"I shall speak to you of glass: a meltable material, almost turned mineral by art and by the power and effect of fire, which originates from the ventures of formidable alchemistic savants."

(Vi diro [del vetro] come materia fusibile & quasi fatta mineral da larte & dala potentia & virtu del fuocho, nata dala speculatione deli buoni ingegni alchimici.)

— Vannoccio Biringuccio, *De la pirotechnia*, Venice, 1540, book 2, chapter 14

David Teniers the Younger (1610–1690), Alchemist in His Workshop. *Southern Netherlands, about 1650. Oil on canvas, 71.1 cm x 87.6 cm. Chemical Heritage Foundation Collections, Philadelphia (Eddleman Collection, 00.03.23).*

INTRODUCTION

WHAT IS GLASS? This seemingly simple question has no easy answer—not even in the present day, when scientists believe they have some understanding of the chemical and physical properties of glasses.

The question must have been much more perplexing to people of earlier ages. Glass did not easily comply with scholarly attempts to classify materials. In 1612, the Florentine priest and alchemist Antonio Neri noted the close resemblance of glass to rocks and minerals, but he emphasized that glass is "a compound, and made by art."[1] The German alchemist Johann Rudolf Glauber described the relationship between glass and metal in this way: "For all Sand or Flint, of which Glass is made, is the Matrix or Mother of all Metals."[2] As late as 1711, Johannes Gnilius, a Strasbourg scholar, seconded Vannoccio Biringuccio's opinion that glass should be positioned between metals and stones because it displayed properties of both, being liquefiable like metals and brittle like stones.[3] Perhaps because the debate was leading nowhere, the Irish nobleman and scientist Robert Boyle considered certain characteristics of glass in 1673 and concluded that it allowed "ponderable parts of Flame . . . to pass through the pores."[4] Nicolas Lemery may have had this comment in mind when he wrote in 1698 that "*glass* . . . is a material that is made transparent by the force of fire. After having chased away the coarse, sulfuric, and weak particles, [the fire] has formed straight pores of a sort that the light can easily pass back and forth through [the glass]."[5]

1. Neri 1612, foreword: "molto si assomiglie ad ogni sorte di minerale, & mezzo minerale, quantunque sia un composto, et dall'Arte fatto."
2. *Pharmacopoea Spagyricae*, chap. 20, after Glauber 1689, p. 167.
3. Gnilius 1711, p. 5: "mihi probabilius videtur. . . . Vitrum positum esse inter metalla & lapides, quippe de utrisque aliquid mutuo petit: v[idelicet] gr.[?] de metallis, quod sit liquabile: de Lapidibus, quod non sit ductile malleo, sed fragile &c."
4. Boyle 1673, pp. 70–71.
5. Lemery 1716, pp. 576–577: "*Vitrum*, en François, *Verre*, est une matiere rendue transparente par la violence du feu, qui après en avoir chassé les parties grossieres, sulfureuses & mollasses, y a formé des pores droits en sorte que la lumiere puisse passer & repasser facilement au travers."

Knowledge.

GLASS must have been attractive to alchemists for one reason in particular: unlike silver, wood, and clay, it was made, not found.[6] Man's own creation was mixed from some simple raw materials and then fashioned in the fire into something entirely new—a substance that showed none of the characteristics of its source ingredients and that could not be turned back into them. For millenniums, the only way this experience had been understood was as an alchemical process, a transformation not unlike the presumed transmutation of base metals into precious metals. While such transmutations were often attempted and never accomplished (although practitioners frequently pretended otherwise), the successful results of glassmaking could be witnessed every day.

Like any other manufacturing process, the production of glass requires trained and skilled workers (Fig. 1). Glassblowing demands considerable control and virtuosity, at least in part because hot glass can be worked only for a short time. More than many other crafts, however, glassmaking relies on knowledge. The slightest change in the composition of the raw materials or even a minor variation in furnace conditions can result in unwanted effects: the glass might suddenly change its color, accumulate various kinds of faults, or even crizzle (deteriorate) soon after it is made. Some glassmakers were content to draw upon the experience of the past, and they did well not to change any of their procedures. This was the case, for example, with the German glasshouses that produced green *Waldglas* (forest glass) of uniform quality for many centuries (Fig. 2). Yet if progress was desired, knowledge became the key ingredient. And the best source of expertise was to be found among the alchemists.

6. Glass does appear in nature, and it was sometimes used for crafts. The use of obsidian in Mesoamerica, for example, is well known. Less well known is the production of buttons from *Proterobas* (lamprophyre) in the Fichtelgebirge region in Germany during the 17th century. However, natural glasses were of no concern to vessel glassmakers in Renaissance and Baroque Europe.

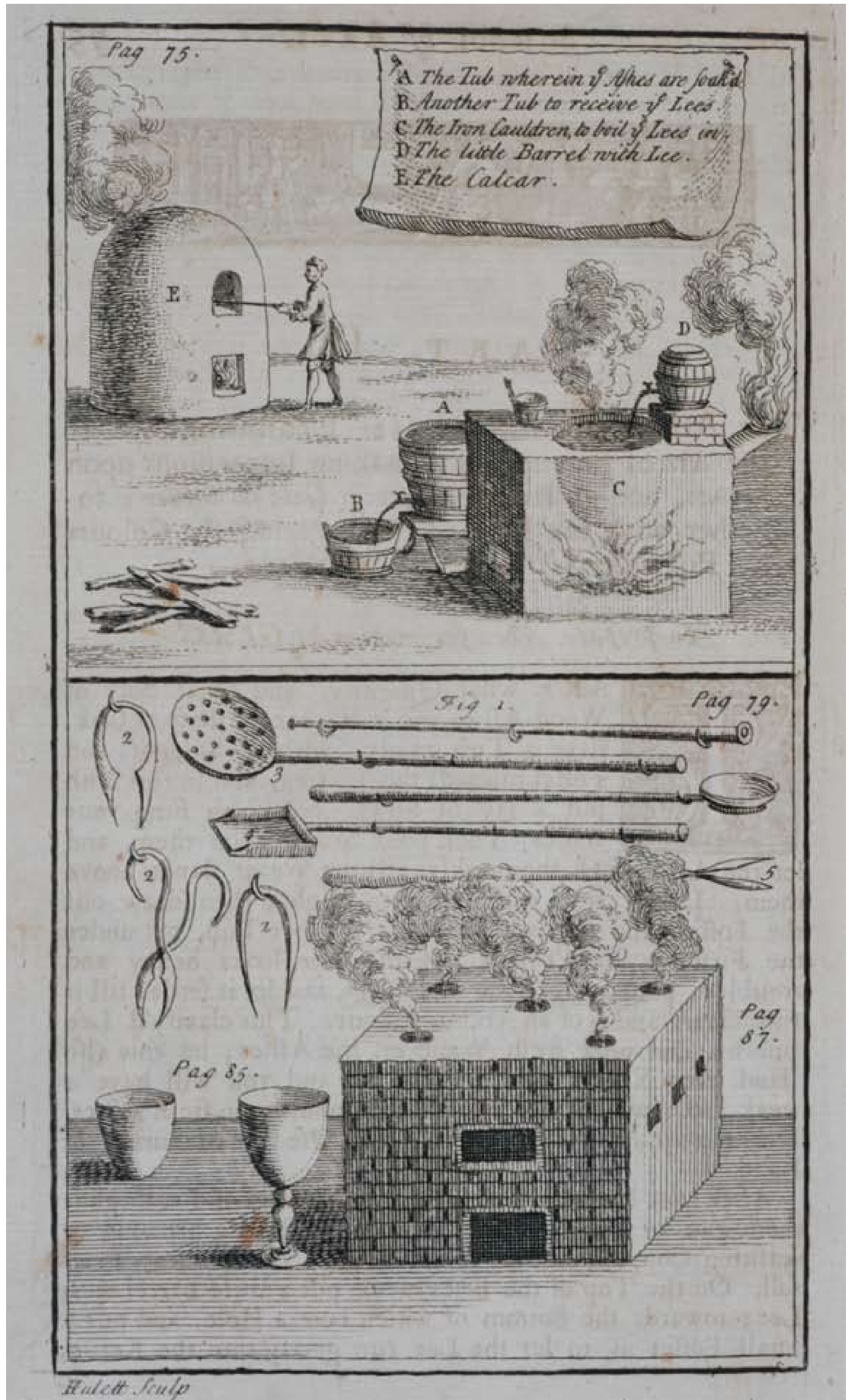

Fig. 1.

Purification of ashes and the making of glass, illustration from Laboratory, or, School of Arts, *1738, pl. before p. 75. The upper half of the illustration shows equipment used to dissolve, boil, and calcine potash, "out of which may be made the finest Glass you can wish or desire." The lower half presents glassmaking instruments, the two parts for a double-walled glass with enclosed gold-leaf decoration (*Zwischengoldglas*), and a kiln to fire the enamels on glass panes.*

Fig. 2.

"Unbreakable" Waldglas *beaker. Germany, dated 1656. H. 13 cm. The Corning Museum of Glass (79.3.617, gift of The Ruth Bryan Strauss Memorial Foundation). The beaker bears the diamond-point engraved and gilded inscription "Trinch mich auss vnnd würff mich Nider/heb mich auff vnnd vill mich wider 1656" (Empty me and throw me down; pick me up and fill me again, 1656).*

Fig. 3.

Three cristallo *goblets. Venice, about 1600. H. (tallest) 17.8 cm. The Corning Museum of Glass (61.3.135, 60.3.17, 70.3.8).*

The term "alchemist" is about as precise a professional characterization as "healer" would be for an otorhinolaryngologist. Alchemy was a form of worldview that involved amateurs as well as professionals. The field of study for the alchemists encompassed the entire world in all its facets, natural and scientific as well as spiritual. Some researchers were specialists, such as the iatrochemists, who employed alchemical principles to create medicines. Those who devoted their attention to what today might be called the "materials sciences" were particularly successful.

The breadth of the inquiry into the subject was matched by the body of literature that it produced. Modern accounts have often added to the confusion about alchemy, leaving readers with the impression that impenetrability was one of its chief features. Some much-needed clarification is provided in the introductory chapters of this catalog by Pamela H. Smith and William R. Newman, two of the best-known experts in the field. Their chapters amount to a translation of alchemical reasoning into modern-day terms. Smith (pp. 23–33) provides an overview of the extent of alchemy and focuses on one of its chief aims, the imitation of nature. This goal was shared by artists, and it gave rise to innumerable points of contact. Smith notes that alchemy, which was concerned with both practical and scientific considerations, bridged the divide between the scholar and the artisan. Newman (pp. 35–47) states that alchemists regarded themselves as "searchers into Nature's secrets." They were "chymists," the true precursors of modern chemists, and it was in the context of "chymistry" that the term "research" was first employed. Newman reports on the scientific reasoning of alchemists in the 17th century—including such concepts as the corpuscular theory and the organic growth of metals in the earth—and their attempts to prove their beliefs in the laboratory.

Recently discovered sketches in the notebook of a 16th-century alchemist perfectly illustrate the ideas of alchemy and their usefulness to humankind (pp. 49–61). The fact that this alchemist, Antonio Neri, was also the author of *L'Arte vetraria*, the single most influential glassmaking manual of all time, makes these drawings even more intriguing. We are very grateful to Paul Engle, their discoverer, for allowing us to include selected drawings from this manuscript in the present volume.

The number of alchemists who followed Neri's example and gained substantial expertise in glassmaking was probably small. But those few practitioners possessed the necessary skills for success. They had a laboratory at their disposal, which permitted them to conduct experiments on a small and thus affordable scale. They were experienced in the treatment of raw materials, and they proceeded to study the effects on glass of a wide range of elements. They formed networks by which they communicated their findings to other experts, and they were able to access publications on the subjects that interested them. None of these benefits was easily available to general glassmakers.

Innovation.

IT IS one thing to claim that improvements in glass were brought about by some interactions between alchemists and glassmakers, but quite another to present proof. Because of a dearth of surviving documents, we know very little about the circumstances surrounding the invention of new types of glass. One of the most important such inventions is Venetian *cristallo*, which is credited to Angelo Barovier on the glassmaking island of Murano in 1453.[7] Not much has been recorded about this event. We do not know, for example, how the development of *cristallo* is related to the emergence of colorless glass in the 13th and 14th centuries, and the meager sources do not tell us if, and to what extent, alchemy informed Barovier's achievements.[8] We do not even have vessels that can be unmistakably attributed to his time or workshop, but we do know that *cristallo* was at the center of Venice's success in glassmaking for the next couple of centuries. It is most typically identified with paper-thin wineglasses of the late 16th and early 17th centuries (Fig. 3), and it is supplemented by such colored and color-patterned glasses as *calcedonio* and *filigrana*.

7. Zecchin 1987, pp. 237–241.

8. Cf. Kerssenbrock-Krosigk forthcoming.

Until the early 18th century, Venice was the undisputed worldwide leader in glassmaking. Factors such as its harbor, which afforded easy access to high-quality raw materials and excellent conditions for exporting finished products, and the skill and inventiveness of its glassblowers helped to keep the city at the forefront of glassmaking developments. Glasshouses on Murano were relatively isolated, and, with few exceptions, the Venetian city-state tried to prevent their recipes and techniques from being dispersed to competitors in other regions. Its efforts were unsuccessful, however, and a recent exhibition at The Corning Museum of Glass provided ample evidence of the achievements of glasshouses that worked *à la façon de Venise* (in the style of Venice).[9]

9. *Beyond Venice* 2004.

Outside Venice, some other new paths in glassmaking were made during the 17th century. Goblets with tall composite stems (**13**) were to become fashionable during the late 17th and early 18th centuries. The delicacy of Venetian glass was gradually abandoned in favor of rich Baroque ornament (**14**). In addition, engraving was introduced. This technique had been used to decorate rock crystal since its introduction in Italy in the late 15th or early 16th century,[10] but it seems not to have occurred to artists to apply it to glass until the late 16th century, perhaps because this relatively inexpensive material did not appear to be worth the effort required by engraving. While a Venetian tazza could be fashioned by a master glassblower in minutes, the fine engraving of an elaborate scene on a goblet could consume weeks.

10. According to Rudolf Distelberger (*Kunst des Steinschnitts* 2002, p. 76), the Vicenza goldsmith Valerio Belli (about 1468–1546) was the first Renaissance artist to whom rock crystal engraving can be attributed.

Nevertheless, the 17th century became a period noted for the engraving of glass vessels in central Europe. The Corning Museum of Glass owns a rare early example (**11**). To be successful, engraving on glass required both a fairly thick vessel wall and a purer batch that would produce a colorless glass with few bubbles. Several generations of masters in Nuremberg created the best engraved glass of this period by applying a very shallow but exquisite relief on glass of fine quality (**15** and **16**). But in order to fully emulate rock crystal, one major step was still required: making a glass so colorless, clear, and transparent that it could be carved in deep relief.

This catalog, as well as the exhibition it documents, focuses on this major advance in the history of glassmaking. Unlike the earlier technological innovations in glass made in Venice, this development did not take place in a single city or region. Instead, it was spread among many glasshouses, from Dublin in the west to Naliboki, Poland, in the east, and from Nøstetangen, Norway, in the north to Munich in the south. The period during which this change occurred is as broad as its geography. While its beginnings can be traced back to the early 1670s, some regions started much later, such as the Nøstetangen glasshouse in the mid-18th century (**56–58**). The principal achievements were recorded during the last quarter of the 17th century, predominantly in England, where George Ravenscroft received a patent for the making of lead crystal in 1674; in Brandenburg, where the alchemist Johann Kunckel developed crystal and gold ruby glass in the late 1670s; in southern Bohemia, where the counts of Buquoy maintained a crystal glassworks, and where the glass production of Michael Müller in his Helmbach glasshouse was highly regarded; and at several locations in central Germany.

Some details concerning these achievements have long been known, but until recently they were treated as isolated incidents. It was assumed that the invention of Baroque crystal was somehow "in the air," and that skilled glassmakers in various parts of Europe independently accepted this challenge.[11] The influence of alchemy was well established in one instance: Kunckel's development of gold ruby in Brandenburg (pp. 123–137), but no further interactions of this kind were suspected. The central argument of this book is that many, if not all, of the decisive improvements in glassmaking during the last third of the 17th century were informed by alchemical knowledge. According to Werner Loibl, the foremost expert in the history of 17th- and 18th-century glasshouses in Germany, this knowledge may have been principally rooted in the work of a single individual: the alchemist and pharmacist Johann Rudolf Glauber (1604–1670).

11. Important general histories of glass, such as Schmidt 1922, tend to concentrate on shapes and decoration rather than on the material; see also Tait 1991, pp. 179–184.

Dissemination.

GLAUBER, who has been called the best practical chemist of his time, is also regarded as one of the founders of industrial chemistry (Ahonen 1981, p. 423). He is best known for his innovative preparations of acids and salts, his improvements in the technical setup of laboratories, and his studies of fermentation, especially in the production of wine. As far as we can tell, glass for decorative or household use was of no concern to him, although he apparently used the facilities of the Rozengracht glasshouse in Amsterdam for some of his experiments (**10**). However, he had a keen interest in the alchemical implications of this material. He developed the process of coloring glass with a gold-tin solution, purple of Cassius, not to produce vessels (as Johann Kunckel later did) but because he saw a link between this process and the transmutation of metals (pp. 27 and 64). Glauber believed that metals showed their true colors only when they were melted into glass, and he hoped that, by extracting these colors, he would move closer to revealing the secret of the philosophers' stone. This effort was unsuccessful, but his experiments yielded a welcome benefit: the qualitative analysis of metal ores. As Robert Boyle reported to The Royal Society, "This was only by mixing some glass with the mineral, and that thereby the metal predominant in the ore is discovered," because each metal produces its own distinct color in glass.[12]

12. Quoted after Merton 1938, p. 607.

Perhaps of greater importance to the history of glassmaking than Glauber's experiments with glass were his preparations of substances that were to become core raw materials of Baroque crystal, such as tartar, saltpeter (Fig. 4), and potash. His process of extracting tartar from wine lees is particularly revealing in regard to his economical manner of thinking, in that the process yields not only tartar but also vinegar, alcohol, and potash, making the enterprise profitable (Glauber 1654).

Unlike other alchemists, Glauber apparently did not attempt to communicate with other important figures in his field. Nevertheless, his work exerted considerable influence, especially in his many writings and in the work of his assistants and followers, who applied Glauber's knowledge to other fields, such as the making of glass.

The advances of alchemists are not easy to trace because many of the movements of these researchers are undocumented and must therefore be conjectured. Most of the alchemists depended upon patrons for support, and thus they often had to abandon half-finished projects and move on when their benefactors died, lost interest in their experiments, or simply stopped making payments.[13] Three contributions to this catalog attempt to follow these relocations in central Europe. Werner Loibl provides an account of the network that can be detected between the main protagonists (pp. 63–73), which extended far beyond the borders of the Holy Roman Empire into Scandinavia and even as far as China (see also **115–117**). Loibl considers Johann Daniel Crafft (1624–1697), Glauber's assistant for a decade, to have been the key intermediary in the dissemination of Glauber's teachings. In maintaining close contacts with many of the leading alchemists/technologists of his time, he fulfilled a role that his master had avoided. Crafft apparently produced no publications of his own, and this makes it hard for researchers to study his work. Fortunately, one of his counterparts, the alchemist and polymath Johann Joachim Becher (1635–1682), was a prolific writer. Martin Mádl, an expert on the arts of the Baroque era, offers a lively portrait of the glass-related technological activities and beliefs of Becher's time (pp. 97–105). Crafft's and Becher's work in various central European regions, including Austria and Bohemia, has been researched, and Olga Drahotová, the grande dame of the history of Baroque glass in Bohemia, provides an overview of early Baroque Bohemian glassworks, including some important earlier Czech research that is here published for the first time in English (pp. 75–95).

13. Glauber was a rare exception to this rule. He refused patronage and lived entirely on the sale of his products.

These contributions afford us a vivid impression of the considerable number of glasshouses in Germany and Bohemia that attempted—some more successfully than others—to produce glass

Fig. 4.

Furnace for transformation of wood into saltpeter, from Glauber 1689, fig. 13 after p. 188. Chemical Heritage Foundation Collections, Philadelphia (Roy G. Neville Historical Chemical Library). The furnace, which "must be like a Glassmaker's Furnace," is filled with layers of wood and limestone, and kindled. The resulting smoke is forced through a long pipe, and it condenses into an acid "juice." By mixing this with the lime and ashes from the furnace, a solution of caustic potash is prepared. In a lengthy process of putrefaction, the solution is subsequently transformed into saltpeter.

of the highest quality. Only a few of them, such as the glassworks in Potsdam and Michael Müller's glasshouse in southern Bohemia, left written records and/or examples of their production for historians to examine. Other factories may have been equally productive, but they sank into oblivion.

The network of alchemists engaged in glass research was not confined to the Continent. Glauber's teachings, and some substantial practical knowledge from Italian glassmakers who had worked in the Netherlands, were carried across the Channel and influenced George Ravenscroft's famous production of flint glass in England in 1674. Colin Brain, who may be described as an amateur—in the best sense of the word—in the history of British glass, has scrutinized all of these events, and he presents a fresh view of the subject, complete with hitherto overlooked details (pp. 107–121). His conclusion that lead crystal was not an exclusively English invention but was instead introduced from the Netherlands is bound to stir some emotions and possibly resistance. Perhaps more importantly, Brain explains that alchemists and glassmakers had parallel interests, in that they worked with many of the same raw materials and techniques, but not necessarily with the same goals. While glassmakers found in lead crystal a perfect batch for clear, faultless glass, alchemists were attracted to glasses with a very high lead content, which they named *vitrum saturni*, because they hoped that this material would serve as a flux to separate base and pure metals (p. 120).

Some alchemists had glassmaking skills, and quite a few glassmakers probably possessed alchemical knowledge. Rare, however, was the individual who engaged in both occupations with an equally high level of expertise. One such gifted practitioner was Johann Kunckel (1637?–1703). He did alchemical research for about 10 years in Saxony, then moved in 1678 to Brandenburg, where he concentrated on glassmaking. Kunckel dramatically increased the usefulness of Neri's *L'Arte vetraria* by providing a carefully considered commentary of his own, and he created some of the most accomplished crystal on the Continent at that time (pp. 123–137). His best-known achievement, however, was the production of gold ruby vessels (cf. **72–80**). These precious objects, in which the addition of gold to the batch turned the glass a deep red color, are the most striking embodiments of the interaction of glass and alchemy.

Prospects.

GLASS of the Alchemists does not claim to present conclusive arguments. Work on this subject is still in the early stages, and all of its aspects are open to further discussion. The contributions to this catalog occasionally reflect on the same episodes, such as that concerning the mysterious alchemist Pietro del Bono and his possible influence on glassmaking in southern Bohemia, in order to assess existing accounts from different viewpoints. General readers may find some insights into the processes, puzzlements, and pitfalls of historical research, while scholars in the field are encouraged to dig deeper and to come up with new evidence.

Beyond the narrow subject of Baroque crystal, there is a wealth of information to be discovered on the achievements of alchemy, or "chymistry," in other materials and periods.[14] A glimpse of this is provided here with the discussion of the work of Johann Friedrich Böttger (1682–1719), an alchemist and the co-inventor of German hard porcelain (**112–114**).

Moreover, there is a striking link between alchemy and modern-day science. Our electronic age has not made the materials sciences obsolete. While the appreciation of pristine household items may have faded, high-tech innovations are pursued in almost every facet of human activity—from the carbon-nanotube tennis racket for an occasional weekend match to more and more sophisticated materials for increasing safety and fuel efficiency in an age of global travel. In all of this, glass continues to play a crucial role. It may represent an old tradition (Fig. 5), but its potential is far from being exhausted. To demonstrate this point, Robert H. Brill and six other scientists, eminent re-

14. Pamela Smith has led the way in delving into this subject. See Smith 1994 and 2004.

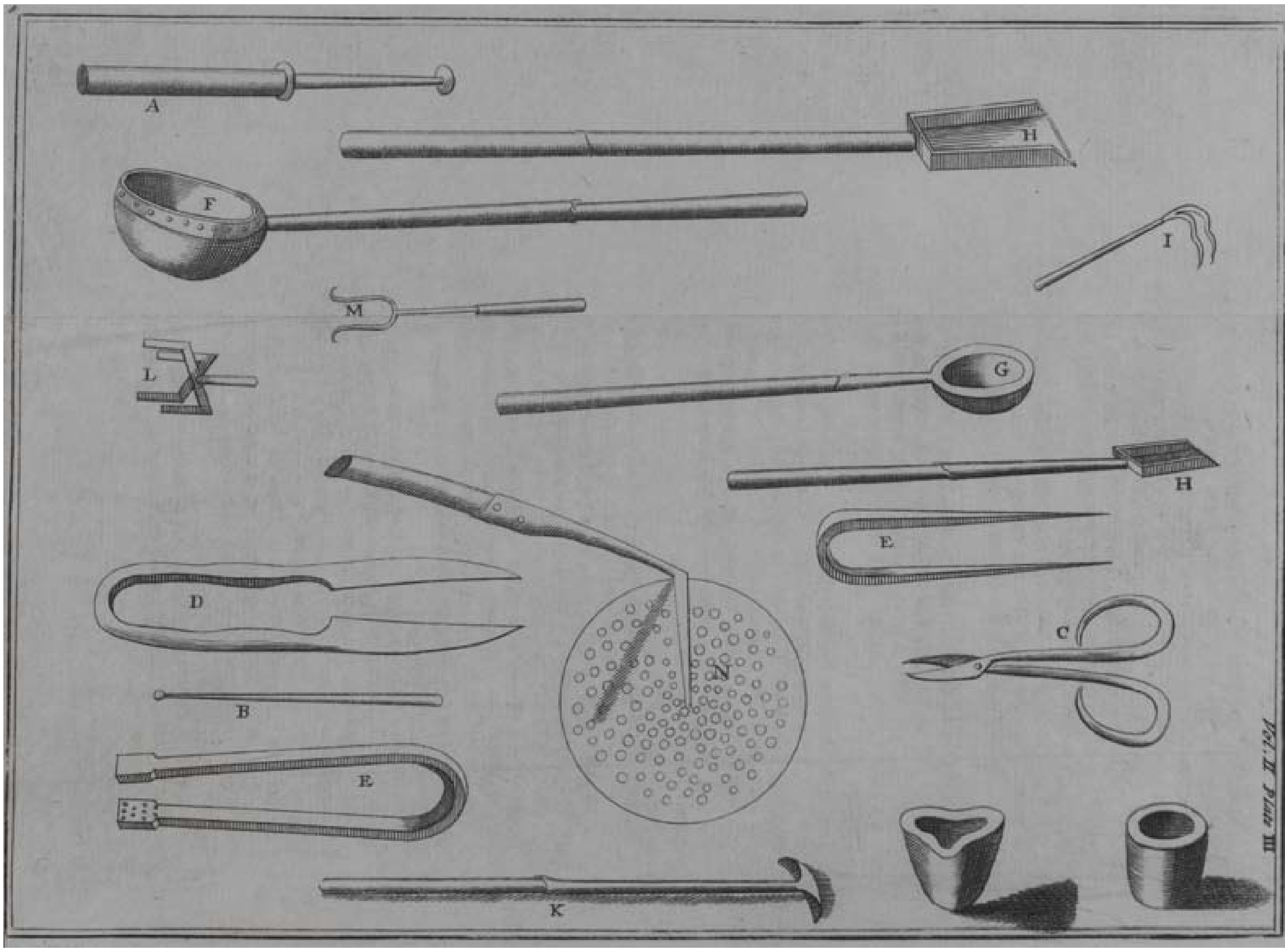

Fig. 5.

Glassmaking instruments, from Barrow 1735, v. 2, pl. III. Most of the instruments shown are still used in the modern-day blowing of glass: (A) blowpipe; (B) pontil rod; (C) "scissors" (straight shears); (D) "sheers" (jacks); (E) "which the Italians call ponteglo, passago, procello, spiei, and also borsello" (pincers); (F) "great ladle [to] take out the metal of the great pot . . . and put it into the little ones for the workmen"; (G) "little ladle . . . for skimming the metal"; (H) "great and little shovels"; (I) "hooked fork . . . to stir the matter in the pots"; (K) "rake . . . to stir the matter, as also to move about the frit in the first oven"; (L) "the Instrument . . . for making champer-pots"; (M) "fork . . . to carry the glass-works into the upper oven to cool them"; and (N) "great ladle . . . to take off the alcali salt from the kettles." This plate follows an illustration of instruments that forms part of various editions of Neri's L'Arte vetraria *(e.g., Kunckel 1679, pl. 5 after p. 334).*

searchers in their fields, offer some insights into present-day glassmaking developments (pp. 303–317). Glass technology has completely changed since the days of the Baroque alchemists, and yet there are connections. The focus, which was then on imitating precious stones, is now on adapting the material to technical needs. Zero-expansion glass for telescope mirrors (pp. 304–305), the emergence of liquid crystal display screens (pp. 306–307), the vitrification of nuclear waste (pp. 307–309), and nanotechnology (pp. 311–313) are entirely modern phenomena, but the approach to these tasks—finding the appropriate batch and fusing the glass in a manner that best serves the required purpose—is not altogether different. In addition, some modern uses of glass have early roots. The development of optics and telescope lenses, in particular, provided a big incentive for improvements in glass following the Renaissance, and the vitrification of nuclear waste employs a property of glass that was highly cherished by alchemists: serving as a flux for the widest range of elements. The attempt to eliminate arsenic from liquid crystal display screens reminds us that this fining agent was introduced in the late 17th century, and it has been used in glassmaking ever since. Putting the theoretical strength of glass (which is much higher than commonly thought) into practice (pp. 309–311) would surely have captured the keen interest of any alchemist. Seventeenth- and 18th-century researchers did not have a thermal-shock-resistant glass, which, in the form of borosilicate glass, is today a common feature in every kitchen.

Is there really anything that we moderns have still to learn from alchemy? To be sure, today's theory of chemistry has little to do with alchemical concepts, which, on the whole, have become obsolete. In the epilogue to this volume (pp. 313–317), Adrian C. Wright shows just how much our current understanding of glass has changed. Nevertheless, the willingness of intrepid alchemists to venture into completely unknown realms of research, as well as their ability to turn many of their findings into profitable enterprises, deserves our admiration. In the end, these remain the qualities that distinguish successful scientists. The distance between them and their predecessors is not so vast. And the question behind the inquiries of researchers old and new—what is glass?—continues to fascinate.

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