Glassware

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The Age of Glassware

From the mid-nineteenth century onwards, every laboratory was filled with glassware, and every trainee scientist learned to work with glass. Not any more. The age of glassware is passing, progressively displaced by the black boxes, new materials, and digital displays of twenty-first century laboratory instrumentation.(23) To anyone under the age of fifty, the contents of this chapter are in danger of appearing like a tale from a strange land. We have already lost much knowledge about glass. All the more reason to write this brief history of glassware in modern science.

What Is—and Was—Special about Glass?

Known since antiquity, glass as material spans both art and science. Made predominantly from sand and formed into objects as decorative as they were functional, glass was prized for its transparency, chemical inertness, and forgiving working properties. Drop a glass flask and it will shatter. But if you heat glass with sufficient skill and care, you can make it take just about any form you choose.

Glass is an almost infinitely variable material. Small changes in the recipe can alter its properties, making it heat resistant, shatter proof, or colored. Glass manages light. In perfectly

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flat float-glass form it is so close to invisible that doors and windows are routinely etched at eye-level to prevent accidents. Silvered on one side, it becomes a mirror. Formed into lenses and prisms, it produces a stunning range of visual effects. When people speak of scientific glass, they almost always mean optical instruments like telescopes, microscopes, and spectroscopes, in which glass renders other dimensions visible to the human eye.(1) This chapter is not about such instruments. Nor is it about thermometers, barometers, and other precision instruments used to study heat, temperature, and pressure.(4) This chapter is about chemical glassware made by bending and blowing glass tubing in the flame of a glassblower's torch. Moving into glass was a fundamental change in the material basis of chemical practice. Its consequences for chemistry were so significant that I have coined the term "glassware revolution" to describe it. The glassware revolution not only changed chemistry, it also changed physiology and physics. The glassware revolution ushered in an age of glassware that lasted for 150 years.(15)

The *Glassware Revolution*: Time and Place

The glassware revolution began when two famous chemists, Jöns Jacob Berzelius in Sweden and Michael Faraday in London, independently tackled the cutting-edge chemical problem of organic analysis. Both sought to discover by analysis how much of the elements carbon, hydrogen, and oxygen particular organic compounds contained. It is important that neither man was in Paris, city of the great Antoine Lavoisier and still the center of the chemical universe in the early 1800s. Both Faraday and Berzelius were isolated from the elite chemical community—but they still managed to do brilliant analytical work. How? They were extremely good glassblowers, and they used this skill to develop a new kind of apparatus.

Fortunately for our historical understanding, they also wrote textbooks, which explain how they used glass, and why they thought this was so important. Being able to make his own apparatus was essential for Berzelius because—unlike Paris—there were very few instrument makers in Stockholm.(2) Faraday had a democratizing goal: he wanted people to be able to do chemistry regardless of their wealth and position. Both chemists valued the fact that making his own apparatus put the chemist in closer touch with his experimental design. And both of their books described basic glassblowing equipment and provided instructions for doing what Faraday called "tube chemistry."(7)

These developments were widely emulated. Between about 1825 and 1835, numerous glassblowing manuals were published across northern Europe. Written by glassblowers and intended for chemists, especially chemistry students, these manuals provide important historical evidence for the glassware revolution. Their authors were well aware of the limitations of text as a medium for transmitting manipulative skill. Publishing a translation of the Parisian instrument maker Ferdinand Danger's *The Art of Glassblowing* in 1831, the British chemist John Griffin explained that: "Unquestionably the best method of learning to work glass is to obtain personal instructions from one who is conversant with the art but such instructions are not easily obtained."(6 piii) That same year in Germany, the glassblower Friedrich Körner published a glassblowing manual to remind his students of what they had seen in class. By 1831, Körner was already teaching glassblowing to chemistry students at the University in Jena.(18 p2–4)

At the heart of this change was the German chemist Justus Liebig's invention of a new piece of analytical apparatus, a small triangular piece of hollow glassware that became known as the *Kaliapparat* [Figure 1]. Liebig developed the *Kaliapparat* in late 1830 during experiments to determine the chemical composition of a series of medicinal alkaloids including morphine and quinine. This new device measured the carbon content of organic compounds reliably and much more simply than was possible with previous methods. Liebig's accomplishment is best known because he integrated analysis using the *Kaliapparat* within an innovative approach to teaching organic chemistry. Liebig's Giessen laboratory became the first site for large scale practical training in research in the sciences.(20,22,12)

Liebig's innovation changed much more than laboratory training. It represented a completely new approach to organic chemistry and a radical solution to the problem of how to provide manpower for that extremely labor-intensive endeavor.(14) It also functioned as an important driver of the glassware revolution. Chemists elsewhere were quick to adopt Liebig's *Kaliapparat* and they soon began to teach its use. In learning how to make and use the *Kaliapparat*, chemists learned that working in hollow glassware could solve problems that much larger, more expensive apparatus could not. This was how glassblowing became an essential component of the chemist's skillset. Chemists everywhere began to learn glassblowing and from the 1830s onwards they worked almost exclusively in flame-worked glass apparatus.

The *Glassware Revolution*: Cause and Effect

Like Berzelius before him, Liebig turned to home-blown hollow glassware in response to the problems of geographical isolation and limited resources. The Parisian chemists who taught Liebig the state of the art of organic analysis could call upon some of the best instrument makers in the world. When Liebig arrived in Giessen, a small market town in rural Germany, he had no laboratory and no instruments, and his income derived entirely from student fees. These were the circumstances that drove Liebig to innovate in glass.

Having made that important move, Liebig soon learned that a skilled glassblower could improve on his ideas. Within a few years, his assistant Karl Ettling had perfected the design and construction of Liebig's *Kaliapparat*.(3 p50) In 1833, Liebig published instructions for how to make the *Kaliapparat* in his journal (the *Annals of Chemistry and Pharmacy*) alongside an introduction to glassblowing, and by 1837 similar instructions were published in his text book of analysis [Figure 2].(19,21) From the mid-1830s, chemists across Europe were analyzing organic substances using the *Kaliapparat*, and they were learning how to blow glass in order to do so.

The success of Liebig's *Kaliapparat* has usually been taken to indicate that it made fixing the composition and formula of organic substances a matter of routine. In fact, this was not the case. Chemists continued to experience great difficulty in determining reliable formulae for organic compounds for many decades. By the early 1840s, using the *Kaliapparat* taught Liebig that it was impossible to make progress in organic chemistry by purely analytical means. In response, he set his best student, August Hofmann, to develop a new and powerful investigative method: synthesis. Far from solving the problem of organic analysis, Liebig's *Kaliapparat* drove the introduction of synthetic organic chemistry.(13)

Organic synthesis soon began producing a large number of new substances and it hugely expanded the domain of organic chemistry in both the academic and industrial spheres. Doing organic synthesis had the potential for significant commercial rewards and this attracted increased student numbers to the field from the mid-century onwards. Synthesis proved even more labor-intensive than analysis, driving a wide range of developments in everything from practical methods to the laboratory itself. It also became the powerhouse of German industry.(25,16)

The vast majority of organic chemistry's new practical methods were implemented in glass. Nineteenth century organic chemists did reactions in sealed glass tubes and they used distillation and recrystallization to purify what those reactions produced. These combinations of flammable organic substances in glass with extremes of temperature and pressure were potentially explosive, especially in the hands of students.(11)

These were powerful factors in the development of the nineteenth-century chemical laboratory. Though it has usually been portrayed as merely a change of scale driven by competition between German states pre-1871, understanding how synthetic organic chemists worked makes clear that the rise of the institutional chemical laboratory was in fact a necessary tool in the development of the discipline. By 1900 chemical laboratories were certainly larger than they had ever been, but chemists' use of glass apparatus to control and manipulate organic nature meant that these laboratories were also different in character. Chemistry had changed dramatically during the preceding century, and these changes prompted fundamental alterations in how laboratories were built, equipped, and operated.(10)

Chemists' increasing reliance on glassware had immediate consequences for suppliers of chemical apparatus. Early nineteenth-century firms supplied items such as flasks and retorts, all produced by working glass gathered from a glassmaking furnace. By the mid-century, these were supplemented by a growing diversity of apparatus made from glass tubing, including Liebig's *Kaliapparat*. Would-be analysts in the 1830s had to make their own *Kaliapparat*, or know someone who could. From about 1850, you could buy a *Kaliapparat* from suppliers across Europe and North America.(8,5)

The glassware revolution resulted in the emergence of a new category of professional scientific glassblower. Just as Ettling had helped Liebig to transform his original innovation into a standard item, so others began to work with skilled glassblowers to realize their experimental visions in glass. Sometimes these collaborations produced entirely new pieces of apparatus. More often they introduced variations on existing pieces of glassware.

One example will clarify why such innovations were important. Liebig's *Kaliapparat* quite soon transcended its original context of invention, organic analysis, instead becoming associated with its gas-absorbing function. When Julius Plücker examined the magnetic behavior of carbon monoxide gas around 1850, he had to be sure the sample was absolutely free from carbon dioxide. Plücker's preparation of carbon monoxide also produced carbon dioxide, which had to be removed. Plücker achieved this by working with the Bonn glassblower Heinrich Geissler. Geissler developed Liebig's original design, producing a new variation of the *Kaliapparat* with significantly improved gas absorption. After passing through two of Geissler's modified devices, Plücker's carbon monoxide was no longer contaminated by carbon dioxide.(24 p162)

Work like this collaboration between Geissler and Plücker established a model for how scientists and glassblowers could work together to solve technical experimental problems—much as scientific glassblowers work today. Geissler went on to develop a successful business for the supply of chemical glassware, both custom and standard. His *Kaliapparat* was widely used in experimental contexts ranging from organic analysis to plant physiology. The glassware revolution transformed physics and physiology as well as chemistry.(17 p68)

Professional scientific glassblowers assisted chemists in tackling one particularly tricky problem: identifying what their reactions made. Chemists today have ready access to formula and molecular structure through a range of instrumental analytical methods. As the difficulty of reliable organic analysis indicates, it was far from straightforward for nineteenth-century chemists to know what they had made. This problem became acute when chemists began trying to synthesize specified natural targets. Successful target synthesis required chemists to demonstrate the identity of their synthetic products with the natural targets. Chemists solved this problem by working with glassblowers like Geissler to develop standard methods of melting and boiling point measurement. Nineteenth-century chemists made melting and boiling point into reliable indicators of purity and identity, and they did so using standard glassware. Glass and glassblowing are central to the early history of laboratory standardization.(9)

Recovering the History of Glassware

Ever since Steven Shapin published his essay "The Invisible Technician" in 1989, historians have been aware that technical expertise in the sciences is not the preserve of people called philosophers and scientists.(26) There is still a long way to go before we have a good account of the rise of technical expertise in any area of science. The present volume, with is focus on tools and materials, provides a most welcome opportunity to highlight this important endeavor. This chapter has situated glass as a material medium and glassware produced by lampworking at the core of the development of modern chemistry, and the sciences generally. It therefore indicates that the history of glassblowing would be a good place to begin telling that story. Yet, despite some excellent studies in the history of physics, for example, we still know remarkably little about glassblowers like Geissler. In part, this state of affairs is a consequence of the difficulty of writing the history of glass. I therefore conclude with some reflections on the important question of how that history may be recovered. Many avenues are open, and they extend far beyond the history of chemistry.

Its fragility is an impediment to historical studies of the material agency of glass in science but it is not an insuperable obstacle. Historical reconstruction is a possible approach. Indeed, several studies within the history of chemistry have used reconstruction to provide a series of useful insights into what it was like to do organic analysis using Liebig's *Kaliapparat*.

Those studies, however, focused on the pedagogically stable analytical procedure Liebig published some seven years after his original introduction of the *Kaliapparat*, and they also mobilized manipulative skills and material resources that were not available in 1830s Giessen. As a result, they are distanced in important ways from both Liebig's process of creative innovation and the work that made his new method of analysis stable in the context of large-scale teaching and collective research.(27)

My work has already begun to answer questions about why and how the glassware revolution happened, and how glassblowers contributed to this development. This chapter has cited several of my essays that used documentary sources, including images and laboratory notebooks, to uncover both the context of Liebig's innovation and its consequences, within and beyond chemistry. Combining documentary sources with the evidence that is only accessible to skilled hands has the potential to illuminate our material and social understanding of how past science was done, and what made the knowledge it produced useful. In this approach, it is possible to ask not just what was done and how, but also by whom. In the end, the goal is to elucidate the limits of possibility of science in its own historical, technical, and social space. The history of glassware is a history of the synergy between head and hands. And this synergy is surely fundamental to understanding science's unrivalled ability to produce reliable knowledge about the natural world. That is why this historian of chemistry is learning to blow glass.

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Figure Captions

Figure 1. Liebig's *Kaliapparat* measured carbon by trapping carbon dioxide gas produced when an organic substance burned in potassium hydroxide (potash) solution. This was how the *Kaliapparat* got its English name: potash apparatus or potash bulbs. Weighing the *Kaliapparat* before and after combustion gave the mass of carbon dioxide, and hence the mass of carbon in the sample.

2016 reconstruction of Liebig's *Kaliapparat* in borosilicate glass by Tracy Drier at the University of Wisconsin-Madison.

Photograph courtesy of Ilia Guzei.

Figure 2. Liebig's 1837 textbook of organic analysis included step by step instructions for

how to make a *Kaliapparat* by glassblowing.(21, Tafel I)

Image courtesy of the Special Collections Research Center, University of Chicago Library.