted, without success, to hire Jacob Berzelius. See Max Lenz, *Geschichte der königlichen Friedrich-Wilhelms-Universität zu Berlin*, 3 vols. (Halle, 1910–1918), i. 305ff., 570f., and ii. 1, 3ff., 224ff., 509f.; Frederick

As a consequence, a strong countercurrent favoring empirical practice arose among even those who were most committed to the nominally idealist neohumanist creed. That countercurrent was most visible in the science of chemistry. The chief representatives of the founding generation of German academic chemistry in the *Vormärz* were Justus Liebig (1803–1873), Friedrich Wöhler (1800–1882), and Robert Bunsen (1811–1899), and behind them the older dominant figure of the Swedish chemist Jacob Berzelius (1779–1848). All four of these men exhibited ardent empirical commitments, coupled with distinct orientations toward medical, pharmaceutical, or technological utility. Significantly, neither Liebig, Wöhler, nor Bunsen spent the most active portions of their careers in Humboldtian Prussia, but rather in Hesse, Hanover, and Baden. In fact, in 1840 Liebig famously attacked the Prussian chemists as representatives of *altmodisch* reaction.[8]

Indeed, Liebig provides the best single exemplar for these themes, in all their complexity and internal tensions. He fashioned his laboratory institute at the University of Giessen following the model of earlier pharmaceutical boarding schools that had emphasized laboratory practica. His institute, founded in 1826 in a disused army barracks, was at first a private establishment like those of his pharmacist predecessors, but in 1835 it was taken over by the university. Liebig demanded intensive laboratory practica for all of his students. He argued that the all-day practicum was not intended to 'train' at all, but to educate. Chemistry, he affirmed, was not merely soap-boiling and drug compounding, but a true science, allied not just with the other natural sciences but also with humanistic disciplines as well. He ardently believed that the best way to teach in any discipline was to supplement didactic lectures with hands-on practice. This claim cut against the instinctive neohumanist derogation of utility, for, paradoxically (so Liebig argued), applications would emerge fastest among those who had in this way learned how to think, especially how to apply their pure understanding to practical tasks, leaving in their wake those who had been trained merely by rote.[9]

Gregory, 'Kant, Schelling, and the Administration of Science in the Romantic Era', *Osiris* 5 (1989), 17–35; and Gregory, 'Kant's Influence on Natural Scientists in the German Romantic Period', in R. Visser et al. (eds.), *New Trends in the History of Science* (Amsterdam, 1989), 53–66.

[8] J. Liebig, *Ueber das Studium der Naturwissenschaften und über den Zustand der Chemie in Preussen* (Braunschweig, 1840); R. Steven Turner, 'Justus Liebig versus Prussian Chemistry: Reflections on Early Institute Building in Germany', *Historical Studies in the Physical Sciences* 13 (1982), 129–62.

[9] J. B. Morrell, 'The Chemist Breeders: The Research Schools of Liebig and Thomas Thomson', *Ambix* 19 (1972), 1–45; Bernard Gustin, 'The Emergence of the German

Liebig thus successfully performed a rhetorical balancing act between neohumanist *Bildung* and utilitarian laboratory practice, between German idealist and French empiricist philosophies. It was a novel pedagogy with a great future. Moreover, this new pedagogy worked hand-in-glove with the invigorated promotion of university research that was closely associated with Humboldtian reforms, for in his laboratory Liebig put to work a subset of his clientele, his most advanced students and postdocs. His groups of young chemists were simultaneously completing their scientific education, while pushing forward a research agenda—Liebig's agenda, but also their own. Starting in the late 1830s, Giessen was thus the site of the earliest identifiable instance of such a teaching-cum-research university laboratory institute.[10] Liebig's practices also strengthened the research mandate more generally, which was then spreading across the German academic landscape.

These occasionally conflicting elements were at the heart of what became known as the German model of higher education and research, whose disparate themes included neohumanist idealist philosophy with its creed of pure *Wissenschaft*, empiricist/objectivist laboratory or seminar pedagogy, the (conflicted) appeal to practice, group research tied to advanced education, and the research mandate. But what should be considered as the essential elements of the 'German model' has been subject, as we will see below, to various interpretations and local modifications, ever since these international discussions over the most effective forms of higher education and research arose in the late nineteenth century. It has become ever clearer from recent historical research that the national context into which the German model was imported was always determinative, and that the specific strains of Humboldtian neohumanist philosophy were invariably modified or even ignored. That was the case even in *Vormärz* Germany, and even in Prussia itself after Humboldt's

Chemical Profession, 1790–1867', Ph.D. dissertation, (Chicago, 1975); Turner, 'Liebig versus Prussian Chemistry'; Christoph Meinel, '*Artibis Academicis Inserenda:* Chemistry's Place in Eighteenth- and Early Nineteenth-Century Universities', *History of Universities* 7 (1988), 89–115; Joseph Fruton, 'The Liebig Research Group: A Reappraisal', *Proceedings of the American Philosophical Society* 132 (1988), 1–66; F. L. Holmes, 'The Complementarity of Teaching and Research in Liebig's Laboratory', *Osiris* 5 (1989), 121–64; William H. Brock, *Justus von Liebig: The Chemical Gatekeeper* (Cambridge University Press, 1997); Ernst Homburg, 'Two Factions, One Profession: The Chemical Profession in German Society 1780–1870', in D. Knight and H. Kragh (eds.), *The Making of the Chemist: The Social History of Chemistry in Europe, 1789–1914* (Cambridge, 1998), 39–76; W. H. Brock, 'Breeding Chemists in Giessen', *Ambix* 50 (2003), 25–70.

[10] For a precise chronology and an analysis of these events, see esp. Holmes, 'Liebig's Laboratory', and A. J. Rocke, *The Quiet Revolution: Hermann Kolbe and the Science of Organic Chemistry* (Berkeley, 1993), 9–34. See also the discussion below concerning Friedrich Stromeyer at Göttingen.

death. In short, it seems that the post-1815 German model was not very neohumanistic, after all.[11]

Organic Chemistry and the 1830 Nexus

Of course, my statement that Liebig is the best single exemplar representing this movement—whatever name one applies to it— comports with mythology that has prevailed for the last 150 years. The contributions of such scholars as Bernard Gustin, Jack Morrell, Steven Turner, William Brock, Frederic L. Holmes, Ernst Homburg, and several others have significantly modified that picture, without however effacing its most essential features. I don't wish to ratify the naïvely teleological 'great man' picture of Liebig self-consciously forging a lonely new path to the future—which has been rightly refuted—but rather to understand how and why Liebig found himself occupying such a central position in these sea changes, and how and why the international Liebig mythology arose. Morrell rightly emphasized several factors that played well into Liebig's hands. Using the further research of the last generation, I want to focus attention on a small number of those factors, some of which have hitherto been insufficiently appreciated.

Namely, we can now see that four crucial events happened virtually simultaneously, all four of these events (amazingly) datable within three years either side of the year 1830. The first of these, appropriately stressed by Morrell, was Liebig's personal acquisition in 1832 of a journal in which he could (and did) publish his and his students' research results at will. Liebig's *Annalen der Pharmacie* (in 1840 renamed *Annalen der Chemie und Pharmacie*, and after Liebig's death *Justus Liebigs Annalen der Chemie*) became the leading journal in the field within a few years after Liebig took it over. A personal organ for publication was critically important for the leader of a research group in those years. Not only did he and his circle have unrestricted access for research publication, but he also used the

[11] Margaret Rossiter, *The Emergence of Agricultural Science: Justus Liebig and the Americans, 1840–1880* (New Haven, 1975); Owen Hannaway, 'The German Model of Chemical Education in America: Ira Remsen at Johns Hopkins', *Ambix* 23 (1976), 145–64; Gert Schubring (ed.), *'Einsamkeit und Freiheit' neu besichtigt: Universitätsreformen und Disziplinenbildung in Preussen als Modell für Wissenschaftspolitik im Europa des 19. Jahrhunderts* (Stuttgart, 1991); R. C. Schwinges (ed.), *Humboldt International: Der Export des deutschen Universitätsmodells im 19. und 20. Jahrhundert* (Basel, 2001); Marc Schalenberg, *Humboldt auf Reisen? Die Rezeption des 'deutschen Universitätsmodell' in den französischen und britischen Reformdiskursen (1810–1870)* (Basel, 2002); Geert Vanpaemel, 'The German Model of Laboratory Science and the European Periphery (1860–1914)', in A. Simões, M. P. Diogo, and K. Gavroglu (eds.), *Sciences in the Universities of Europe, Nineteenth and Twentieth Centuries* (Dordrecht, 2015), 211–25.

journal as a bully pulpit to self-promote, editorialize, harangue, and occasionally even insult. It was a significant element in the rapid rise of the Giessen institute in the 1830s and 1840s.

The other three events all relate to a field to which Liebig devoted his fullest efforts, namely organic chemistry, which was poised for explosive growth in 1830. Before going further, I want to suggest a sense of the nature of that growth. In 1820 there existed a little more than a thousand known chemical substances, 90% of which were inorganic compounds. That changed dramatically over the course of the following decades, which saw an explosion in the number of organic compounds. Today, well over 99% of all the millions of known chemical compounds are organic.[12] The difference, of course, is that unlike inorganics, organic compounds have carbon-based skeletons that can form stable distinct molecules containing scores, hundreds, or even thousands of atoms. Simple combinatoric analysis suggests the nearly infinite variety of substances that were (and are) possible. It is also important to note that it was organic chemistry that provided the engine of growth in new chemical industries in the second half of the century. The production of synthetic dyes, drugs, food additives, explosives, and a variety of important new artificial materials was enormously stimulated when the science of organic chemistry allowed researchers to manipulate molecules with ever greater power and certainty.

The ascendancy over European chemical publications by Germans, and the ascendancy over the index of known substances by organic compounds, were connected, since German chemistry was generally oriented toward the organic field from the 1830s on, and became ever more concentrated in that area during the second half of the century. A deliberate multi-pronged campaign by Liebig was partly responsible for this German predilection for organic chemistry. As a young man, Liebig had worked in the Paris laboratory of the great French chemist Joseph Louis Gay-Lussac. Gay-Lussac, who specialized in the science of gases and held the Sorbonne chair of physics, told the 20-year-old Liebig, 'You must occupy yourself every day with organic chemistry; that is what we lack.'[13] Liebig followed his teacher's advice.

[12] Joachim Schummer, 'Scientometric Studies on Chemistry', *Scientometrics*, 39 (1997), 107–23, 125–40.

[13] In a long toast given in French at a Paris dinner on 22 April 1867, Liebig recalled the words of his mentor, spoken 43 years earlier: '"Il faut vous occuper", me disait-il, "tous les jours de la Chimie organique, voilà ce qui nous manque."' Cited from the Roger Gay-Lussac MS Collection by Maurice Crosland, *Gay-Lussac: Scientist and Bourgeois* (Cambridge, 1978), 278. An English version is 'Liebig's Recollection of Gay-Lussac and Thenard', *The Laboratory*, 1 (1867), 285.

So the second of my four formative events ca. 1830 is the emergence of the phenomenon that was the key to recognizing this explosive potential of organic chemistry: isomerism. At the beginning of the nineteenth century, chemists implicitly assumed that a substance's elemental composition determined its identity. For that reason some were mystified in the 1810s and 1820s by the discovery of instances that violated that correlation, such as glucose versus starch, acetic acid versus cellulose, wax versus spermaceti, and distinct species of sugar with identical compositions. It was the collision between the youthful discoverers of another case of such chemical twins, Wöhler's cyanic acid and Liebig's fulminic acid, that brought the issue to a head. In 1830 Berzelius focused attention on this phenomenon, named it 'isomerism', and argued for its generality and importance; he suggested that differing arrangements of the atoms in the molecules could provide an explanation of such chemical twins.[14]

Isomerism was not unknown in the inorganic chemical realm, but the great majority of instances of that phenomenon known already in 1830 were organic compounds. And the example of the sugars immediately suggested that it was not just a question of twins (i.e., *two* isomers for a given composition); rather, a single composition might correspond to three, four, or really any number of possible distinct substances. In 1829 Wöhler could privately express relief that a purported second species of cyanic acid was a fiction, so that one might eliminate at least one organic compound from the already rapidly expanding handbooks. By the 1860s chemistry students were 'frightened' by the numbers of new substances, and the stupefying proliferation was 'becoming enough to make [even Liebig] mad'.[15] In fact, in 1862 we find Marcellin Berthelot calculating that a single organic compound, sorbitol, must have 1.4 quintillion possible isomers; the number of printed books that would be required even simply to list them all, he wrote, would require a library as big as Paris itself.[16]

Suddenly, it was no longer sufficient for chemists to compile a putatively complete list of just a few dozen substances, all derived from organic nature and each with a unique composition, collectively serving as a minor

[14] J. Berzelius, 'Ueber die Zusammensetzung der Weinsäure und Traubensäure . . . nebst allgemeinen Bemerkungen über solche Körper, die gleiche Zusammensetzung, aber ungleiche Eigenschaften haben', *Annalen der Physik* [2] 19 (1830), 305–35; J. R. Partington, *A History of Chemistry*, 4 (London, 1964), 203, 256, 258–60, 272, 751.

[15] Wöhler to Liebig, 8 June 1829, in A. W. Hofmann (ed.), *Aus Justus Liebig's und Friedrich Wöhler's Briefwechsel*, 2 vols. (Braunschweig, 1888), i. 4; Liebig to Hofmann, 24 January 1868, in E. Heuser and R. Zott (eds.), *Justus von Liebig und August Wilhelm Hofmann in ihren Briefen* (Mannheim, 1988), 45.

[16] M. Berthelot, 'Sur les principes sucrés', *Leçons de chimie et de physique professées en 1862* (Paris, 1863), 248–9.

adjunct to the 'real' chemistry of inorganic earths, oxides, acids, bases, and salts. Suddenly, the sky was the limit for organic chemistry. From 1830 on, the new phenomenon of isomerism opened eyes and minds to the radically expanded possibilities for the science of organic chemistry. This is the world that the farsighted Gay-Lussac had glimpsed.

My third nearly simultaneous event was the development of a means of understanding and heuristically manipulating—that is to say, of mastering, exploring, and teaching—this potentially limitless body of substances and reactions. I am referring to the introduction and development of chemical formulas as paper tools, a subject that was introduced and has been well studied by Ursula Klein. In the work of Dumas, Berzelius, Liebig, and Wöhler in the period from 1827 to 1833 we see for the first time written formulas being used in a generative fashion to construct and to justify the theoretical modeling of chemical compounds and their reactions. This was a new epistemic technique that went far beyond mere shorthand representation. The formulas were being used—as they are still used today—as true paper tools, in the fullest sense of the word 'tool'. Klein has further pointed out that it was precisely organic chemistry for which this epistemic technique was crucial, for organic reactions are dynamic in a way that inorganic reactions are generally not, and tend to produce confusing cascades of products. The heuristic manipulation of formulas gave chemists a handle on the complexities with which they were forced to deal, and provided a productive theoretical tool to create endless ideas for investigation, and endless new substances to create.[17]

All of this would have played to a slow tempo, however, without our fourth event, namely Liebig's invention in the fall of 1830 of a modified method of combustion analysis for organic substances that was fast, simple, and precise; so simple and precise, in fact, that even junior chemists could readily master the technique and produce analyses that routinely passed muster. Morrell stressed the importance of Liebig's invention of his so-called Kaliapparat for the ascendancy of the Giessen laboratory; recent research in the laboratory of Melvyn Usselman has thrown important new light on just how transformative the innovation really was. Usselman's historical replications were actually performed by two of his undergraduate chemistry students, like those in Giessen, who scrupulously followed Liebig's published directions. Astonishingly, these replications of 1830s-era analyses achieved routine accuracy that rival current professional

[17] Ursula Klein, 'Paving a Way through the Jungle of Organic Chemistry', in M. Heidelberger and F. Steinle (eds.), *Experimental Essays – Versuch zum Experiment* (Baden-Baden, 1998), 251–71; Klein (ed.), *Tools and Modes of Representation in the Laboratory Sciences* (Boston, 2001); Klein, *Experiments, Models, Paper Tools: Cultures of Organic Chemistry in the Nineteenth Century* (Stanford, 2003).

standards for elemental organic analysis. Moreover, an important and unexpected feature was revealed: Usselman and his students found that Liebig's procedure provides a variety of sensual feedback information that confirms, during the course of the analysis, whether or not that analysis would be reliable. If the sample were sufficiently pure to start with, and if the feedback indicated a good run, then the outcome could almost certainly be trusted as a single precise datum.[18]

This experience offers an important historical insight. Since Liebig and his students knew (ceteris paribus) that they could place immediate confidence in the quality of retained data from the Kaliapparat, good analyses could often be achieved with three, two, or even one sample run. This efficiency of effort must have greatly accelerated productivity. All this helps to explain why Liebig's lab so quickly became a mass-production factory of new results in the burgeoning field of organic chemistry. To put it simply, from the late 1830s on, the work in Giessen was generally done by *teams* consisting of students and senior researchers; it was good data; and it came fast. Now, it is certainly true that chemical analysis is only the last stage in the process of introducing a new substance into the chemical literature. But analysis was probably what chemists would call a 'rate-limiting step' for much of organic chemistry in these glory years of scientific productivity.

Liebig was at the very center of the nexus for every one of these four developments: a proprietary journal in which to publish at will; the emergence of isomerism; formulas as paper tools; and fast, simple, reliable chemical analysis. Equipped with this newly improved analytical method, and empowered by a productive new theoretical approach to the exploration of organic reactions and compounds, Liebig and other organic chemists in the second third of the nineteenth century discovered themselves in possession of a 'kit' that would enable them to master the dismaying proliferation of new organic substances. The first institutional laboratory that achieved a significant approach to such mastery was Liebig's in Giessen.

The Rise of the Giessen Laboratory: Was It Really New? Was It Really First?

Let us pause for some further qualifications. We have known for many years now that Liebig's Giessen laboratory, contrary to his later representations, was far from the first in Germany to offer practical exercises as part of a course of chemical study. A partial list of his predecessors in this regard

[18] Melvyn Usselman et al., 'Restaging Liebig: A Study in the Replication of Experiments', *Annals of Science*, 62 (2005), 1–55.

would include the universities in Göttingen, Tübingen, Jena, Landshut, Breslau, and Bonn.[19] And we have already noted that Liebig's initial idea upon his arrival in Giessen in 1824 was not to develop a university research school at all, but rather to create an institute devoted to pharmaceutical training, similar to well-established concerns in Erfurt, Jena, and elsewhere. Furthermore, Liebig's route to the 'German model' included significant elements of serendipity and chance. At the end of his detailed examination of the gradual development of Liebig's enterprise during the 1830s, Holmes summarized his conclusions:

> Liebig took each formative step in this development in response to immediate opportunities or problems . . . [H]e probably did not foresee in detail the pattern of systematic training and group investigations, the strong symbiotic relation between teaching and research, that was to take shape by 1840.[20]

However, Liebig realized no later than 1838 that he had grasped the lion's tail, for in the summer semester of that year he had 33 Praktikanten, a very large number from whom he could and did recruit advanced research collaborators. By 1843, in a newly enlarged space and with a new branch laboratory for beginners, there were no fewer 68 practicum students, and by this time he had a well established senior research group, including foreigners and guest workers who had been attracted by Liebig's rising reputation. Liebig cleverly drew attention to his dramatic success by writing two arresting polemical articles on 'the state of chemistry in Austria' (1838) and 'the state of chemistry in Prussia' (1840). By this time, his laboratory had gained worldwide fame; it had become the 'Mecca of chemistry', and was regarded (not just by Liebig himself) as a distinctly new phenomenon.[21]

But was it truly new? Ernst Homburg has recently investigated the role of an unjustly neglected figure in this story, namely Friedrich Stromeyer (1776–1835), a respected older chemist at the University of Göttingen.[22] From 1810 until his death in 1835 Stromeyer ran a highly successful university chemistry practicum. More than twenty of Stromeyer's former Praktikanten later became professors at European universities, technical institutes, or mining academies, including three famous names: Leopold Gmelin in Heidelberg, Mitscherlich in Berlin, and Bunsen in Marburg

[19] Turner, 'Liebig versus Prussian Chemistry'; Homburg, 'Chemical Profession'; Homburg, 'The Rise of Analytical Chemistry and its Consequences for the Development of the German Chemical Profession (1780–1860)', *Ambix* 46 (1999), 1–32; Rocke, 'Giessen Model', 100.

[20] Holmes, 'Liebig's Laboratory', 163.

[21] Ibid, 146–62; Turner, 'Liebig versus Prussian Chemistry'; Brock, *Liebig*, 65–70.

[22] Homburg, 'Rise of Analytical Chemistry'; Homburg, 'Chemical Profession'.

and later Gmelin's successor in Heidelberg.[23] Despite his remarkable career, and his contemporary renown, Stromeyer's name is little known to prosperity, partly due to Liebig's exaggerated and self-promoting rhetoric.

Stromeyer is probably the single best contender for the 'Giessen model' before Liebig. However, his practicum differed in some crucial respects from Liebig's, and the differences can help us to understand more clearly what was distinctive about the latter. Stromeyer's subject was inorganic chemical analysis, his clientele was mostly medical students, and he made no attempt to combine teaching and research. For all of these reasons his practicum had little relationship to the great organic-chemical nexus of ca. 1830 described above. Stromeyer did believe, probably correctly, that he had been the first to introduce a regular university-sanctioned chemistry practicum in the German lands[24]—his model was probably the Ecole Polytechnique in its earliest incarnation—but he never made any wider pedagogical or philosophical claims for it.[25]

The fact that group research was absent from Stromeyer's pedagogy is not surprising. Stromeyer's students worked on inorganic samples that were *known* 'unknowns'; the practicum consisted solely of analysis training with no admixture of actual experimentation, so students were not normally exposed to truly unidentified materials. Liebig's case was different. As he found that student organic analyses with his Kaliapparat could be virtually as good as his own, it was a natural step for him to begin

[23] However, it should be noted that Gmelin was educated by his famous father and by his cousin, in addition to Stromeyer, and he spent nearly a year learning from Gay-Lussac and Vauquelin in Paris. Similarly, Mitscherlich was decisively influenced by his period in Stockholm with Berzelius. Bunsen, too, spent nine months in Paris, and was strongly influenced by contacts with Berzelius, Liebig, and Wöhler. In short, of the three personalities who were Stromeyer's most illustrious pupils by far, it is not possible to say that it was Stromeyer's imprint that was most decisive. One of the many merits of Homburg's essays is to direct appropriate attention, regarding the sources of the rise of German chemistry, to French and Swedish chemists during the period around 1780–1825. This very point is relevant not only for Stromeyer's most famous students, as we note here, but also regarding Stromeyer himself, who was educated partly in France.

[24] F. Henrich, 'Zur Geschichte des chemischen Unterrichts in Deutschland', *Chemiker-Zeitung* 47 (1923), 585–7; Georg Lockemann, 'Der chemische Unterricht an den deutschen Universitäten im ersten Viertel des neunzehnten Jahrhunderts', in J. Ruska (ed.), *Studien zur Geschichte der Chemie* (Berlin, 1927), 148–58; G. A. Ganss, *Geschichte der pharmazeutischen Chemie an der Universität Göttingen* (Göttingen, 1937), 46–64; G. Lockemann and R. Oesper, 'Friedrich Stromeyer and the History of Chemical Laboratory Instruction', *Journal of Chemical Education* 30 (1953), 202–4.

[25] Even Stromeyer's partisans carefully qualified their arguments. After cogently disputing Liebig's self-serving exaggerations, Lockemann still regarded Liebig as the 'true founder' of laboratory instruction in Germany, because of the totality of his accomplishments and because of his great influence ('Unterricht', 157). Similarly, Henrich, who argued keenly for Stromeyer's importance, was careful to state that Liebig expanded and developed the model established first in Göttingen, in particular toward the education of future *research* chemists ('Geschichte', 587).

to make use of some of those hands—the more practiced students, and guest workers—in advancing a broad research front. Connected with this, the explosion of new compounds on which to operate provided a great incentive to create research groups that included students and what we now call postdocs and other non-enrolled visitors. Only *groups* could make substantial progress in such a large and fast-moving field.

What really made all the difference, I emphasize once more, was that Liebig's endeavors were in the field of *organic* chemistry. To chemists at the beginning of this period, organic chemistry (to use Wöhler's famous metaphor from 1835) appeared as a trackless tropical jungle, bursting with exotic wonders, but into which one scarcely dared to enter.[26] Liebig's troops, and those who were inspired by his leadership, rapidly began to bushwack pathways into that wilderness. These developments gained power not just through productive theoretical practices, but also through a new laboratory culture, with all the relatively easily scalable apparatus and equipment of the modern (19th-century) chemical laboratory—a point to which we will return, with further elaboration, in the next section.

The Model Pursued in Other German States

After Liebig's close friend Wöhler was hired at Göttingen (1836), he used the laboratory left him by Stromeyer, and like his predecessor he taught a regularly rostered Praktikum. Although the Göttingen Universitätsarchiv does not hold course enrollment data before 1842, we can use other kinds of evidence to follow the earliest years of Wöhler's Göttingen career.[27] Wöhler's trajectory as regards practical chemical pedagogy and the gradual building of a small research group followed the same general path as Liebig's, with a lag of something like two or three years. The timing of Liebig's and Wöhler's respective trajectories—especially the use of selected students in research programs, which was genuinely novel in European science—as well as some explicit statements by Wöhler suggest that he had a clear idea regarding who the leader of this movement was. A few years after these events, Wöhler wrote to Liebig, half-seriously complaining of his own workload at Göttingen: 'You are the one who is really to blame, by raising chemistry to its great reputation through your achievements and

[26] Wöhler to Berzelius, 28 January 1835, in O. Wallach (ed.), *Briefwechsel zwischen J. Berzelius und F. Wöhler* (Leipzig, 1901), i. 604. 'Die organische Chemie kann einen jetzt ganz toll machen. Sie kommt mir vor wie ein Urwald der Tropenländer vor, voll der merkwürdigsten Dinge, ein ungeheures Dickicht, ohne Ausgang und Ende, in das man sich nicht hinein wagen mag.'

[27] For details, see Rocke, *Quiet Revolution*, 9–34, and Rocke, 'Giessen Model', 103–6.

writings, that we must slave as we do, since now the whole world wants to do chemistry. But the damage you have inflicted must be borne.'[28]

Robert Bunsen was a fellow traveler in this movement. A student of Stromeyer in Göttingen, Bunsen spent almost two years on a Wanderjahr in France, Germany, and Austria; he was much influenced by Berzelius, and learned the Kaliapparat method directly from Liebig during a visit to Giessen in August 1832. He was hired at the University of Marburg in 1839, and the following year he created a university-sanctioned Praktikum—his and Marburg's first enterprise of this character. Lockemann, an authority on the life of Bunsen and an avid admirer of Stromeyer, stated that Bunsen began his Praktikum 'following Liebig's example'. However, despite his well justified reputation as a masterly and caring instructor, Bunsen never created a Liebig-style teaching-research group; he usually worked alone, and usually on inorganic topics.[29]

Wöhler and Bunsen were the most eminent members of the German chemical community to adopt major aspects of the new model early on, but they were not alone. Otto Erdmann, a respected chemist at the University of Leipzig with no personal ties to Liebig, began a new-style practicum there in 1843. In a description of his laboratory practice in 1844, he wrote that Liebig's research school at Giessen had provided a new model that had drawn 'the most general attention' of the scholarly world, and was being rapidly emulated 'überall'. The novelties, he continued, included the idea of all-day practica, and the incorporation of a pedagogy that mixed research with instruction. This made the students 'witnesses and collaborators in the research of the professor', and encouraged them on to their own research. His new laboratory institute, he wrote, was designed to follow Liebig's pattern.[30]

We pass by Liebig's prize student August Wilhelm Hofmann (whom we will discuss later), to provide another example in Hermann Kolbe, who enthusiastically adopted the Liebig model in its most complete version when he was called to Marburg in 1851, after Bunsen was hired at Breslau.[31]

[28] Wöhler to Liebig, 10 May 1851, in Hofmann, *Briefwechsel*, i. 364. 'Du, durch die große Geltung, die Du der Chemie durch Deine Arbeiten und Werke verschafft hast, bist eigentlich Schuld, daß man sich so plagen muß, daß nun alle Welt Chemie treiben will. Indessen läßt sich der Schaden, den Du angerichtet hast, tragen.

[29] G. Lockemann, *Robert Wilhelm Bunsen* (Stuttgart, 1949), 75; C. Meinel, *Die Chemie an der Universität Marburg seit Beginn des 19. Jahrhunderts* (Marburg, 1978); Christine Nawa, 'A Refuge for Inorganic Chemistry: Bunsen's Heidelberg Laboratory', *Ambix* 61 (2014), 115–40.

[30] Otto Erdmann, 'Das chemische Laboratorium der Universität Leipzig', *Journal für praktische Chemie* 31 (1844), 65–70, on 65–6.

[31] Meinel, *Chemie an der Universität Marburg*; Rocke, *Quiet Revolution*, 108–33.

The following year Bunsen was called to Heidelberg to replace Wöhler's former teacher there, Leopold Gmelin. This began an elaborate chain of chemical-professorial successions that would fundamentally transform the German academic chemical community. In the post-1848 world the newer model quickly proliferated in academic chemical institutes throughout all the German states.[32]

As detailed above, neohumanist university reform, an invigorated research mandate, and the influence of an experientialist pedagogical philosophy stressing active learning conditioned the rise of new-style practica in Vormärz German universities, and it is not surprising that these influences were felt in other scientific disciplines, as well. In the field of physiology and as early as the 1830s, for example, Johannes Müller in Berlin and Jan Purkyně in Breslau moved beyond experiments simply as demonstrations, and were putting selected students behind microscopes and dissection apparatus. In analyzing these developments, however, Coleman cautions that this was 'but one and a still quite tentative step' toward the late-nineteenth-century academic physiological laboratory institute, for in each case it remained a 'small affair' and never realized its potential. For physiology, a better case for the new model can be made for the efforts of Jacob Henle at Heidelberg after 1843.[33]

In the field of physics, Wilhelm Weber's practicum at Göttingen (from 1833), Franz Neumann's mathematical-physical seminar at Königsberg (1834), and Gustav Magnus's practicum at Berlin (1843) have sometimes been mentioned as the earliest efforts along these lines. However, these examples do not fully compare to what was happening in chemistry in Giessen, Göttingen, Marburg, and Leipzig in the late 1830s and 1840s. The physics seminars all remained quite small, and none exhibited the full constellation of characteristics of intensive study, broad clientele, university sanction, and group research activity. Mature examples of this model in physics did not emerge until after 1848.[34]

[32] Regarding the period before 1848, Jeffrey Johnson's impressive summary of renovations and new constructions of nineteenth-century German university chemical laboratory institutes includes only Giessen (1839) and Göttingen (1842), whereas no fewer than 34 projects were carried out from 1851 to 1895; see his 'Academic Chemistry in Imperial Germany', *Isis* 76 (1985), 500–24, esp. the table on 502.

[33] William Coleman, 'Prussian Pedagogy: Purkyne at Breslau, 1823–1839', in Coleman and F. L. Holmes (eds.), *The Investigative Enterprise: Experimental Physiology in Nineteenth-Century Medicine* (1988), 15–64, on 38–40; Arleen Tuchman, *Science, Medicine, and the State in Germany: The Case of Baden, 1815–1871* (Oxford, 1993).

[34] Kathryn Olesko, 'On Institutes, Investigations, and Scientific Training', in Coleman and Holmes (ed.), *Investigative Enterprise*, 295–332; Olesko, *Physics as a Calling: Discipline and Profession in the Königsberg Seminar for Physics* (Ithaca, 1990); David Cahan, 'The Intellectual Revolution in German Physics, 1865–1914', *Historical Studies in the Physical Sciences* 15 (1985), 1–65, on 6–12.

Given the parallel influences, why were the other science disciplines in Germany behind the curve set by chemistry? We have argued above that the explosive growth of the specialty field of *organic* chemistry beginning around 1830 was a crucial background factor in the formation and development of Liebig's school, but now we need to emphasize that there were two ways in which chemistry *in general* was distinguished from its sister disciplines in the natural sciences; both pertain directly and specifically to the pedagogical question raised here.

First, Homburg has drawn attention to a late-eighteenth-century European transformation of the chemical laboratory from workshops containing imposing furnaces and large pieces of earthenware, metal, and glass, to precision workplaces with bench-top apparatus using such small analytical apparatus as blowpipes, lamps, test tubes, and reagent glasses.[35] In the light of this research, we can see that Liebig's accomplishment in the field of analysis was in a sense simply to achieve for organic chemistry what had recently been seen in the inorganic field—a dramatic improvement in routine and precise analytical procedures, coupled with a substantial reduction in the physical size of the apparatus necessary to conduct the analysis. The miniaturization and routinization that inorganic analysts had pioneered had now also emerged in organic chemistry.

So by comparison with other sciences, chemistry was henceforth intrinsically and uniquely well suited to the new pedagogical model. In comparison to the relatively complex and expensive instrumentation required of a physics laboratory, or microscopes necessary for pathology or physiology, or apparatus and dissection subjects in anatomy classes, chemists faced only quite modest challenges in scaling up from the earlier laboratories that were designed merely to support lecture demonstrations, to those much larger facilities needed for broadly-based student practica. By comparison to nearly every other field of science, chemical apparatus was relatively inexpensive, and rather easily multiplied for student use. Nearly all individual chemical apparatus were made from inexpensive materials such as glass, rubber, wood, and cork. Expensive items, such as pumps, platinum crucibles, or precision balances, could be shared by an entire laboratory. All this is not to suggest that running a chemical laboratory for student practica was ever *cheap*; just that, by comparison to other fields of science, the cost of scaling up from experiments for lecture demonstrations to experiments performed by students as a routine element

[35] E. Homburg, *Van beroep 'Chemiker': De opkomst van de inustriële chemicus en het polytechnische onderwijs in Duitsland* (Delft, 1993); Homburg, 'Rise of Analytical Chemistry'; Homburg, 'Chemical Profession'; Peter Morris, *The Matter Factory: A History of the Chemistry Laboratory* (London, 2015).

of pedagogy was generally manageable. This laboratory revolution in chemistry was one of the essential conditions that made the new pedagogy possible.

And there was a second issue favoring chemistry over its sister disciplines. Regarding the resources that states were willing to put to these purposes, it obviously mattered that chemists—especially organic chemists—were able to argue effectively for the social and technological utility of their work. Liebig was always powerfully oriented to the applicability of his research. At first this was mostly directed towards the relevance of his research to pharmacy and human physiology, although from 1840 on he also stressed plant physiology, agricultural science, and pharmaceutical and clinical medicine as fields of application for his work. All of these potential practical benefits of academic chemistry far outstripped in importance what the other sciences (excepting perhaps pathology) could lay claim to, even in terms of plausible rhetoric alone. Both the rhetoric and the reality of applications gave additional force to the perceived social promise of chemistry, and especially organic chemistry.

In a landmark book published more than forty years ago, Peter Borscheid argued that following the abortive revolutions of 1848, German princes and political elites moved to adopt elements of Liebig's prescriptions for agricultural chemistry and science pedagogy, in order to create conditions that might promote better-fed and therefore politically more docile populations. This, he argued, was a leading factor that led to the munificent financial support for academic chemistry by German princes and legislatures during the 1850s and later. To whatever degree the Borscheid thesis is correct, there is no question but that Liebig, and academic chemistry more broadly, benefited from the close association of chemistry in general, and organic chemistry in particular, with socially important applications. And there is also no question that political elites across the German lands did support university science munificently after 1848.[36]

In the 1850s and 1860s, magnificent edifices began to appear in the German university landscape to house chemistry departments.[37] For comparison, it should be remembered that academic laboratories in the early (*Vormärz*) stages of the German ascendancy were far from munificent; they had all been shoe-horned into jury-rigged spaces usually in existing buildings, often old, small, and decrepit ones. Liebig's Giessen institute had been a barracks; Wöhler's, although new, a barely adequate

[36] Peter Borscheid, *Naturwissenschaft, Staat und Industrie in Baden (1848–1914)* (Stuttgart, 1976); for a concordant perspective on Baden's science policies, see Tuchman, *Science, Medicine, and the State in Baden*.

[37] Johnson, 'Academic Chemistry'.

half-timbered house; and Bunsen's, Kolbe's, and Gmelin's were all medieval buildings. That began to change immediately after the Revolution of 1848 was defeated. As we have seen, it was sparked by a widespread sense among German political elites that investments in academic science were an essential element of a stable modernizing state, and it was fueled by competition engendered by the decentralized nature of what was collectively called 'Germany.' In that pseudo-international marketplace, and moreover with the freedoms of *Lehr-* and *Lernfreiheit* that enabled both professors and students to 'vote with their feet' all over the German-speaking lands, the price of excellence in university science steadily rose, and was just as steadily paid for by pliant princes and legislatures.[38]

So when Liebig contemplated leaving Giessen (in the Grand Duchy of Hesse), and universities in other German states began to bid for his services, the dominoes began to fall. In 1851 Bunsen was induced to leave Marburg (Electoral Hesse) for Breslau (Prussian Silesia), attracted by the promise of a new chemical laboratory to be built there; but after just three semesters there, the promise of an even more magnificent new laboratory drew him to Heidelberg (Baden). Liebig, sought in vain by both these universities, went to Munich (Bavaria) instead, with the most lavish offer of all in his pocket. Slightly later significant hires included Hofmann to Berlin in 1865, Kolbe to Leipzig also in 1865, and August Kekulé to Bonn in 1866. Each one of these transfers was accompanied by the construction of a palatial new laboratory institute, and all of them were built for chemists who pursued a single subfield, organic chemistry. Moreover, most of the great German chemists of the next generation, such as Liebig's successor Adolf Baeyer, Hofmann's successor Emil Fischer, and Wöhler's and Bunsen's successor Victor Meyer, were also '*organikers*'; they, too, were treated to large new laboratory institutes at the respective universities. And other scientific disciplines—e.g., pathology, physiology, and physics—shared in the wealth. French and British observers looked at these developments with envy and even fear.

I have yet to mention a further crucial factor in the rise of German academic chemistry, and the associated expansion of the field of organic chemistry, namely the theories of atomic valence and chemical structure. These ideas, which shed a bright new light on the mysteries of the composition of organic molecules, were developed in the 1850s and 1860s,

[38] See the references in the previous two notes; also Avraham Zloczower, 'Career Opportunities and the Growth of Scientific Discovery in Nineteenth-Century Germany', M.S. dissertation, Hebrew University, 1960, reprint, (New York, 1981); Joseph Ben-David (ed.), *The Scientist's Role in Society*, 2 (Chicago, 1984); R.S. Turner, E. Kerwin, and D. Woolwine, 'Careers and Creativity in Nineteenth-Century Physiology: Zloczower Redux', *Isis* 75 (1984), 523–9.

just at the time when those earliest grand purpose-built chemical palaces were mushrooming across the German states. Structure theory provided an astonishingly productive compass into (and through) the now exploding field, and benefiting not just academic scientific research, but also the rising fine chemical industry.

In 1865, August Kekulé, the leading figure in these theoretical developments, added another powerful theory, a molecular-structural means to understand the nature of so-called aromatic compounds. We noted earlier that well over 99% of all chemical compounds known today are organics. What we need to add is the fact that the great majority of these are aromatic compounds, and aromatics proved to be the foundation of most dyes and drugs in the new science-based chemical industries of the last third of the century. Consequently, after 1865 chemistry was given another powerful stimulus, a stimulus felt especially in the country that had so successfully pioneered the scientific understanding of organic substances.

Regarding the job market for chemists, there was a growing need for teachers of chemistry, paralleling the steady increase in the numbers of schools providing basic and advanced training in applied areas. University departments also saw growth due to the gradual splitting off of professorships in specialty fields of chemistry, including not just organic, but also inorganic, analytical, mineralogical, biological, and physical chemistry, and because of the need for additional academic personnel below the rank of *ordentlicher* Professor. There were also increased demands for food, drug, and clinical analysts, and towards the end of the century there was a real and growing market for trained chemists for industrial research, as well.[39] All of these intersecting and self-reinforcing factors made German chemistry, especially German organic chemistry, recognized around the world as ascendant.

Exportation to Other Countries

In post-Napoleonic France, the advanced degrees required for university teaching were the *agrégation* (roughly comparable to the German tradition of *Habilitation*), and the *doctorat d'état*; the former was granted simply by examination, but after about 1830 the latter required a dissertation describing original research carried out by the candidate. Such research generally required a mentor, and, for the laboratory sciences, a facility in which to work; both often posed challenges for ambitious French students. Laboratories in the *Facultés* of the *Université de France*, even in the famous Sorbonne, were few and in general seriously deficient, and even the labs at the *grandes écoles* and research institutions of the capital were starved for

[39] Homburg, 'Two Factions, One Profession'.

funding. Despite holding multiple simultaneous positions in Paris, leading *cumulards* in chemistry during the July Monarch, Second Republic, and Second Empire—luminaries such as Dumas, Gay-Lussac, Pelouze, and Regnault—spurned their official workplaces and instead chose to open private or consulting labs, where young would-be scientists sought places in which to work through individual patronage, or through their own independent means. The farsighted moves of the reformist education minister Victor Duruy brought some redress during the 1860s—especially the creation of the Ecole Pratique des Hautes Etudes, partly modeled on the German system of higher education—but further progress was stymied by Prussia's sound defeat of France in the 1870–71 war. Thoroughgoing reforms were finally seen after 1875 in the new environment of the Third Republic, including a full renovation of the Sorbonne, now equipped for the first time with proper scientific laboratories. But the damage had been done; the new Sorbonne did not open until 1894.[40]

Let us return to the late 1830s, and add some further details to this overview. Liebig's principal European rival was Jean-Baptiste Dumas in Paris, who was sorely troubled by the near-absence of state-supported academic laboratories in France, and who early on saw the handwriting on the wall. 'How very fortunate you are', he wrote to Liebig in November 1837, 'to have a battalion of eager chemists at your disposal.… [F]or the moment I am far from that'. Six months later, he told Liebig that he was about to open a new teaching-research laboratory, where he hoped to put about ten selected students to work. 'Only then will I be in a position to resume my experiments in competition with yours. At the moment I can't keep pace with you.'[41]

Dumas was the author of no fewer than four official reports on French higher education, commissioned by the Ministry of Public Instruction and submitted to the Orleanist government in 1837, 1840, 1846, and 1847. In each of these reports, Dumas deplored the paucity of state-supported academic labs, and urgently advocated that France should adopt reforms, several of which proposals Dumas was obviously basing on what he had learned from the practices and facilities specifically in Giessen

[40] The material in this and the following paragraphs is condensed from my treatment in *Nationalizing Science: Adolphe Wurtz and the Battle for French Chemistry* (Cambridge, MA, 2001), and sources listed therein. See also the sources cited in n. 3 above.

[41] Dumas to Liebig, n.d., but ca. November 1837 (Liebigiana IIB, Bayerische Staatsbibliothek, Munich), 'Que vous êtes heureux de pouvoir ainsi disposer d'un bataillon de chimistes zélés. J'espère vous en offrir autant quelque jour; mais pour le moment je suis loin de là.' Dumas to Liebig, n.d., but ca. May 1838 (Ibid), 'Alors seulement, je serai en mesure de reprendre des expériences en concurrence avec les vôtres. Je ne puis pas aller votre pas dans ce moment.'

(without, however, explicitly mentioning this foreign site). In one of these reports he wrote:

> The *Faculté des Sciences* [in Paris], which has allowed itself to be overtaken by Germany and England, would soon regain its rightful place . . . if it could direct a competition of well-organized efforts toward the solution of some of the problems of science, as it is practiced on the other side of the Channel and the Rhine. Today it is necessary for a university . . . not to be forced to wait for a question to be resolved by the individual work of one of its professors extended over several years, when it can do so in a few weeks under his direction by the collective effort of a dozen beginners in science . . .[42]

Faced with repeated failures of the July Monarchy to do anything positive for science, in 1838 Dumas tried, with mixed success, to emulate Liebig by opening a private lab in Paris (referred to above). In the same year Jules Pelouze, whom Liebig had mentored in Giessen and who was ardently longing to bring at least a trace of Giessen to Paris, opened his own private lab adjoining his residence at the Paris Mint.[43] In 1850 the French Liebigian Adolphe Wurtz opened a similar and rather ephemeral private teaching laboratory in Paris, and the following year yet another French former student of Liebig, Charles Gerhardt, did the same.

All four of these men told Liebig that these Parisian installations were modeled in essential respects on what he had done in Giessen; the circumstance that all of the labs were private enterprises had essentially been forced by the government's failure to act. But Wurtz's and Gerhardt's start-ups quickly failed; Dumas's lab, although influential, lasted only ten years; and Pelouze's business, although financially successful, was without significant influence. In any case, none of these was comparable to the Giessen institute; they were all private laboratory training schools rather than higher educational/research institutions. Wurtz subsequently created the only truly successful French academic teaching and research group similar to the German model, which from 1854 on was housed rather incongruously at the *Faculté de Médicine* simply because that was where Wurtz happened to be employed. Only after twenty-three years of Wurtz's pleading with government functionaries did his lab finally win official sanction by the Paris Medical School.

Although Dumas had told his superiors in the education ministry that Britain as well as Germany was outdistancing French efforts, many British

[42] This report was printed in the *Moniteur universel*, (28 October 1846), 2448–50. For more on these four reports, with citations to archival and printed sources, see Rocke, *Nationalizing Science*, 109, 127–8, 270–3.

[43] 'Giessen, Giessen, ah!' the nostalgic Pelouze exclaimed in his letter to Liebig of 25 January 1838, 'jamais matelot n'a demandé la terre avec plus d'impatience.' Bayerische Staatsbibliothek, Liebigiana IIB.

chemists were just as unsatisfied as the French, and just as anxious to apply German models. In the 1830s and 1840s, reforms were moving slowly at Oxbridge. There was better reason for hope at the modernist University College London, where Thomas Graham taught. Graham sought Liebig's recommendation, then hired Giessen-educated George Fownes; when Fownes died at a young age, Graham again asked for Liebig's advice, then hired the likewise Giessen-educated Alexander Williamson. It was at UCL that the first purpose-built academic laboratory in Britain, the Birkbeck Laboratory, was opened in 1845.

Nearly simultaneously with the opening of the Birkbeck Lab was founded the private Royal College of Chemistry, also in London. Liebig's advice was once more avidly sought, including by the German-born Prince Consort, and this time the hire was not just a Briton who happened to be educated at Giessen, but an actual German student of Liebig, namely August Wilhelm Hofmann, who imported the Giessen system bodily into the Royal College of Chemistry.[44] Hofmann's twenty years in London proved providential for British chemistry. Then, when private philanthropy created (as it had for the RCC in London) the nucleus of what became the University of Manchester, who was hired there to provide instruction in physical science but a leading student of Bunsen and Liebig, Edward Frankland. It is no wonder that William Brock labeled his masterly biography of Liebig, *The Chemical Gatekeeper.* Other prominent British chemists of this and a slightly later period, such as Henry Roscoe, Alexander Crum Brown, and William Henry Perkin, were, like Fownes, Williamson, and Frankland, German-educated. We recall that Frankland was ever more concerned about German chemical hegemony through the 1870s, especially after the amazing Hofmann had emigrated home to Prussia in 1865.

Ten years later, shortly after the death of Baron von Liebig, his former student Friedrich Schödler wrote:

> In the last fifty years, chemistry has enjoyed a very special advantage: it has crossed, as it were, into hitherto untouched California gold fields; one only needed to dig in order to uncover riches. . . . What once were only dozens [of academic chemists], are now just as many hundreds of them. The obvious question must be asked: is it not inevitable that chemistry will now advance with giant steps, and by this massive attack continually reveal novel and important knowledge?[45]

[44] Gerrylynn K. Roberts, 'The Establishment of the Royal College of Chemistry', *Historical Studies in the Physical Sciences* 7 (1976), 437–85; Catherine M. Jackson, 'Re-examining the Research School: August Wilhelm Hofmann and the Recreation of a Liebigian Research School in London', *History of Science* 44 (2006), 281–319.

[45] Schödler, 'Das chemische Laboratorium unserer Zeit', *Westermanns illustrierte deutsche Monatshefte*, 38 (1875), 21–47, on 30 and 45.

In studying this great change, exogenous market factors and structural social changes are obviously highly important. However, it is also crucial to pay attention to less obvious factors such as the laboratories that chemists use for education and research, and the equipment in them. Liebig's work, and the apparatus he invented, really did open doors. In nineteenth-century Europe, it was the Germans who walked through those doors first.

I do not intend to attempt even to summarize the importation of the German model to the United States, but I will close by citing the well-known circumstance that Johns Hopkins University was founded explicitly on the German model (although as happened with all imports of that model, the receiving country modified it in certain essential ways).[46] One of the first hires there was Ira Remsen, fresh from a Ph.D. from the Liebig institute in Munich. The first president of Hopkins was Daniel Gilman, who ever after looked to the German founding mythology. The Sheffield Scientific Laboratory at Yale University had acquired its first gifts as early as 1847. 'But for twenty years prior to 1847', Gilman intoned as guest speaker at the Sheffield semicentennial,

> . . . a force had been at work in a little country town of Germany destined to affect the education of Christendom, and at the same time to enlarge the boundaries of human knowledge, first in chemistry and the allied branches, then in every other one of the natural sciences. The place was Giessen; the inventor, Liebig; the method, a laboratory for instruction and research.[47]

This was the Liebig mythology, which was perhaps too uncritically adopted for decades after Liebig's death. The rise and persistence of that mythology was surely at least partly due to Liebig's genius both for chemistry, and for self-promotion. But one quality has been too little stressed: along with everything else, Liebig was supremely fortunate. He was fortunate to find himself in Germany, which had the right combination of movements just at this time; he was fortunate to find himself at the University of Giessen, whose administration did indeed endorse his activities;[48] he was fortunate to find himself close to the starting point of the branch of science to which he devoted his efforts, organic chemistry. Above all, he was fortunate to have chosen chemistry at all, and organic chemistry in particular, for (as I have argued here) organic chemistry around 1830 was uniquely positioned to provide a home for the style of research and education which Liebig so skillfully helped to develop, and which has spread so universally throughout the world.

Case Western Reserve University

46 Hannaway, 'Ira Remsen at Johns Hopkins'.
47 Daniel Gilman, *University Problems in the United States* (New York, 1898), 120.
48 For which, see Brock, 'Breeding Chemists in Giessen'.