The Development of Blowpipe Analysis

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1. The Indispensable Instrument

Though a very modest instrument by modern standards, the blowpipe was, nonetheless, a laboratory staple of the analytical chemist and the mineralogist for more than a century. By the middle of the 19th century it had played a small, but significant, role in the discovery and characterization of close to a dozen chemical elements (Table I) and had actually been used by Reich and Richter in 1863 to isolate the first specimen of the element indium (1).

Table I. Some elements discovered with the aid of the blowpipe (61).

Year	Element	Discoverer
1751	Nickel	Cronstedt
1774	Manganese	Scheele & Gahn
1781	Molybdenum	Scheele & Hjelm
1783	Tungsten	Scheele & de Elhuyar
1795	Titanium	Klaproth
1798	Tellurium	Müller & Klaproth
1801	Niobium	Hatchett
1802	Tantalum	Ekeberg
1803	Cerium	Klaproth, Hisinger, & Berzelius
1830	Vanadium	Sefström
1863	Indium	Reich & Richter

Descriptions of its merits and uses are to be found in virtually every handbook of laboratory methods and techniques and virtually every analytical chemistry text published during the last century. Writing in the 1831 edition of his book, *Chemical Manipulation*, no less a luminary than Michael Faraday characterized the blowpipe as "an instrument which cannot be dispensed with in the laboratory," commenting further that (2):

The chemist does not possess a more ready, powerful, and generally useful instrument than the mouth blowpipe, and every student should early accustom himself to its effectual use and application.

Thirty years later W. A. Miller gave a similar assessment in the 1860 edition of his textbook, *Elements of Chemistry*, noting that (3):

The mouth blowpipe is one of the most valuable and portable instruments which the chemist possesses; he is enabled by its means to arrive with certainty and economy at results which without its aid would require much expenditure both of fuel and time, and it often affords information which could be obtained in no other way.

By the last quarter of the century, W. A. Ross, in his comprehensive treatise on *The Blowpipe in Chemistry, Mineralogy, and Geology*, was, if possible, even more enthusiastic in his praise, at times reaching an almost evangelical tone (4):

Of the determinative sciences, Anhydrous Analysis is the most simple and fascinating. Charmed with the rapidity of his results, eager with expectation, cheered in his labors by the general success of his experimental plans, the blowpipe analyst springs from theorem to problem – from designs to facts – with a facility of mind and hand unexampled in any other branch of chemical physics, until he obtains results which might perhaps excite the generous envy of older and better chemists than himself.

2. The Nature of Blowpipe Analysis

Ross's somewhat purple prose aside, his comments on the simplicity and rapidity of blowpipe analysis are essentially accurate. In its final form, broadly outlined in Figure 1, the method consisted of little more than the systematic observation of the thermal behavior (e.g., flame coloration, sublimation, decomposition, etc.) of a solid sample when subjected to high temperatures under a variety of conditions (e.g., oxygen deficient versus oxygen rich, oxidizing versus reducing, behavior with and without fluxes, etc.) or in conjunction with a few simple reagents (leading to high-temperature solid-

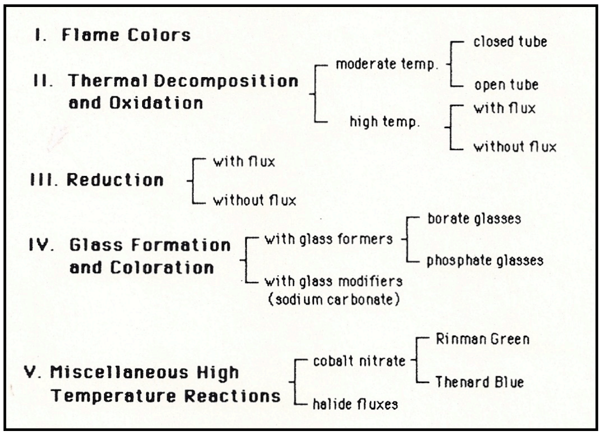


Figure 1. An outline of standard blowpipe tests.

state reactions, such as colored glass and spinel formation).

The requisite high temperatures were, in turn, obtained by use of the blowpipe itself, which, in its simplest form, consisted of a small curved brass tube 7 to 9 inches long (Figure 2). This terminated in a fine-bore nozzle through which the operator, by use of his breath, could direct a thin blast of air through the flame of a candle, oil lamp, or luminous gas burner (Figure 3), resulting in a small, easily controlled, directional, high temperature flame with well developed oxidizing and reducing regions, which could be brought to bear on small "pea-sized" samples of the material being analyzed.

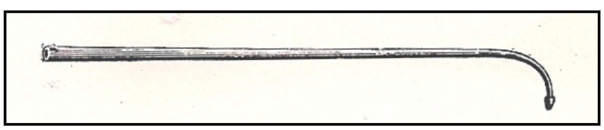


Figure 2. A simple brass blowpipe (62).

In addition, the small number of necessary reagents and fluxes (mostly in the form of dry solids), coupled with the the simplicity and small size of the equipment, readily lent itself to the construction of portable kits for blowpipe analysis, allowing the chemist and mineralogist to apply the technique while in the field. The net result was a method of qualitative analysis that was not only rapid, but portable, inexpensive, and semi-micro in scale – its only obvious disadvantage being its limitation to the analysis of solid samples.

3. The Origins of Blowpipe Analysis

The blowpipe is not an example of a scientific instrument designed and developed by scientists to perform a

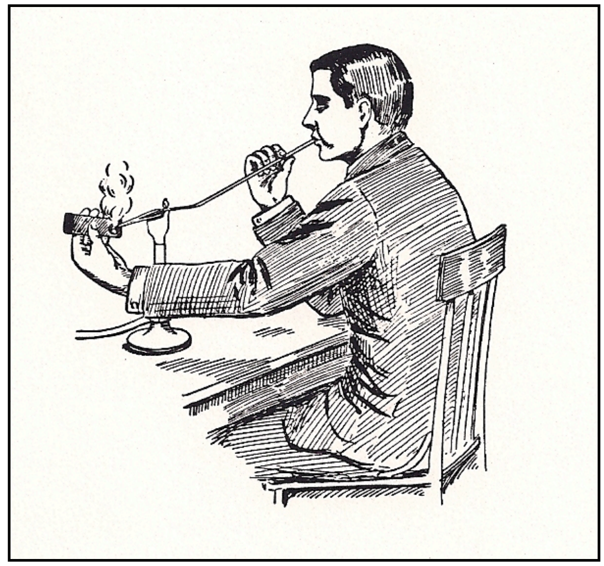


Figure 3. Use of the blowpipe, circa 1911 (63).

specific task in the laboratory. Its origins are rather to be found among the arts and crafts and are lost in antiquity. As numerous tomb paintings testify (Figure 4), Egyptian metal workers and goldsmiths were well aware of its use several millennia before Christ (5) and, indeed, the ancient Babylonian word for smith, *nappachu*, is actually derived from the name of the reed blowpipe used in their craft (6). The form of the blowpipe eventually adopted by the chemist is essentially that perfected by jewelers, metal workers, and goldsmiths during the Middle Ages, as testified to by its current German name of *Löthrohr* or soldering tube (5).

The first references to the blowpipe in the chemical literature occur in the late 17th century (Table II)

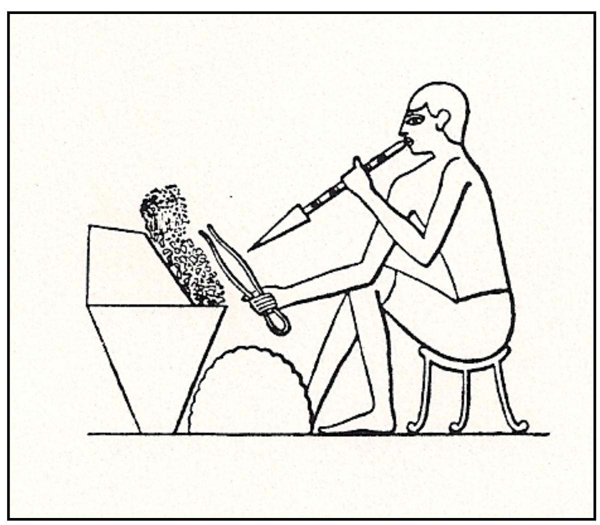


Figure 4. Egyptian tomb painting illustrating the use of the blowpipe, circa 1500 BC (5).

Table II. Early mention of the blowpipe in the chemical literature (64).

Year	Author	Source
1670	J. Bartholinus	*Experimenta crystalli islandici*
1677	J. Kunckel	*Ars vitraria experimentalis*
1739	J. A. Cramer	*Elementa artis dociasticae*
1740	S. A. Marggraf	*Micellenea berlinensa*
1746	S. Rinman	*KAH*, **7**, 146
1748	A. Swab	*KAH*, **9**, 99
1751-1758	A. F. Cronstedt	Various papers in *KAH* & *Försök till Mineralogiens eller Mineral-Rikets upställning*
1759	J. G. Wallerius	*Chemia physica*
1767	T. Bergman	*De confectione aluminis*

and begin to rapidly multiply about the middle of the 18th century. In all of these cases the blowpipe is either mentioned in passing as being an extremely useful addendum to the laboratory or the effects of heating various materials with the blowpipe are described. In no case, however, is it suggested that such behavior could form the basis for a systematic method of analysis, nor are specific procedures for the application of the blowpipe described in any detail.

The first person (Table III) to bridge the gap between random reference and systematic application was the Swede Gustaf von Engeström, who published a small work entitled *A Description of a Mineralogical Pocket Laboratory* in 1770 (7). This did not describe von Engeström's own work with the blowpipe, but rather the apparatus and procedures developed nearly a decade earlier by his teacher and mentor Axel Frederik Cronstedt (Figure 5). Engeström had been trained by Cronstedt in the art of assaying and blowpipe analysis at the Swedish Mint and while traveling in England had decided to publish an English translation of Cronstedt's essay on systematic mineralogy, *Försök till Mineralogiens eller Mineral-Rikets upställning*, which had first appeared in Swedish in 1758. In this influential work, Cronstedt forcefully argued for a natural classification of minerals based on the study of their chemical composition and properties rather than on their external appearance. Since Cronstedt made frequent reference to the behavior of different mineral species when heated both with and without fluxes using the blowpipe, Engeström thought it proper to add his small treatise as an appendix to the translation.

Table III. The early development of systematic blowpipe analysis (64).

Year	Author	Source
1770	G. von Engeström	*Description of a Mineralogical Pocket Laboratory*
1779	T. Bergman	*De tubo ferruminatorio*
1785 -1794	H. B. Saussure	*Obs. Phys.*, **25**, 409, 492; *Ibid.*, **43**, 1
1810	J. F. Hausmann	*Leonhard's Taschenbuch gesamm. Mineral.*, **4**, 17
1812	J. Berzelius	*Lärbok i Kemien*, Vol. II
1818	J. B. Gahn	*Ann. Phil.*, **11**, 40
1820	J. Berzelius	*Om Blåsrörets Användande i Kemien och Mineralogien*

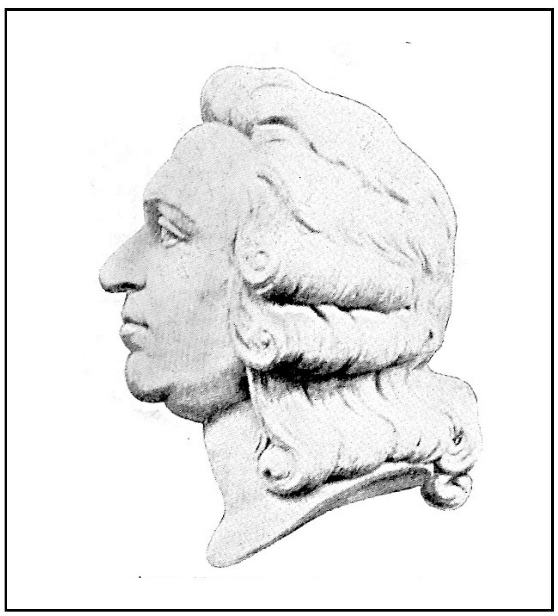


Figure 5. Axel Frederik Cronstedt (1722-1765) (1).

About the same time a second Swede, Torbern Bergman (Figure 6), who had been appointed as professor of chemistry at the University of Uppsala in 1767, began to publish a series of systematic essays on various topics in both pure and applied chemistry. As part of his overall plan Bergman attempted to collect, classify, and critically assess all of the then current methods of chemical analysis. His essay on "wet" analysis or the analysis of mineral waters, *De analysi aquarum*, first appeared in 1778, and his essay on "dry" analysis or blowpipe analysis, appeared the next year (Table III) (8). In the space of about 50 pages Bergman summarized the current state of blowpipe analysis, describing the various instruments, the use of borax, microcosmic salt (sodium ammonium phosphate) and soda as fluxes and for the formation of glass beads, the use of charcoal and silver or gold spoons as supports for fusions and reductions, and the outer and inner structure of the blowpipe flame. Most of these innovations were already employed by Cronstedt and, as we now know, Bergman's knowledge of the latter topic was a result of his correspondence with Scheele, who had clearly recognized the oxidizing or phlogiston-deficient nature of the outer flame and the reducing or phlogiston-rich nature of the inner flame (9).

Figure 6. Torbern Bergman (1753-1784) (65).

In the second part of the essay Bergman summarized the known blowpipe reactions of a large number of mineral species, having first experimentally verified the results in his own laboratory. Owing in part to Bergman's ill health, most of this experimental work was actually performed by his assistant, Johan Gottlieb Gahn (Figure 7), and, indeed, Partington goes so far as to suggest that it was Gahn who brought the technique of blowpipe analysis to Bergman's attention in the first place (10). Gahn was generally acknowledged by his contemporaries to have been the supreme master of the art of blowpipe analysis (11). After leaving the university in 1770 with a degree in mining engineering, Gahn went to work for the *Bergskollegium* or Mining Board, where he was assigned the task of improving the copper smelting at the mines in Falun. There, in a private laboratory which he built at his own expense in the garden of his home, Gahn refined and extended the technique of blowpipe analysis, introducing the use of both platinum wire and the cobalt nitrate test.

Gahn, however, published virtually nothing about his work. Some of his results were made known by the German mineralogist, Johann F. Hausmann, who had met Gahn while traveling in Sweden in the years 1806-1807 (12), and who published a summary of Gahn's techniques in *Leonhard's Tachenbuch für die gesammte Mineralogie* in 1810 (13). J. J. Berzelius likewise persuaded Gahn to summarize his techniques for inclusion in the second volume of the 1812 edition of Berzelius'

Figure 7. Johan Gottlieb Gahn (1745-1818) (65).

textbook of chemistry (14). An English version of this summary also appeared in the *Annals of Philosophy* in 1818 (15), the year of Gahn's death, apparently at the instigation of the journal's editor, Thomas Thomson, who had also met Gahn while traveling in Sweden in 1812 and who admired him greatly (16).

The definitive summary of Gahn's methods, however, came from the pen of Berzelius (Figure 8), who, convinced of the importance of Gahn's work, had visited him at Falun during the summers of the years 1813-1816, where, as he later wrote in his autobiographical notes (17):

I learned his method of handling the blowpipe, with which he had acquired unusual skill, and which was furthered by the methods he had developed with it of obtaining microchemical results. Henceforth the blowpipe became an altogether indispensable tool for the analytical chemist as well as for the mineralogist. A number of simple chemical instruments, moreover, had been devised by Gahn for his use but had never been described and therefore were not known. I learned from him not only their use but also how to make them at the lathe and joiner's bench.

Berzelius had also hoped to experimentally verify the reported blowpipe reactions of the known minerals under Gahn's tutelage, but the latter died before the project could be completed (18). Berzelius, nevertheless, completed the project on his own and in 1820 summarized Gahn's achievment and his own in his famous book, *Om Blåsrörets Användande i Kemien och Mineralogien* (19).

In a letter written shortly before the publication of the book, Berzelius rather humorously commented on the amount of experimental work it had entailed (20):

I am fascinated by the mass of information one obtains merely by blowing on one sample after another. Among the metals there is hardly one which the blowpipe will not reveal. I have almost dislocated my jaws in the routine analyses of the metals to be presented in the book.

Though, to paraphrase Szabadvary (21), it is an exaggeration to claim that blowpipe analysis was totally unknown outside of Sweden prior to the publication of Berzelius' book – one need only examine the writings of Hausmann in Germany, H. B. de Saussure in Switzerland, and Wollaston, Hatchett, and Smithson Tennant in England to see that this is not the case – there is little doubt that it played a major role in converting blowpipe analysis from a method used by a privileged few into a standard analytical technique used by virtually every chemist and mineralogist.

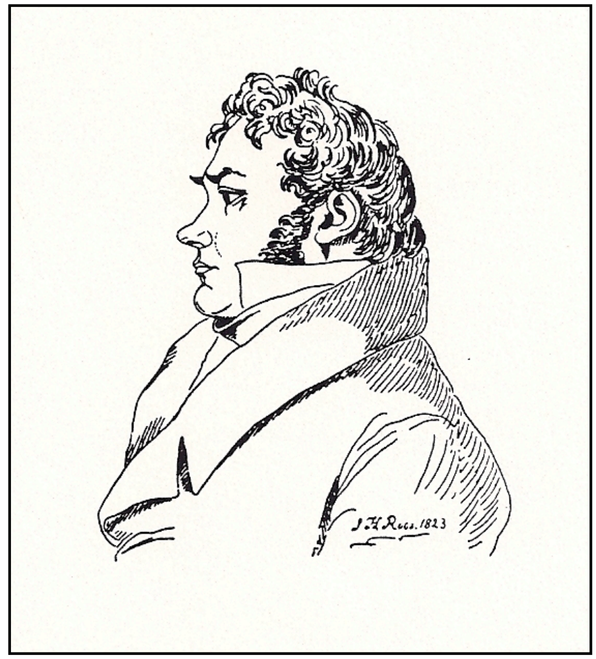


Figure 8. Jöns Jacob Berzelius (1779-1848) (1).

The historical introduction to Berzelius' book, his autobiographical notes, and his unpublished papers, all contain delightful anecdotes concerning the use of the blowpipe. These include a demonstration of its use for the aged poet and amateur geologist Goethe (17), dinner parties in which points of debate in mineralogy were resolved at the table by producing and using a pocket blowpipe (20), tales of Gahn's ability to detect a tin impurity of less than 1% in a sample of Ekeberg's newly discovered tantalum oxide, and of his ability to separate metallic copper from the ashes of a piece of writing paper (18) – though a later writer doubted the truth of this claim, arguing instead that Gahn had accidently volatilized the copper from the brass of his oil lamp (22).

In his famous *Geschichte der Chemie*, Kopp suggested that many of the specific procedures used in blowpipe analysis could be viewed as scaled down versions of previously known methods of dry analysis and metal extraction, such as cupellation, the reduction and purification of metals with charcoal and salt fluxes, etc. The particular advantage of the blowpipe was that it allowed the operator to employ small pea-sized samples and an oil lamp rather than crucibles and a large muffle furnace (23-24). This point of view is certainly that adopted by many later writers on the blowpipe. Berzelius' reference to Gahn's perfection of "microchemical" techniques has already been mentioned, and Griffin's famous 19th-century catalogs of chemical apparatus always listed the blowpipe equipment next to the section on "Apparatus for Assaying and Metallurgical Operations in General" under the heading of "Blowpipe Apparatus and Apparatus for Micro-Chemical Operations" (25).

Other possible sources for the origins of various blowpipe tests can be found in the ceramics, glass, and pigments industries. Kopp, for example, mentions the work of Johann Pott, who had been commissioned by the King of Prussia to establish the composition of Meissen porcelain. Pott attempted to solve the problem using synthesis rather than analysis, and proceeded to systemically examine the behavior of over 30,000 minerals, mineral mixtures, and mineral-salt flux combinations when subjected to high temperatures. Though he never did succeed in solving the riddle of Meissen porcelain, Pott did conscientiously record the melting points, color changes, etc. of his various mixtures. These he published in three volumes between 1746 and 1754, thus providing a valuable compendium of the high-temperature solid-state reactions of materials of use in the ceramics industry (26).

Likewise, long before they were recognized as metallic ores, certain minerals were mined for their ability to impart specific colors to glass. The most famous of these, of course, are the ores of cobalt and manganese, which were used from the 16th century onwards for the production of blue and violet glasses. A mixture of roasted cobalt ore and sand, variously known as *Zaffer, Safflor* or *Safran*, also came into use about the same time as a blue pigment (1). The logical way to recognize these materials was to test their ability to give a colored glass in a trial run, a procedure recommended by Biringuccio in the 1540 edition of his *Pirotechnia* (27):

Zaffre is likewise another semi-mineral as heavy as metal. It does not melt of itself, but in the company of vitreous things it becomes like water and colors them blue ... Another semi-metal of similar nature is also found. This is called manganese ... It does not melt in such a way that metal can be extracted from it, but when it accompanies things disposed to vitrify it colors them a beautiful violet, and with it glass makers color their glasses to that shade.

It is only a short step from these observations to the use of borax, phosphate, and soda glass beads in blowpipe analysis to identify such metals as cobalt and manganese.

In short, most of the chemistry involved in blowpipe analysis can be reasonably viewed as an adaptation and miniaturization of known methods of purification, extraction. and "raw materials testing" already current in the 17th and 18th centuries in the fields of metallurgy and the manufacture of ceramics, glasses, and pigments. This contention is also supported by an examination of the social context in which most of the scientists listed in Tables II and III did their work and at the same time explains the virtual domination of the early history of blowpipe analysis by Swedes.

In his study of 18th-century Swedish science, Tore Fränsmyr noted that the early development of chemistry in Sweden was to some extent unique in that it was initially fostered by institutions other than the universities (28). The most important of these was the *Bergskollegium* or Board of Mines which had been founded by the government in the middle of the 17th century to administer the Swedish mining industry. Following the death of Charles XII in 1718, Sweden began to experience a period of growing political liberalism, coupled with a revival of its flagging economy and a drive toward increased industrialization. Economic utility, to paraphrase Fränsmyr, became the motto of the day, and essentially dominated Swedish science for the next few decades.

Under this social impetus the role of the *Bergskollegium* began to change. In addition to its traditional administrative role, it became increasingly involved in applied research directed at improving existing industries and at uncovering and exploiting new mineral resources. As early as 1683 Urban Hiärne had established a *Laboratorium chymicum* as a sub-department of the *Bergskollegium*, and eventually a technical college designed to train mining engineers and supervisors was added as well. It is within the *Bergskollegium*, rather than the universities, that many of the scientists listed in Tables II and III found their employment and often their education as well, including Anton Swab (1703-1768), Sven Rinman (1720-1792), Axel Cronstedt (1722-1765) and Gutaf von Engeström (1738-1813) (29). Cronstedt was a close personal friend of Rinman, and it was through Rinman's example that Cronstedt decided to join the *Bergskollegium*. Here Cronstedt also met and worked with Swab on a process for producing calamine from Swedish zinc blende, a project which Swab later continued in collaboration with Rinman (30). As mentioned early, von Engeström, in turn, received his training under Cronstedt and Swab.

The strong emphasis on practical chemistry within the *Bergkollegium* also tended to dominate the direction of chemistry within the universities, and indeed the initial success of the *Bergskollegium* may have even played a role in retarding the establishment of chemistry within these institutions (28). The first chair of chemistry at Uppsala was created in 1750 and occupied by Johan Gottschalk Wallerius (1709-1785). Wallerius wrote extensively on the subject of metallurgy and was aided by Daniel Tilas, who was one of Cronstedt's supervisors at the *Bergskollegium*, in writing his handbook of mineralogy (30). Likewise, both Cronstedt and Rinman attended Wallerius' lectures on chemistry and mineralogy at the university. Wallerius' successor at Uppsala was Torbern Bergman, and Berzelius received his chemical training under Johann Arfzelius, (1753-1837), who was one of Bergman's pupils and, in turn, his successor at Uppsala.

An even better example of the manner in which all of these men are interconnected is the career of Gahn, who, as already mentioned, was trained at the university under Bergman, worked for the *Bergskollegium*, collaborated with Berzelius, and was instrumental in introducing Torbern Bergman to the apothecary Carl W. Scheele. who, as we now know, made a significant but unpublished contribution to the theory of blowpipe analysis (30). In addition, virtually all of these men belonged to the Swedish Academy of Sciences and published papers in its proceedings (abbreviated as *KAH* in Table II).

In others words, the evidence clearly shows that we are not dealing with a series of independent references in Tables II and III but rather with the publications of a small interconnected community of chemists, mineralogists and metallurgists, all of whom were part of a common professional, educational, and often personal nexus. Moreover, most of these men were explicitly trained in the very metallurgical and industrial processes which appear to form the basis of most blowpipe procedures. It would seem that an appreciation of usefulness of the blowpipe was already widespread in the mining circles of Sweden and, to a lesser extent, those of Northern Germany by the beginning of the 18th century. Extensive reference to its use in print awaited only the development of a community of educated technologists with a tradition of publishing applied research – a set of conditions which had evolved in Sweden by the middle of the 18th century. In this context, it is interesting to note that Kunckel, one of the earliest writers to mention the blowpipe, though born in Schleswig-Holstein and holding a variety of positions in Germany, eventually ended up in Sweden as Minister of Mines for Charles XI, where he died in 1703 (32).

During the last century this common community background gave rise to a minor debate over the true origins of systematic blowpipe analysis. Bergman, in his treatise on the blowpipe, mentioned in passing that it was Swab who first made use of the blowpipe for testing minerals around the year 1738, though in actual fact nothing was published on the subject by Swab until 1748, and the similarity in the dates strongly suggests a typographical error on Bergman's part. This is further supported by the fact that Bergman incorrectly reported Swab's first name as Andreas rather than Anton, thereby confusing him with a half brother who had died in 1731. Additional confusion was produced by the fact that Cronstedt had originally published his 1758 essay on mineralogy anonymously. Upon Swab's death in 1768, Linné, connecting Bergman's comment with the extensive references to the blowpipe in the anonymous, but now well known, essay on mineralogy, incorrectly suggested that Swab was its author (33).

These comments were picked up again by W. A. Ross in the last quarter of the 19th century and in the introduction to his 1884 treatise on the blowpipe, he concluded that both Engeström's English translation of Cronstedt's essay, on which Cronstedt's name had appeared for the first time, and the appended essay on blowpipe techniques, were in reality the work of Swab, which Cronstedt and von Engeström had conspired to take credit for after Swab's death (4) These charges were examined in detail by Landauer in 1893, who concluded that they were totally unfounded, and that, indeed, Swab himself had acknowledged that Cronstedt was really the first to truly apply the blowpipe as a method of systematic mineral analysis (9). This was also the conclusion of Cronstedt's biographer, Nils Zenzen, who nevertheless emphasized the substantial debt that Cronstedt owned to his senior colleagues in the *Bergskollegium* (30).

In passing it should be noted that the unique "chemical-mineralogical" tradition that developed out of the *Bergskollegium* in Sweden (and which was present to a lesser degree in Germany as well) was not just responsible for the development of a new method of qualitative analysis. A concomitant of this process was the gradual emergence of the operational or analytical concept of a chemical element or simple substance. It was Thomas Thomson who first suggested more than 180 years ago that this concept was to be found in the writings of late 18th-century Swedish chemists, and especially in those of Scheele and Bergman (34). This proposition was reexamined a number of years ago by Cassebaum and Kauffman, who concluded that Thomson's assertion, though somewhat oversimplified, was essentially correct (35), and quite recently Llana has raised the subject once again (36).

Llana argues that it was the natural history approach to the classification of chemical substances and especially to minerals, fostered, in turn, by the practical aims of the *Bergskollegium*, which gave rise to this essential chemical concept. Broad classifications based largely on extremely general physical properties, and embodied in abstract elements or principles, such as earth, air, fire, and water, tended to discount subtler differences in chemical behavior. Yet it was precisely these subtle chemical differences – the fact that not all earths were really alike – which could spell the difference between disaster and success for the industrial chemist. The drive to discover and effectively exploit new mineral resources required an ever increasing ability to make these distinctions. resulting, on the one hand, in the development of ever more refined methods of chemical analysis (of which blowpipe analysis is a specific example), and, on the other hand, in new ways of thinking about and classifying substances so as to take these chemical differences into account, leading ultimately to the definition of a chemical substance as a unique collection of chemical properties and to the operational concept of a simple substance or element (recall Cronstedt's chemical approach to mineralogy mentioned earlier). In Llana's opinion, it is the translation of virtually all of the major works of the Scandinavian and German chemical-mineralogical tradition, and especially those of Pott, Cronstedt, and Bergman, into French in the years between 1750 and 1780 that accounts for the change in the thinking of French chemists on the subject of chemical elements that can be seen in passing from the writing of Rouelle, Macquer, and Venel to those of Guyton, and ultimately to those of Lavoisier himself.

4. Evolution of the Blowpipe as an Instrument

Though minor modifications were introduced throughout the 19th century, Berzelius' book essentially gave blowpipe analysis its final form. Plattner (37) and Harkort (38), for example, attempted to develop methods for the quantitative assay of selected metals using the blowpipe, and Ross unsuccessfully tried to introduce both the use of aluminum plates for sublimations and fusions, and the use of boric acid beads (4). A detailed discussion of these developments is beyond the scope of the present paper. However, in keeping with the theme of the current symposium, some comments on the evolution of the blowpipe as a scientific instrument are appropriate. Since our interest is restricted to the hand blowpipe used in analysis, the development of larger table-top blowpipes for glass blowing and bulk metal working, such as the oxy-hydrogen blowpipe, will not be discussed.

Suggested modifications of the simple hand blowpipe can be conveniently divided into those designed to increase the blowpipe's portability and to deal with the problem of moisture condensation from the breath, on the one hand, and those directed at maintaining a constant air supply, on the other. An overview of modifications of the first type can be had from Figure 9, which shows a variety of blowpipes from the collections in the London Science Museum (39). Starting with the simple brass blowpipe on the right, and passing from right to left, we have examples of blowpipes designed or recommended by: 1) Cronstedt (c. 1750), with a spherical moisture trap; 2) Bergman (c. 1770), with an improved moisture trap; 3) Gahn (c. 1780), with a cylindrical moisture trap, removable ivory mouth piece, and removable tips or nozzles of varying sizes and materials; 4) Tennant (c.1790), with a tip that can be rotated 360 degrees; 5) Wollaston (c. 1810), which comes apart in three sections for greater portability; 6) Black (c. 1802), in which the conical bore automatically acts as a moisture trap; 7) Bucknell (c. 1910), for use with a source of coal gas; and 8) Pepys (c. 1810), which attempts to combine the virtues of Bergman's moisture trap with Tennant's variable angle tip. A survey of 19th century blowpipe manuals seems to indicate a preference for the designs of Cronstedt and Gahn.

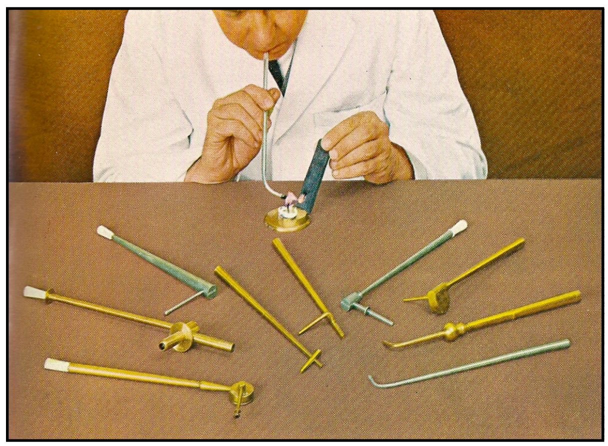


Figure 9. A selection of typical blowpipes from the London Science Museum (29).

Modifications of the second type stem from the fact that it is frequently necessary to sustain an air blast for longer than one can hold one's breath. Though procedures were developed for blocking the back of the throat with the tongue, while simultaneously releasing air from the cheeks and inhaling, these are somewhat difficult to master (at least from written instructions – the author has tried several times without success!). Consequently considerable ingenuity was expended on devices designed to maintain an uninterrupted blast of air while the operator caught his breath. An example dating from around 1824 is shown in Figure 10 along with a modern cross-sectional drawing based on the original description of its working mechanism (40). Part of the air supply is diverted into a water reservoir

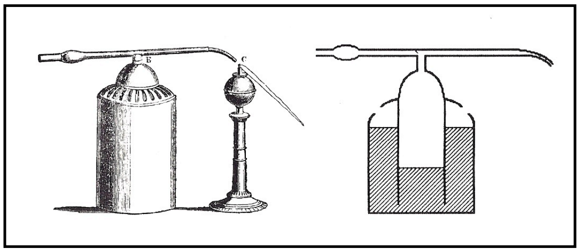


Figure 10. Blowpipe with a water reservoir, circa 1824 (40).

underneath the blowpipe, where it was used to raise the level of the water in the outer chamber. When the operator stopped to take a breath, the gravitational potential of this water forced air out of the inner chamber into the blowpipe while simultaneously closing a one-way valve leading to the mouth piece. A similar principle was used later by de Luca (Figure 11), save that part of the breath was used to inflate an india rubber bulb (41). The original location of this bulb was not very convenient and Ross later suggested an improved

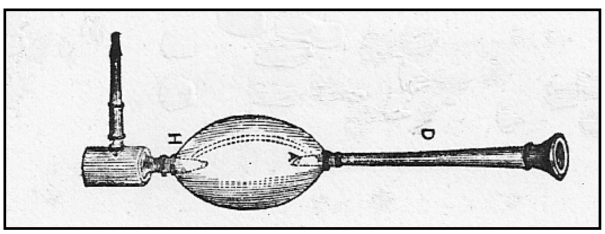


Figure 11. De Luca's blowpipe with a rubber reservoir (41).

version with the bulb off to one side (4).

Finally, for those who did not want to use their breath at all, the india rubber reservoir could be combined with a second bulb for pumping air, giving rise to what Ross affectionately called the "old Freiberg hand-blower" (figure 12) (4).

Other possible air supplies included hand and foot operated bellows, and, later in the century, piped in gas in combination with compressed air or oxygen supplies. However, these changes destroyed one of the blowpipe's strongest virtues – its portability. Indeed, most writers on the blowpipe seemed to be less than enthusiastic about these modifications. Faraday, commenting on various forms of the blowpipe in 1831, wrote that "as is usually the case in contrivances for the attainment of any particular object, the most common is the most valuable" (2). Likewise, in the 1906 edition of their blowpipe manual, Brush and Penfield noted that (42):

Various mechanical contrivances have been devised where air is supplied from bellows, but they are regarded as unnecessary. The strength of the blast needs to be often varied in order to bring about different effects, and with the breath this can be most readily accomplished. Only students showing enterprise and patience sufficient to master the ordinary instruments will be likely to make much progress in blowpipe analysis.

As mentioned earlier, one of the strong points of blowpipe analysis was not only the portability of the blowpipe itself but of the accompanying equipment and reagents, allowing for the construction of portable kits for analysis. As the title of von Engeström's 1770 manual indicates, this advantage was recognized from the very beginning (43). An excellent source of information about such kits can be found in the 19th-century catalogs of the British firm of J. J. Griffin and Sons (Figure 13) (25), and a detailed description, along with a large number of photographs, of a kit dating from the 1830s and belonging to the American chemist, James Curtis Booth, has been published by Edelstein (44). Dr. Edelstein bought this kit at auction in the 1940s, and has informed the author that it is still in his possession. The catalog for the Daubeny collection of chemical apparatus at the Oxford Museum of the History of Science lists a similar kit as well as several separate blowpipes, and doubtlessly additional examples are to be found in other European museums (45).

5. The Parting of the Ways

The unique Swedish chemical-mineralogical tradition persisted well into the first half of the 19th century. In addition to Berzelius, who is in many ways its culmi-

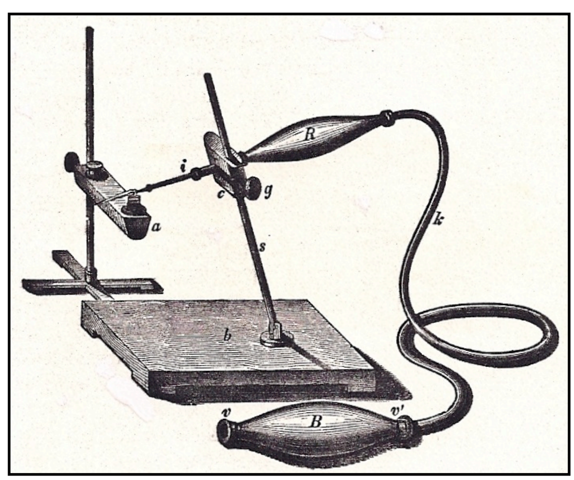
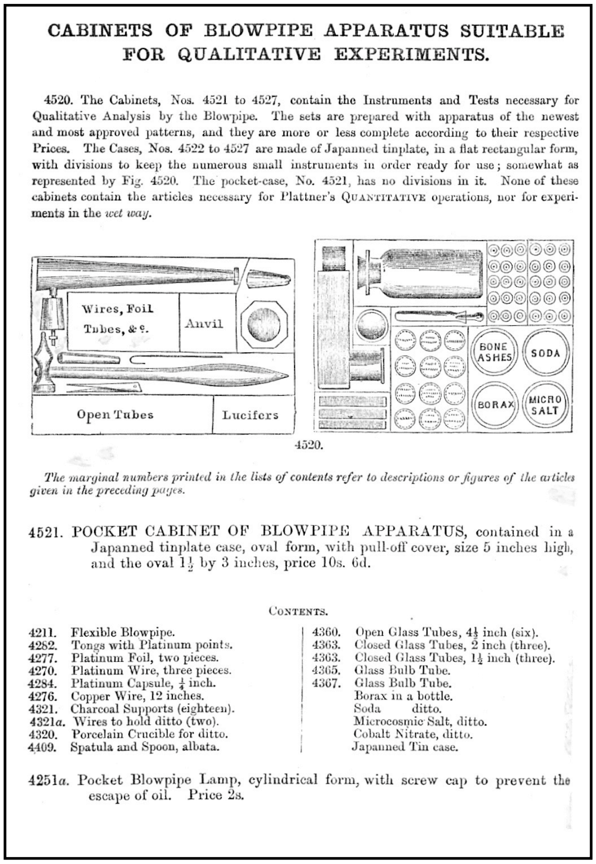


Figure 12. The "old Freiberg hand-blower" (47).



CABINETS OF BLOWPIPE APPARATUS SUITABLE FOR QUALITATIVE EXPERIMENTS.

4520. The Cabinets, Nos. 4521 to 4527, contain the Instruments and Tests necessary for Qualitative Analysis by the Blowpipe. The sets are prepared with apparatus of the newest and most approved patterns, and they are more or less complete according to their respective Prices. The Cases, Nos. 4522 to 4527 are made of Japanned tinplate, in a flat rectangular form, with divisions to keep the numerous small instruments in order ready for use; somewhat as represented by Fig. 4520. The pocket-case, No. 4521, has no divisions in it. None of these cabinets contain the articles necessary for Plattner's QUANTITATIVE operations, nor for experiments in the *wet way*.

4520.

The marginal numbers printed in the lists of contents refer to descriptions or figures of the articles given in the preceding pages.

4521. POCKET CABINET OF BLOWPIPE APPARATUS, contained in a Japanned tinplate case, oval form, with pull-off cover, size 5 inches high, and the oval $1\frac{1}{2}$ by 3 inches, price 10s. 6d.

CONTENTS.

4211.	Flexible Blowpipe.	4360.	Open Glass Tubes, $4\frac{1}{2}$ inch (six).
4282.	Tongs with Platinum points.	4363.	Closed Glass Tubes, 2 inch (three).
4277.	Platinum Foil, two pieces.	4363.	Closed Glass Tubes, $1\frac{1}{2}$ inch (three).
4270.	Platinum Wire, three pieces.	4365.	Glass Bulb Tube.
4284.	Platinum Capsule, $\frac{1}{4}$ inch.	4367.	Glass Bulb Tube.
4276.	Copper Wire, 12 inches.		Borax in a bottle.
4321.	Charcoal Supports (eighteen).		Soda ditto.
4321*a*.	Wires to hold ditto (two).		Microcosmic Salt, ditto.
4320.	Porcelain Crucible for ditto.		Cobalt Nitrate, ditto.
4409.	Spatula and Spoon, albata.		Japanned Tin case.

4251*a*. Pocket Blowpipe Lamp, cylindrical form, with screw cap to prevent the escape of oil. Price 2s.

Figure 13. 19th-century kits for blowpipe analysis sold by the British firm of J. J. Griffin and Sons, circa 1867 (25).

nation, mention should be made of Johann Arfvedson (1792-1841), the discoverer of lithium; Nils Sefström (1787-1845), the discoverer of vanadium; and Carl Mosander (1797-1858), the discoverer of several rare earths and Berzelius' assistant and successor. That Mosander strongly identified with this tradition is apparent from a portrait done later in life showing him posing with his blowpipe and a bust of Berzelius in the background (Figure 14). A similar amalgamation, however, did not exist in other countries and there the mineralogical and purely chemical applications of blowpipe analysis tended to take separate paths. This parting of the ways was further reenforced by the early establishment of two separate textbook traditions, for although Berzelius' book was of extreme importance in introducing the techniques of blowpipe analysis to the practicing research chemist and was rapidity translated into German, French, English, Italian, and Russian (20), it does not appear to have been all that successful as an introductory text for the beginning student in chemistry and mineralogy.

The mineralogical branch of these traditions was essentially established by the publication of Carl Friedrick Plattner's (Figure 15) text *Die Probirkunst mit dem Löthrohre* in 1835 (37). Plattner was professor of metallurgy and blowpipe analysis at the Freiberg Mining Academy (46), and his text, to judge from the acknowledgements in later 19th century manuals of blowpipe analysis, rapidly became the standard in the field, and was itself kept in print long after Plattner's death (47). The final format that eventually evolved for the mineralogical approach to blowpipe analysis tended to be extremely short on theory and only moderately long on technique, most of space being taken up instead by elaborate "determinative tables for common mineral species" which allowed the student to deduce the identity of his mineral sample from the results of his blowpipe tests and a few physical parameters, such as color, luster, hardness, and specific gravity (42, 48-51).

The chemical tradition, on the other hand, was established by Carl Remigius Fresenius (Figure 16), who published his famous text *Anleitung zur qualitativen chemischen Analyse* in 1841 (52). Like Plattner's manual, Fresenius' book was kept in print for most of the 19th century and gave qualitative analysis a form which it retains to this day (53). In his book Fresenius introduced the use of some extremely simple blowpipe tests in the section on the preliminary examination of solid samples. Though this use of the blowpipe was essentially supplementary to the wet analysis that was

Figure 14. Carl Gustav Mosander (1797-1858) posing with his blowpipe and a bust of Berzelius (20).

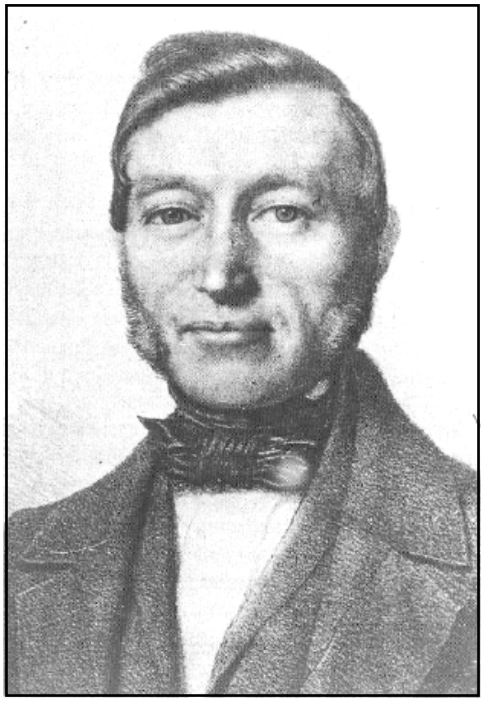


Figure 15. Carl Friedrich Plattner (1800-1858) (46).

the core of the book, and consequently nowhere as elaborate and self-sufficient as the version found in the mineralogical tradition, it was nevertheless part of every chemist's training and is to be found in virtually every qualitative analysis manual written before 1915. The extent to which chemists of the period also encountered the more detailed mineralogical version through required mineralogy courses is unknown and would require a study of the training curriculums required by 19th-century chemistry departments. Ross, however, did complain in a footnote in his 1884 treatise that the City and Guilds of London Institute had recently dropped blowpipe analysis from its curriculum on the advice, as he phrased it, "of an irresponsible chemist" (4).

The ultimate fates of these two traditions also differ. After about 1915 the rationale for a required course in qualitative analysis began to radically change. Its goal became less and less to impart a practical day to day laboratory skill which would allow the practicing chemist to analyze virtually any inorganic substance presented to him. Rather the orientation became increasingly theoretical, tending to make use of the analytical scheme as a mere source of example reactions designed to illustrate the aqueous chemistry of ions and the principles of equilibria and mass action developed at the end the the 19th century by the rising discipline of physical chemistry under the leadership of Ostwald, Arrhenius, and van't Hoff. This trend is perhaps best illustrated by the title of Louis Hammett's 1929 qualitative analysis text, *Solutions of Electrolytes* (54), and it is largely this orientation which continued to dominate the course until its ultimate "demise" in the early 1970s. The influence of Ostwald's classic text, *The Scientific Foundations of Analytical Chemistry*, is apparent here and it would be of some interest to compare the educational backgrounds of those chemists who authored manuals of qualitative analysis before and after 1915 (55).

As the groups of illustrative ions and unknowns became increasingly selective and artificial, the more general supplementary procedures, whose chemistry was irrelevant to the theoretical principles being illustrated, were gradually eliminated, including the sections on the blowpipe. An examination of qualitative analysis manuals written after 1915 shows that most had dropped this section, the trend being virtually complete by the 1930s. Likewise, only three references to the teaching of blowpipe analysis could be found in *The Journal of Chemical Education*, all of them appearing before 1935 (56-58).

Though blowpipe analysis was also largely displaced as a practical method of analysis in geochemical and mineralogical research circles by the 1900s, it has persisted as an inherent part of the introductory undergraduate mineralogy course even to the present day, where its continued use is still largely a matter of its

Figure 16. Carl Remigius Fresenius (1818-1897) (65).

simplicity and economy (59). Unlike wet "qual," it has never become subservient to the teaching of theoretical principles, though such an elaboration is of some interest, since the chemistry involved is largely supplemental to and nonoverlapping with that illustrated by wet analysis, and indeed represents many topics in industrial and solid-state chemistry which are grossly underrepresented in the current Freshman chemistry curriculum (60).

The use of qualitative analysis to teach theory prolonged its life several decades after it ceased to be an analytical method of major importance. Perhaps a similar approach to blowpipe analysis could lead to a revival of interest in this classic technique. For the present, however, it is a thing of the past, and perhaps no better epitaph can be found than that penned by the curmudgeonly Ross over a hundred years ago (4):

It will then, I hope, be manifest to the student that he shall be able, by means of his lamp and blowpipe, after patient and persevering utilization of his leisure time in this most fascinating study, to literally excel the miracles fabulously performed by "Aladdin and his Wonderful Lamp." He shall use it as a key of fire to unlock the secret and solid stores of nature; as an instrument of torture, to force her to confess how she colors her amethysts, emeralds, and sapphires; as a "pencil of light," wherewith to trace in imperishable records, and with electric rapidity, the precise composition alike of her soft, sulfurous ore, or her adamantine corundum.

6. References and Notes

1. M. E. Weeks, *Discovery of the Elements*, 6th ed., Journal of Chemical Education: Easton, PA, 1960. For indium, in particular, see F. Reich and T. Richter, "Vorläufige Notiz über ein neues Metall," *J. prakt. Chem.*, **89**, 441 (1863).

2. M. Faraday, *Chemical Manipulation*, Carey and Lea: Philadelphia, PA, 1831, pp. 117-118.

3. W. A. Miller, *Elements of Chemistry*, Parker: London, 1863, p. 258.

4. W. A. Ross, *The Blowpipe in Chemistry. Mineralogy. and Geolog*y, Crosby & Lockwood: London, 1884, pp. vii -xii.

5. A, Smith, *The Blowpipe Characters of Minerals*, Williams and Norgate: London, 1862, p. 1.

6. J. R. Partington, *Origins and Development of Applied Chemistry*, Longmans: London, 1935, p. 15.

7. Secondary sources give a variety of conflicting titles. Partington (10, p. 174) lists the title page as: *An Essay towards a System of Mineralogy by Axel Frederic Cronstedt. Translated from the Original Swedish, with Notes, by Gustav von Engestrom. To which is added, A Treatise on the Pocket-Laboratory, containing an Easy Method, used by the Author, for Trying Mineral Bodies, Written by the Translator. The Whole Revised and Corrected, with Some Additional Notes by Emanuel Mendes da Costa, London, 1770.* Some sources also list, apparently incorrectly, an earlier 1765 English edition.

8. T. Bergman, *Commentatio de tubo ferruminatorio*, Vienna, 1779.

9. J. Landauer, "Die ersten Anfänge der Löthrohranalyse," *Berichte. deut. chem. Gesell.*, **26**, 898 (1893). An older treatment of the early history of blowpipe analysis, which the author has not seen, can be found in C. E. Weigel. "Versuch einer Geschichte des Blaserohrs und seine Anwendungen," *Crell's Beyträge*, **4**, 262, 393 (1790), *ibid.*, **6**,198 (1794).

10. J. R. Partington, *A History of Chemistry*, Vol. III, Macmillan: London, 1962, p. 185.

11. For biographical information on Gahn, see Weeks (1), Partington (10), and U. Bokund in C. Gillespie, Ed., *Dictionary of Scientific Biography*, Vol. V, Scribner: New York, 1970, p. 222.

12. J. F. L. Haussman, *Reise durch Skandinavien in den Jahren 1806 und 1807*, Leipzig, 1811-1818.

13. J. F. L. Hausmann, *Leonhard's Taschenbuch gesamm. Mineral.*, **4**, 17 (1810).

14. J. J. Berzelius, *Lärbok i Kemien*, Vol II, Stockholm, 1812, p. 473.

15. J. G. Gahn, "On the Blowpipe," *Ann. Phil.*, **11**, 40 (1818). A German translation also appeared in volume 24 of *Schweigger's Journal für Chemie und Physik* in 1820.

16. T. Thomson, *Travels Through Sweden in the Autumn of 1812*, Baldwin: London, 1813. See also (31).

17. J. J. Berzelius. *Autobiographical Notes*, Williams and Wilkins: Baltimore, MD, 1934. pp. 92-93 and pp. 112-114.

18. J. J. Berzelius, *The Use of the Blowpipe in Chemistry and Mineralogy*, 4th ed., Ticknor: Boston, MA. 1845, pp. 3-7.

19. J. J. Berzelius, *Om Blåsrörets Användande i Kemien och Minealogien*, Stockholm, 1820.

20. J. E. Jorpes, *Jac Berzelius: His Life and Work*, Almqvist and Wiksell: Stockholm, 1966, pp. 87-91.

21. F. Szabadvary, *History of Analytical Chemistry*, Pergamon: London, 1966. pp. 50-55.

22. J. Nickles, "Correspondence to the Editor," *Am. J. Sci.*, **45**, 67 (1868).

23. H. Kopp, *Geschichte der Chemie*, Vol. II, Vieweg und Sohn: Braunschweig. 1844, pp. 36 -49.

24. J. O. Nriagu, "Cupellation: The Oldest Quantitative Chemical Process," *J. Chem. Educ.*, **62**, 668 (1985).

25. J. J. Griffin, *Chemical Handicraft: A Classified and Descriptive Catalogue of Chemical Apparatus*, Griffin & Sons: London, 1866.

26. J. H. Pott, *Chemische Untersuchungen welche fürnehmlich, von lithogeognosia oder Erkennung und Bearbeilung der gemeinen einfacheren Steine und Erden, ingleichen von Feuer und Luft handeln*, Potsdam, 1746, 1751, and 1754.

27. V. Biringuccio, *Pirotechnia*, 1540. English translation and reprint, MIT Press: Cambridge, MA, 1942, p. 113.

28. T. Fränsmyr, "Swedish Science in the Eighteenth

Century," *Hist. Sci*, **12**, 29 (1974).

29. For biographical information see Weeks (1), Partington (10), Gillespie (11), and Lindroth (30).

30. N. Zenzen, "Johan Gottschalk Wallerius and Axel Fredrik Cronstedt," in S. Lindroth. Ed., *Swedish Men of Science:1660-1950*, Almqvist & Wiksell: Stockholm, 1952, pp. 92 -104.

31. T. Thomson, *The History of Chemistry*, 2nd ed., Vol. II, Colburn and Bentley: London, 1830-1831. pp. 55-57 and 242-247.

32. J. J. Partington, *A History of Chemistry*, Vol. II, Macmillan: London. 1961, p. 363.

33. C. von Linné, *Systema naturae*, Vol. III, Holm, 1768, p. 1.

34. T. Thomson, *A System of Chemistry*, Edinburgh. 1802, pp. 385-386.

35. H. Cassebaum, G. Kauffman, "The Analytical Concept of a Chemical Element in the Work of Bergman and Scheele," *Ann. Sci*., **33**, 447 (1976).

36. J. W. Llana, "A Contribution of Natural History to the Chemical Revolution in France," *Ambix*, **32**, 71 (1985).

37. C. F. Plattner, *Die Probirkunst mit dem Löthrohre*, Leipzig, 1835.

38. E. Harkort, *Die Probierkunst mit dem Löthrohr*, Freiberg, 1827.

39. F. Greenway, C*hemistry 1: Chemical Laboratories and Apparatus to 1850*, Science Museum: London, 1966., p. 9.

40. Anon., "Chemical Apparatus," *The Chemist*, **1**, 95-99 (1824).

41. C. Morfit, C. Morfit, *Chemical and Pharmaceutical Manipulations*, Lindsay and Blakiston: Philadelphia, PA, I857, p. 573.

42. G. J. Brush, S. L. Penfield, *Manual of Determinative Mineralogy with An Introduction to Blowpipe Analysis*, 16th ed., Wiley: New York, NY, 1906. p. 13.

43. W. A. Smeaton, "Portable Chemical Laboratories of Guyton de Morveau, Cronstedt, and Gottling," *Ambix*, **13**, 84 (1966).

44. S. W. Edelstein, "An Historic Kit for Blowpipe Analysis," *J. Chem. Educ*., **26**, 126 (1949).

45. C. R. Hill, *Catalogue I: Chemical Apparatus*, Museum of the History of Science: Oxford, 1971, pp. 13 - 15.

46. For biographical information on Plattner see I. Westermann, "Aus Plattner's Leben und Werken," *Metall und Erz*, **30**, 101 (1933).

47. T. H. Richter, *Plattner's Manual of Qualitative and Quantitative Analysis with the Blowpipe*, Van Nostrand: New York, NY, 1902.

48. H. B. Nason, *Elderhorst's Manual of Qualitative Blowpipe Analysis and Determinative Mineralog*y, Porter & Coates: Philadelphia, PA, 1881.

49. J. Landauer, *Blowpipe Analysis*, Macmillan: London, 1892.

50. W. O. Crosby, *Tables for the Determination of Common Minerals*, Published by the Author: Boston, MA, 1911.

51. J. V. Lewis, *Determinative Mineralogy with Tables*, 2nd ed., Wiley: New York, NY, 1915.

52. C. R. Fresenius, *Anleitung zur qualitativen chemischen Analyse*, Bonn, 1841.

53. C. R. Fresenius, *Manual of Qualitative Chemical Analysis*, 10th ed., Wiley: New York, NY, 1891.

54, L. P. Hammett, *Solutions of Electrolytes*, McGraw-Hill: New York, NY., 1929.

55. W. Ostwald, *The Scientific Foundations of Analytical Chemistry*, Macmillan: London, 1895.

56. C. H. Almfelt and S. S. Beebe, "Glass Blow-Torch for Blowpipe Analysis," *J. Chem. Educ*., **8**, 968 (1931).

57. E. McAndress, "A Course in Elementary Blowpipe Analysis as a Fundamental Laboratory Project in High-School Chemistry," *J. Chem. Educ*., **8**, 1397 (1930).

58. I. A. Cowperthwaite, "A Simple Burner for Blowpipe Reactions," *J. Chem. Educ*., **10**, 96 (1933).

59. C. S. Hurlbut and C. Klein, *A Manual of Mineralogy*, 19th ed., Wiley: New York, NY., 1977, pp. 170-176.

60. W. B. Jensen, "Blowpipe Analysis Reconsidered," to be published.

61. Compiled from Weeks (1) and the short abstracts in H. M. Davis, *The Chemical Elements*, The Science Service: College, PA, 1952.

62. *Price List of Scientific Laboratory Apparatus*, E. H. Sargent and Co: Chicago, IL., 1914, p. 44.

63. L. Kahlenberg and J. H. Walton, *Qualitative Chemical Analysis*, 2nd ed., Cantwell: Madison, WI. 1915.

64. Abbreviations for older journals and the spelling and capitalization of titles and names has been kept consistent with Partington (10) whenever possible.

65. Illustration from the Oesper Collections in the History of Chemistry of the University of Cincinnati.

7. Publication History

Originally published in J. T. Stock, M. V. Orna, Eds., *The History and Preservation of Chemical Instrumentation*, Reidel: Dordrecht, 1986, pp. 123-149. In this reprint several of the original illustrations have been replaced by higher quality examples on the same subject from the Oesper Collections at the University of Cincinnati.

8. 2009 Update

Since the original publication of this paper in 1986 three events of great relevance have occurred. Jan Trofast has published the first full-length biographical study of Gahn as well as a two-volume set of Gahn's collected letters:

* J. Trofast, *Johan Gottlieb Gahn: En Bortglömd Storhet*, Wallin & Dalholm Boktryckeri: Lund, 1996.

* J. Trofast, Ed., *Johan Gottlieb Gahn: Brev*, Wallin & Dalholm Boktryckeri: Lund, Del I, 1991, Del II, 1996.

and Ulricht Burchardt has published a detailed history of blowpipe instruments and kits heavily illustrated with photographs of surviving artifacts:

* U. Burchardt, "The History and Apparatus of Blowpipe Analysis," *Mineralogical Record*, **25**, 251-277 (1994).