Derek A. Davenport is Professor of Chemistry at Purdue University, West Lafayette, IN 47907, where he teaches a course on the history of chemistry. A former Chair of the Division of the History of Chemistry of the ACS, he has, in addition to the Faraday symposium, organized historical symposia on Priestley, Dalton and G. N. Lewis, and is currently putting together a symposium on C. K. Ingold.

MICHAEL FARADAY AND THE ART AND SCIENCE OF CHEMICAL MANIPULATION

William B. Jensen, University of Cincinnati

Though a vast secondary literature now exists chronicling the life and achievements of Michael Faraday (figure 1), virtually none of it deals with his only full-length book, *Chemical Manipulation*, first published in 1827 (1). His numerous biographers mention only the fact of its publication, but tell us nothing of its contents and little of the circumstances surrounding its writing. Given the vast amount of important scientific work done by Faraday, this oversight is perhaps understandable. Unlike his famous *Diary* (2), the three volumes of his *Experimental Researches in Electricity* (3), and the companion volume of *Experimental Researches in Chemistry and Physics* (4), *Chemical Manipulation* records no significant scientific discovery. Unlike his famous juvenile lectures on the *Various Forces of Matter* (5) and the *Chemical History of a Candle* (6), or the lesser known *Lectures on the Non-metallic Elements* (7), it lacks accessibility and popular appeal. Yet, as already mentioned, it was the only book explicitly written by Faraday (Table 1) - the volumes of *Experimental Researches* were actually reprints of previously published scientific papers and all three of the juvenile lecture series were transcribed from stenographic notes and edited by others - *Forces of Matter* and the *Chemical History of a Candle* by William Crookes and the *Non-metallic Elements* by John Scoffern.

Nevertheless, it can be argued that *Chemical Manipulation* does merit closer examination, if for no other reason than it gives us valuable insight into the extent of Faraday's training as a chemist and the minutiae of the laboratory environment in which he worked on a daily basis. I would like to approach this examination in four stages, starting with an analysis of the origins of the book and the laboratory milieu in which Faraday worked at the Royal Institution, followed by a brief survey of some of the book's predecessors, followed by a survey of its contents, and finally, by a brief look at some of its successors.

Table 1. Faraday's books.

Chemical Manipulation, 1827
Six Lectures on the Nonmetallic Elements, 1853
Experimental Researches in Electricity, 3 vols., 1839-1855
Experimental Researches in Chemistry and Physics, 1859
Six Lectures on the Various Forces of Matter, 1860
Six Lectures on the Chemical History of a Candle, 1861

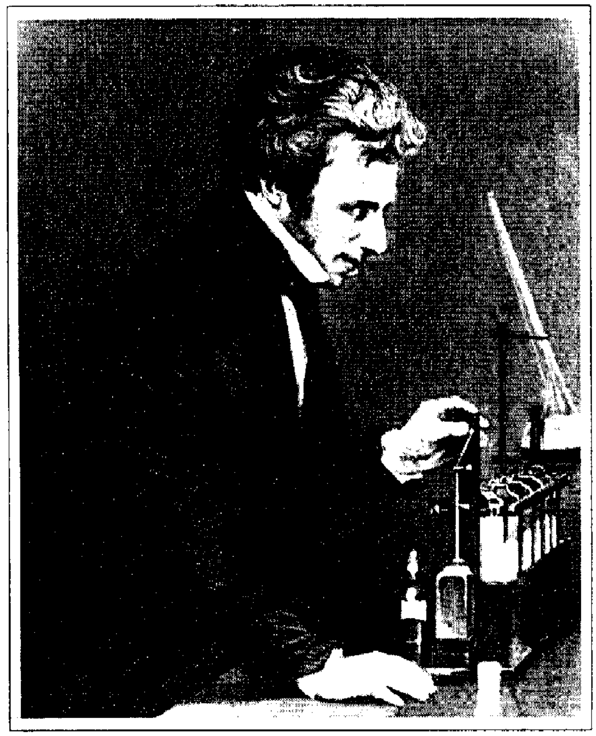


Figure 1. Michael Faraday

Faraday first entered the laboratory of the Royal Institution in the spring of 1813, at age 21, as Humphry Davy's laboratory assistant. After a 19-month leave of absence (October 1813-April 1815) to accompany Davy and his wife on a continential tour, he returned to the Royal Instituiution as an assistant to William Brande, who had succeeded Davy as Professor of Chemistry after the latter's resignation in 1813. In 1821 Faraday was appointed, at age 29, as "Superintendent of the House and Laboratory" - a promotion which allowed him to marry Sarah Barnard - and in 1825 he became "Director of the Laboratory". It was only in 1834, at age 42, that he was finally appointed Fullerian Professor of Chemistry (8).

The institution in which Faraday found himself had been organized in 1799, largely at the instigation of the American expatriat, Count Rumford, and was located in a remodeled house at 21 Albermarle Street, London (the current front of the building with its stucco pillars was not added until 1838, see page 7 of this issue). As was typical of most laboratory design of the period, the architect in charge of the remodeling placed the chemical laboratory in the basement, where it occupied a position roughly corresponding to that of the original out-

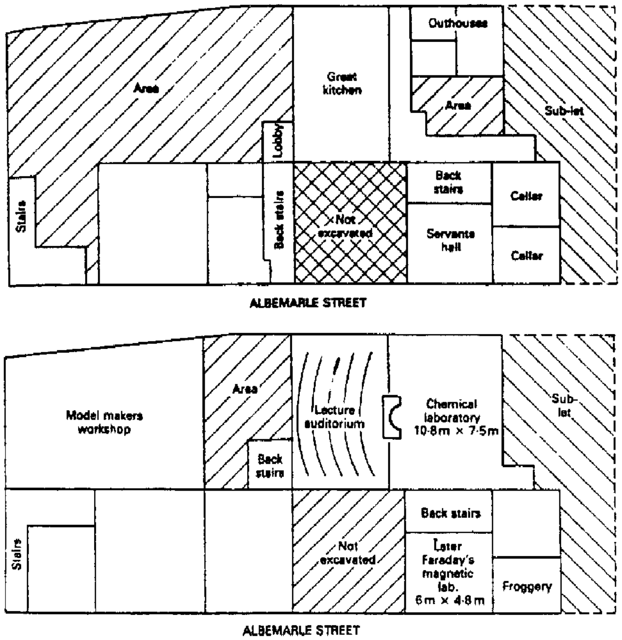


Figure 2. Floor plans of the basement of 23 Albemarle Street before and after being remodeled in 1799 (from reference 9).

houses (figures 2).

We have a rather good idea of what this original laboratory looked like, as William Brande included a view of it in the 1819 edition of his textbook, *A Manual of Chemistry* (figure 3), and Harriet Moore painted two water colors of it in 1852 - one showing Faraday at work by the large sandbath (figure 4) and the other showing Charles Anderson, a former Sergeant in the Royal Artillery, who had become Faraday's assistant in 1827 (figure 5) (8). The first of these water colors was later reproduced in the form of an etching as the frontispiece for the first volume of Bence Jones' 1869 biography of Faraday.

As can be seen in these views, one wall of the laboratory was open to a small lecture hall, roughly located on the site of the original kitchens and capable of accommodating about 120 persons. This was used by Brande to give his annual course of lectures on chemistry and physics (largely to local medical students) and was removed after Brande's retirement in 1852. It should not be confused with the large lecture hall on the ground floor (still extant) which is pictured in most representations of lectures at the Royal Institution, including the famous one of Faraday lecturing in front of the Prince Consort and his son, the Prince of Wales (see page 29 of this issue).

The third important component of the basement laboratory complex was also documented by Harriet Moore in another water color done in 1852 (figure 6). This was the store room located in the former servant's quarters and entered through a door located under the back basement steps. By the time Moore did her painting, it had been converted into Faraday's magnet room. The entrance to this room is also clearly visible in the background in two of the views of the main laboratory (figures 3 and 4). For further details on the history of the laboratory, the reader should consult the superb study by Chilton and Coley (9).

This then was the environment in which Faraday received his training as a chemist and which he encapsulated in his volume on *Chemical Manipulation* in 1827, the year he turned 36. However, the precise reasons for writing the book are more difficult to come by. Agassi claims that it was based on lectures on practical laboratory technique which Faraday was required to give, in keeping with the Royal Institution's original educational mission, as part of his assigned duties as Superintendent of the Laboratory (10). These lectures were held in the small basement lecture hall adjacent to the laboratory to facilitate the presentation of practical demonstrations. Likewise, Bence Jones mentions a similar series of 12 lectures on laboratory technique that Faraday gave at the London Institution in Finsbury Circus (not to be confused with the Royal Institution) in 1827, the year the book appeared (11), and Sylvanus Thompson mentions a series of eight lectures on the same subject which Faraday gave at the Royal Institution in 1828 (12).

Based on this evidence, we may surmise that, whatever the exact details, the book was largely the product of Faraday's assigned teaching duties at the Royal Institution and not necessarily a labor of love. This supposition is further supported

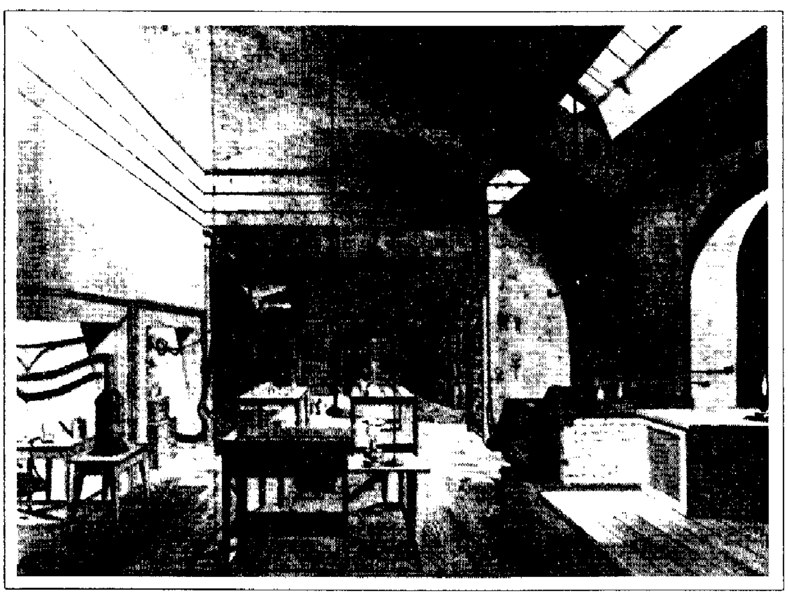


Figure 3. View of the chemical laboratory at the Royal Institution from the 1819 edition of William Brande's *Manual of Chemistry*.

by Faraday's own testimony. Thus we know that he did not like lecturing on this subject, since he was later quite critical of the lecture series mentioned by Thompson (13):

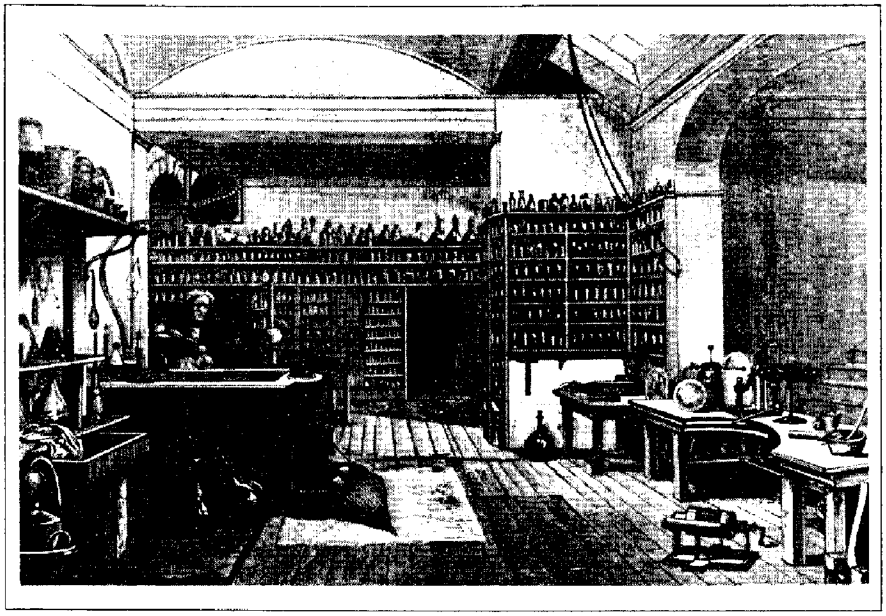


Figure 4. Faraday at work in the chemical laboratory of the Royal Institution. This etching is based on the 1852 water color by Harriet Moore. Note the lecture hall just visible through the arch to the right.

> The 8 lectures on the operations of the laboratory at the Royal Institution, April 1828, were not to my mind. There does not appear to be that opportunity of fixing the attention of the audience by a single clear, consistent and connected chain of reasoning which occurs when a principle or one particular application is made. I do not think the operations of the laboratory can be rendered useful and popular in lectures.

We also know that he did not particularly enjoy writing the book. At least this seems to be implied in a letter written to his friend, Edward Magrath, in July of 1826 (14):

> I am writing away here & get on pretty well but it will be a more laborious job than I expected. I tire of writing day after day but have stuck to it pretty well this far.

Figure 6. Harriet Moore's water color of Faraday's magnet room, formerly the storeroom. The entrance to this room is visible in both figure 3 and figure 4.

The completed volume (figure 7), published by William Phillips, the brother of Faraday's close friend, Richard Phillips, ran to 656 pages and, despite his apparent dislike for the subject, Faraday consented to produce a second edition three years later (15). This entailed a fair number of additions and deletions which, by balancing one another, kept the overall size of the book fairly constant (646 pages versus the original 656). A third edition was issued in 1842 but this was merely a reprint of the second edition with minor corrections (16). Though urged to do so, Faraday refused to produce further revisions (Table 2).

The first edition was also rapidly translated into French, appearing as a two-volume set in 1827 (17). This was followed by a German translation in 1828 (18) and a second German edition in 1832 (19). In 1831, the American physician and chemist, John Kearsley Mitchell, brought out an American edition of the second British edition. This contained a number

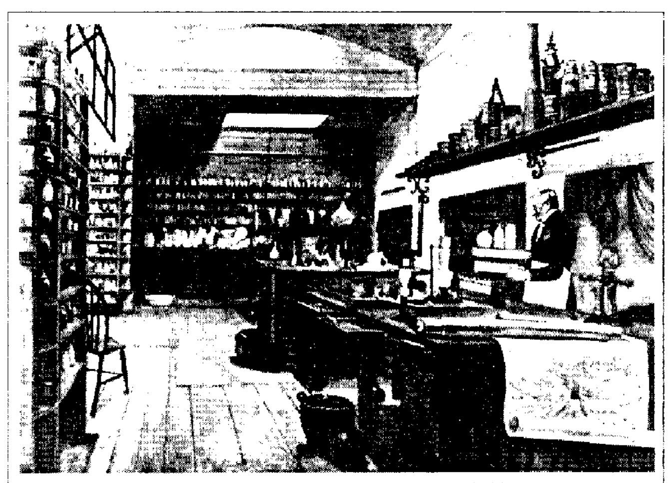


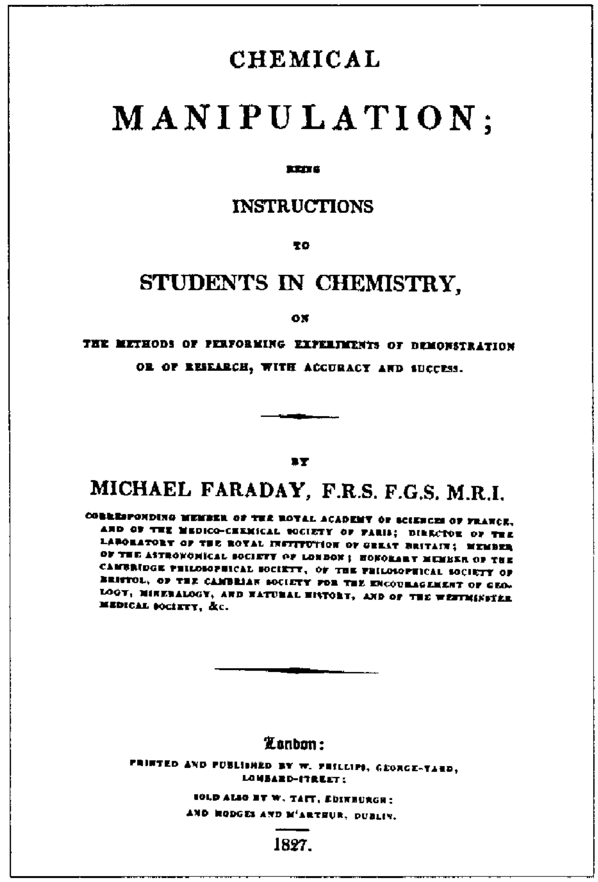
Figure 5. A second view by Harriet Moore of the chemical laboratory at the Royal Institution showing Faraday's assistant, Charles Anderson.

Table 2. Editions of *Chemical Manipulation.*

First British, London, 1827	
First French, 2 vols., Paris, 1827	
First German, Weimar, 1828	
Second British, London, 1830	
First American, Philadelphia, 1831	
Second German, Weimar, 1832	
Third British, London, 1842	

of additions by Mitchell emphasizing American contributions (particularly those of Robert Hare) which Mitchell felt had been slighted by Faraday (20).

Chemical Manipulation was hardly the first book to deal with the subject of chemical apparatus and laboratory operations. Descriptions of equipment and common laboratory procedures, such as distillation, sublimation, filtration and digestion, had been an integral part of most chemical textbooks since the early 17th century. The prototype of this tradition was the famous *Alchymia* of Andreas Libavius, published in 1597 (21). Generally considered by historians to be the first explicitly didactic treatment of chemistry (actually of alchemy), the book contained more than 191 woodcuts (figure 8) devoted to the description of laboratory apparatus and laboratory design (22). The opinions of Libavius on the latter subject are perhaps best personified by his insistence that his plan for the ideal "Chemical Institute" include not only a chemical laboratory and library but a wine cellar.


CHEMICAL

MANIPULATION;

BEING

INSTRUCTIONS

TO

STUDENTS IN CHEMISTRY,

ON

THE METHODS OF PERFORMING EXPERIMENTS OF DEMONSTRATION OR OF RESEARCH, WITH ACCURACY AND SUCCESS.

BY

MICHAEL FARADAY, F.R.S. F.G.S. M.R.I.

CORRESPONDING MEMBER OF THE ROYAL ACADEMY OF SCIENCES OF FRANCE, AND OF THE MEDICO-CHEMICAL SOCIETY OF PARIS; DIRECTOR OF THE LABORATORY OF THE ROYAL INSTITUTION OF GREAT BRITAIN; MEMBER OF THE ASTRONOMICAL SOCIETY OF LONDON; HONORARY MEMBER OF THE CAMBRIDGE PHILOSOPHICAL SOCIETY, OF THE PHILOSOPHICAL SOCIETY OF BRISTOL, OF THE CAMBRIAN SOCIETY FOR THE ENCOURAGEMENT OF GEOLOGY, MINERALOGY, AND NATURAL HISTORY, AND OF THE WESTMINSTER MEDICAL SOCIETY, &c.

London:

PRINTED AND PUBLISHED BY W. PHILLIPS, GEORGE-YARD, LOMBARD-STREET:

SOLD ALSO BY W. TAIT, EDINBURGH:

AND HODGES AND M'ARTHUR, DUBLIN.

1827.

Figure 7. Title page of the first edition of *Chemical Manipulation.*

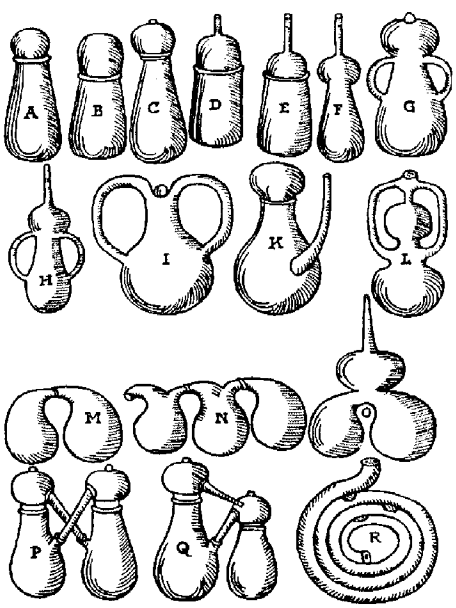


Figure 8. Typical late 16th-century chemical apparatus from Libavius' *Alchymia* of 1597.

An overview of typical chemical apparatus in the late 17th century can be had from the plate in figure 9, which is taken from Johann Becher's *Tripus hermeticus* of 1680 (23). Most modern chemists are rather surprised at how many items in this plate are still to be found in today's laboratory, including the lab coat and apron depicted in boxes 62 and 63.

Moving to the end of the 18th century, we encounter yet another famous example of this textbook tradition in the form of Lavoisier's *Traité élémentaire de chimie* of 1789 (24). Though generally ignored by historians, the last third of this book, covering roughly 176 pages in the English translation of 1790, was devoted to chemical apparatus and operations. Indeed, the famous plates at the end of the book, based on Madame Lavoisier's original sketches, largely refer to this final section (figure 10). Lavoisier organized this part of his text around different classes of operations, such as grinding, manipulation of gases, distillation, etc. - an approach, as we will see, identical to that taken by Faraday in his own book 38 years later.

By the 18th century, not only textbooks, but entire monographs were devoted to the subject of chemical apparatus and laboratory operations. Some representative 18th and early

19th-century examples, extracted from Bolton's massive *Bibliography of Chemistry*, are given in Table 3 (25). Several of these appear to have been organized along the lines of dictionaries or encyclopedias, whereas others are probably thinly disguised catalogs for apparatus dealers (unhappily Bolton doesn't provide enough information to make this distinction).

As shown in Table 4, Faraday divided his own book into 24 sections (rather than chapters or lectures), organized, like Lavoisier's, around general classes of operations. As might be inferred from its length, the book is meticulous in its detail, often to the point of being tedious, but is redeemed by the fact that Faraday often draws on his personal experience and describes short cuts he has discovered, pitfalls he has learned to avoid, or inexpensive pieces of homemade apparatus he has devised. The book is illustrated by small line drawings, apparently done by Faraday himself, as they are identical in style to those appearing in his research papers. These are integrated within the printed text, rather than appearing as the beautifully etched plates typical of many of the book's predecessors.

It would be tedious and unnecessary to summarize each of Faraday's 24 topics, so I propose instead to single out a few instances where Faraday either described an interesting innovation or provided some insight into his personal philosophy of laboratory work, though it must be confessed that the latter instances merely reinforce what historians have already inferred from the study of his diary and published research papers.

The first topic of interest in this regard is Section 4 which deals with "Sources and Management of Heat". 17th- and 18th-century laboratory equipment was often quite bulky, being adapted from pharmaceutical apparatus designed to manufacture marketable quantities of products. Heating usually involved large brick ovens or smaller charcoal braziers. In fact, furnaces and ovens seemed to hold a particular fascination for earlier writers on chemical apparatus and Libavius devoted

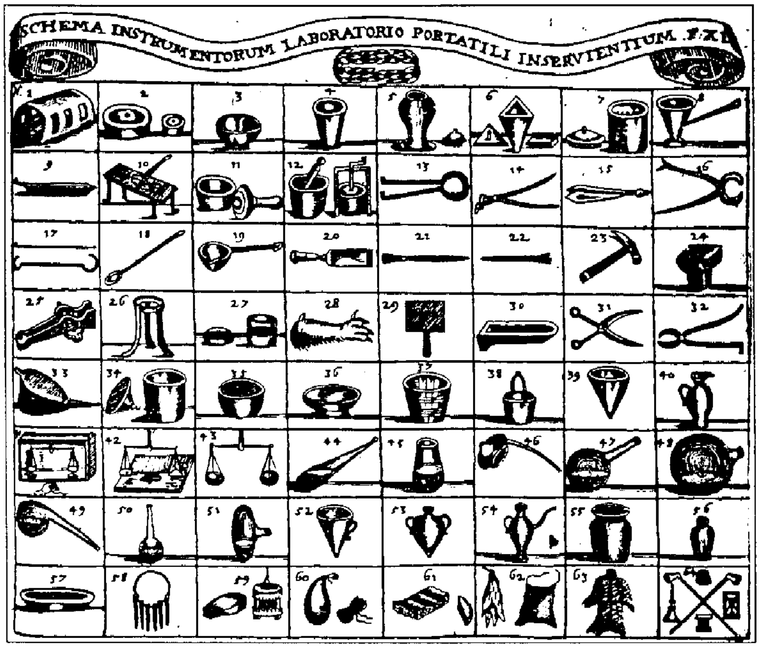


Figure 9. A plate of typical late 17th-century chemical apparatus from the 1680 edition of Becher's *Tripus hermeticus*.

Table 3. Some predecessors of *Chemical Manipulation*.

Year	Author	Title
1711	Hellwig	*Lexicon medio-chymicum ...*
1771	Hauboldus	*De usu instrumentorum physico-mathematicorum recte aestimando ...*
1783	Israel	*De chemicorum instrumentis mechanicis, errorum et dissensus fontibus ...*
1792	Geissler	*Beschreibung und Geschichte der neuesten und vorzüglichte Instrumente*
1821	Accum	*A Dictionary of the Apparatus and Instruments Employed in Operative and Experimental Chemistry, Exhibiting their Construction and the Method of Using Them to Greatest Advantage*
1824	Anon.	*An Explanatory Dictionary of the Apparatus and Instruments Employed in Various Operations of Philosophical and Experimental Chemistry*
1825	Anon.	*Eine Sammlung von Abbildungen und Beschreibungen der besten und neuesten Apparate zum Behuf der practischen und physikalischen Chemie*

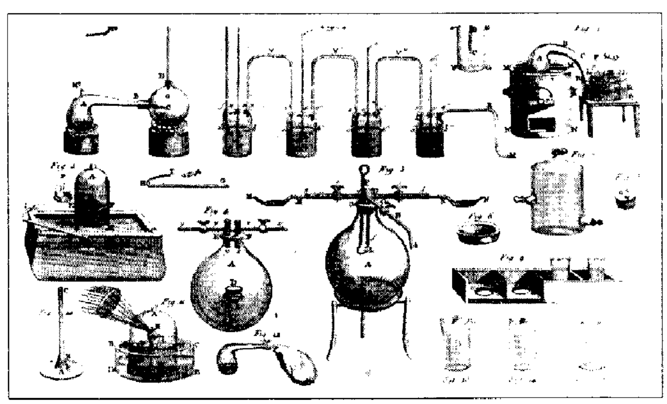


Figure 10. A plate of typical late 18th-century chemical apparatus from the 1789 edition of Lavoisier's *Traité élémentaire de chimie*.

Table 4. The contents of *Chemical Manipulation.*

1.	The Laboratory
2.	Balance; Weighing
3.	Measures; Measuring
4.	Sources and Management of Heat
5.	Comminution, Trituration, Mortars, Granulation
6.	Solution, Infusion, Digestion
7.	Distillation, Sublimation
8.	Precipitation
9.	Filtration, Decantation, Washing
10.	Crystallization
11.	Evaporation, Desiccation
12.	Coloured Tests, Neutralization
13.	Crucible Operations, Fusion, Reduction
14.	Furnace Tube Operations
15.	Pneumatic Manipulation or Management of Gases
16.	Tube Chemistry
17.	Electricity
18.	Lutes; Cements
19.	Bending, Blowing and Cutting of Glass
20.	Cleanliness and Cleansing
21.	General Rules for Young Experimenters
22.	Uses of Equivalents - Wollaston's Scale
23.	Miscellanea
24.	A Course of Inductive and Instructive Practices

114 of the 191 woodcuts in his 1597 treatise to this subject. Faraday, by contrast, described only six kinds of furnace, including the famous sandbath (figure 11) mentioned earlier. The reason for this, Faraday noted, was that (26):

... the character of chemical operations has changed so much as to render many of these contrivances useless, or of little importance ...

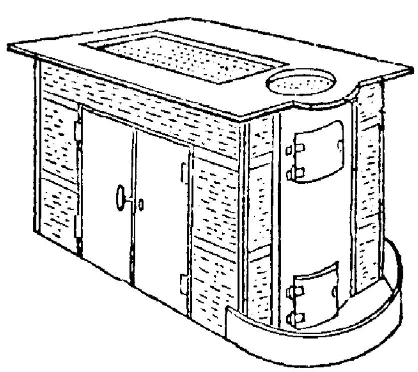


Figure 11. The large sandbath at the Royal Institution. This is visible in both figures 3 (right side) and figure 4 (left side).

The "character" to which Faraday was referring was the scale of the apparatus, which was becoming smaller. Indeed, as will become increasingly apparent, Faraday was strongly attracted to semi-microscale laboratory techniques and his favorite heat source was the spirit or alcohol lamp.

However, a second change in laboratory heat sources was also occurring about this time and is also prefigured in Faraday's book - the use of gas burners. In the first edition of *Chemical Manipulation* Faraday actually described his own experimental laboratory gas burner, consisting of an adjustable metal cone placed over the tip of a gas jet (figure 12). He further observed that (27):

The erection of gas works for public service is now so general in most large towns and in numerous private establishments, that the chemical gas lamp, which was a few years ago a mere curiosity, is now becoming a valuable and economical auxiliary to the establishment of the chemist.

These remarks, coupled with Faraday's description of his prototype burner, gave rise to a minor debate in the 1950s over the origins of the modern Bunsen burner. In his autobiography, the English chemist, Henry Roscoe, claimed that Bunsen was

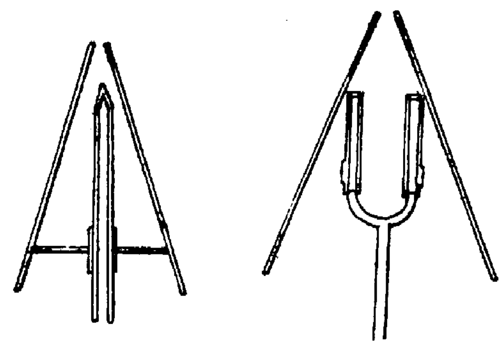


Figure 12. Two designs for laboratory gas burners proposed by Faraday in the first edition of *Chemical Manipulation.*

stimulated to develop his burner as a result of his attempts to improve a laboratory gas burner that Roscoe had brought with him to Heidelberg in 1853 and which was in common use in the chemical laboratories of London at the time (28). Many years later, Bunsen's biographer, Georg Lockemann, connecting Roscoe's comment with Faraday's description of his burner, concluded that the burner that Roscoe had brought from London was in fact Faraday's burner (29). However, in a detailed analysis published in 1955, Paul Dolch showed that the burner referred to by Roscoe was probably a "gauze burner" (figure 13) similar to the kind used by A. W. Hofmann and his students at the Royal College of Chemistry in the 1850s (30).

The term "gauze" referred to the fact that the gas-air mixture in these burners issued through a wire gauze before

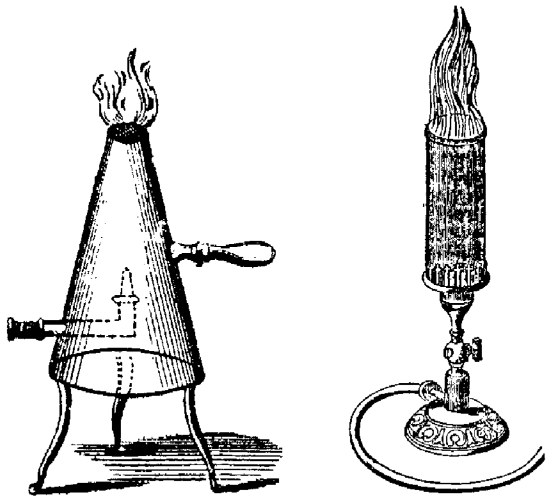


Figure 13. Gauze burners: left - Marcus (1855), right - Abel and Bloxam (1854) (46).

being lit, in order to prevent (in keeping with the principles of Davy's safety lamp) the danger of a flashback. Unfortunately, the resulting flame was very diffuse, not very hot (due to the large air to gas ratio used), and difficult to control. In addition, the gauze made the flame of the burner very uneven. Bunsen's innovation was to use gas under pressure which drew the air along with it so as to minimize the volume of the unlit gas-air mixture and thus minimize the danger of flashback while simultaneously giving an even, controllable flame that could be concentrated at a fixed point. In Faraday's design the gas and air mixed in the large volume under the metal cone and then issued from the opening at the top by virtue of their own "levity". No protective screen was used to prevent flashback. Though Faraday characterized his device as "promising" in the first edition of his book, he removed the description of his burner from the later editions, probably because he had discovered that it was dangerous.

A second item of interest in this section is Faraday's description of laboratory stands for supporting apparatus during the heating process. The most common commercial form at the time was the so-called "retort stand", consisting of rod with a circular base that was heavily weighted with iron or lead (figure 14). However, this had a tendency to tip over so it was occasionally necessary to use two stands (31):

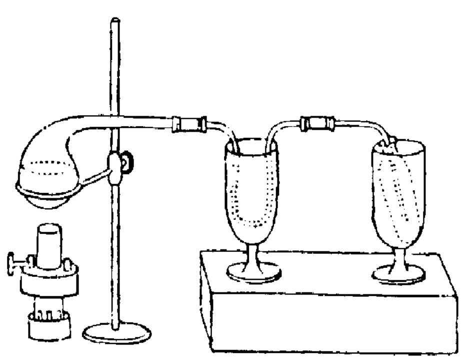


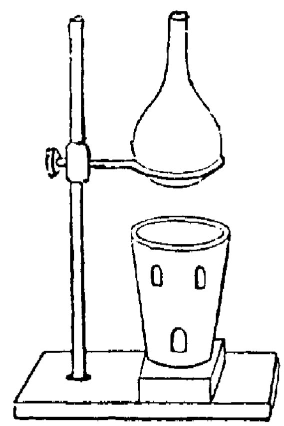
Figure 14. Drawing from *Chemical Manipulation* of a typical retort stand.

> ... on opposite sides, the ring of one being placed under the other, and the flask or basin on the upper most ... [or] it may now and then be necessary to put on a second ring in an opposite direction to the first, and to add weights for the purpose of equipoising the whole.

To remedy this defect, Faraday suggested an alternative (figure 15) (32):

> It is much better to make the foot [of the stand] of stout board, about twelve inches in length, six inches in width, and an inch thick. The upright rod should be fixed about one inch and a half from one end of it, the lamp or furnace should be placed upon it, and the ring of course in a corresponding direction. Such an arrangement is perfectly steady, and cannot be overset by any weight which it is strong enough to bear.

Figure 15. A drawing from *Chemical Manipulation* of Faraday's homemade ring stand. The object sitting on the base is a homemade charcoal furnace constructed from a "blue pot".



What Faraday is describing in this passage is, of course, our modern day ring stand. However, since Faraday did not reference all of the details of his book, we cannot say with certainty that he was the first to suggest this solution. Nevertheless, his instructions for making the stand strongly imply that it was not commercially available at the time and that we are witnessing the approximate date of its birth. It is also interesting to note that, despite its apparent advantages, a fair amount of time was to pass before the ring stand completely displaced the older retort stand from the chemist's repertoire, and drawings of the undergraduate chemistry laboratory at the University of Cincinnati show that the students were still using the circular-based retort stands as late as 1890.

Perhaps the most innovative topic in *Chemical Manipulation*, for those interested in the evolution of laboratory equip-

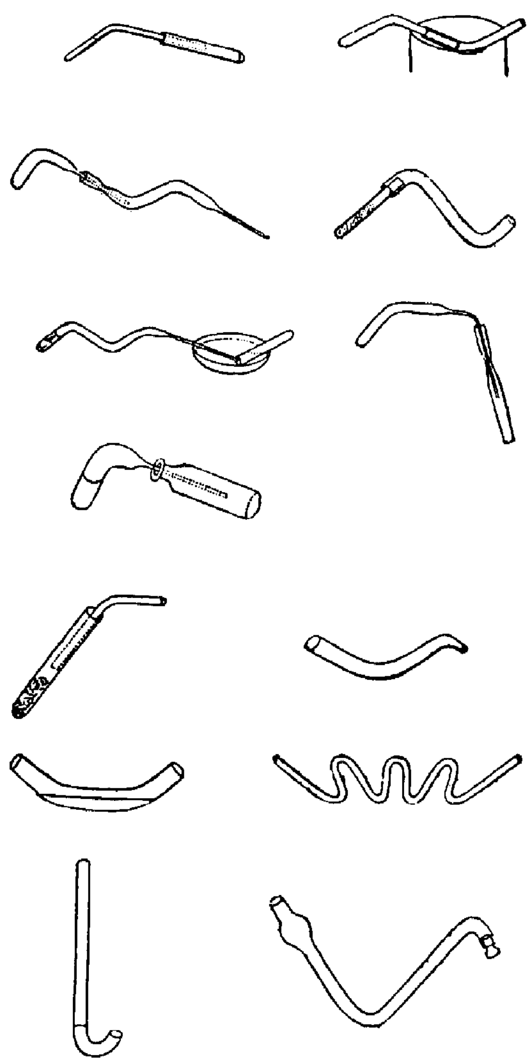


Figure 16. Examples of Faraday's tube apparatus for microscale laboratory work.

ment, is found in Section 16, which deals with what Faraday called "tube chemistry". In this section, Faraday's fascination with the miniaturization of chemical apparatus reveals itself in an elaborate array of devices - all of which are made from bent glass tubes - for heating, distilling, subliming and extracting small quantities of materials. Most of Faraday's drawings of these devices are collected together in figure 16. His use of sealed bent-glass tubes in the liquefaction of chlorine also falls into this category as does his suggestion that common test reactions using liquid solutions could be conveniently done in small glass tubes (33):

... closed at one end, of all diameters and lengths from one inch to five or six ... These tubes answer all the purposes of test-glasses, and in the small way precipitates are made, preserved, and washed very conveniently in them ... Those who frequently use them will find a tube-rack very convenient. It may be formed of two boards, one supported two or three inches above the other, and the upper pierced with holes to admit the tubes. Or a very simple one may be made of a board a foot in length and six inches in width, having a piece of coarse wire trellis about three inches above it, supported at the corners by upright pieces of strong wire. The apertures in the trellis serve to receive and retain the tubes.

Since one conducted qualitative "tests" in these tubes using characteristic color or precipitation reactions, they eventually became known as "test tubes" and Faraday's tube rack became the "test tube rack". On the other hand, as suggested by its shape (figure 17), the larger "test glass" mentioned by Faraday probably evolved from the wine glass. This is certainly implied by my study of the evolution of the chemistry set as I have found that the manuals to 18th-century chemistry sets make no mention of test tubes but invariably recommend that the owner use wine glasses to conduct test reactions which required no heating (34). As with the ring stand, we cannot definitely assert that Faraday was the inventor of the test tube and the test tube rack, but again the tenor of his descriptions strongly suggests that neither was commercially available at time and that one is witnessing the incipient stages of their introduction.

Faraday was not alone in his interest in semi-micro laboratory techniques. His fascination was shared by his older contemporary, William Hyde Wollaston, and in the latter's case was the subject of a famous anecdote (35). It is reported that on one occasion Wollaston was inopportuned by an overzealous visitor wishing to see the famous laboratory in which Wollaston had made so many important discoveries. At first Wollaston demurred but, when pressed by the visitor, finally ordered his footman to bring the laboratory out on a serving tray. Some additional predecessors and successors in this tradition, again extracted from Bolton, include a 1735 monograph by Shaw and Hauksbee entited *An Essay for Introducing a Portable Laboratory* and a 1830 volume by Schuster on *Kleiner chemischer Apparat*.

As John Stock's account in this issue shows, many of Faraday's qualitative experiments in electrochemistry were also carried out on a semi-micro scale using strips of paper impregnated with chemicals or small amounts of salts fused on pieces of glass or platinum by means of an alcohol lamp (36).

Insights into Faraday's philosophy of laboratory work may

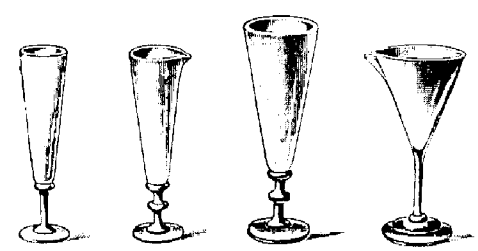


Figure 17. Test glasses.

be found in Section 20 on "Cleanliness and Cleansing", and especially in Section 21 on "Rules for Young Experimenters". In the latter section he emphasizes the necessity of making detailed notes in a timely fashion, a habit well documented in his diaries and other laboratory notebooks (37):

The laboratory note book, intended to receive the account of the results of experiments, should always be at hand, as should also pen and ink. All the results worthy of record should be entered at the time the experiments are made, whilst the things themselves are under the eye, and can be re-examined if doubt or difficulty arise. The practice of delaying to note until the end of a train of experiments or to the conclusion of the day, is a bad one, as it then becomes difficult to accurately remember the succession of events. There is a probability also that some important point which may suggest itself during the writing, cannot then be ascertained by reference to experiment, because of its occurrence to the mind at too late a period.

Faraday also comments on the virtues of a laboratory storage area (38):

Besides the working place another unconnected with the busy part of the laboratory, should be appointed, from which nothing is to be moved without the experimenter's direction. There are many occasions on which experiments or solutions are to be placed aside for a week or two, to be again resumed. These should be labelled, and put into a place which, from previous appointment, is considered as containing nothing that may be disturbed. In this way the experimenter will often avoid the disagreeable circumstance, of finding that what he intended to reserve for future examination, has been dismissed to the sink or the dust-hole.

and he records an even more important consequence of this long-term storage policy in the form of a quote from the 18th-century French chemist, Pierre Macquer (39):

When new researches and enquiries are made, the mixtures, results, and products of all the operations ought to be kept a long time well ticketed and noted. It frequently happens that at the end of some time these things present very singular phenomena, which would never have been suspected. There are many beautiful discoveries in chemistry which were made in this manner, and certainly a much greater number which have been lost because the products have been thrown away too hastily, or because they could not be recognized after the changes which happened to them.

On the other hand, the spirit of Section 20 is best conveyed by the title of one of the subsections, "The Sink and Its Accompaniments". In short, this section suggests a kind of prissy obsessiveness on Faraday's part that seems to be modeled more on the personality of Wollaston than of Davy. Indeed, the latter's rather slapdash laboratory technique may well have served as a compelling negative example for Faraday, who summarized his own philosophy on this subject at the end of Section 21 by again quoting Macquer (40):

Table 5. Some successors to *Chemical Manipulation.*

Date	Author	Title
1831	Berzelius	*Chemische Operationen und Gerätschaften*
1844	Robierre	*Traité des manipulations chimique*
1857	Williams	*Handbook of Chemical Manipulation*
1857	Morfit & Morfit	*Chemical and Pharmaceutical Manipulations*
1882	Rivière & Rivière	*Traité de manipulations de chimie*
1882	Weyde	*Anleitung zur Herstellung von physikalischen und chemischen Apparaten*
1883	Wisser	*Chemical Manipulations*
1885	de Walque	*Manuel de manipulations chimique ou de chimie opératoire*

These employments [i.e. maintaining laboratory cleanliness] are capable of cooling and retarding the progress of genius, and are tedious and disgusting; but they are nevertheless necessary ... We cannot depend too much on ourselves in these matters, however minute, on account of their consequences.

By contrast, one suspects that Davy was never one to patiently tolerate such impediments to the "progress of genius".

The concluding section of *Chemical Manipulation* outlines a course of practical laboratory exercises based on the book's contents and presumably gives us some of the flavor of the course taught by Faraday at the Royal Institution which had given rise to the book in the first place.

Just as Faraday's book was not the first to deal with the subject of chemical manipulation, so it wasn't the last. The titles of some of its successors, again extracted largely from Bolton, are listed in Table 5. The absence of later German, French and American editions of Faraday's book strongly suggests that it was rapidly displaced by these successors. Though the book received favorable reviews when it first appeared, most of these, as Ross has shown (41), were written by Faraday's close friends and one gets the impression that, while the book was respected (in large part because of Faraday's reputation as a research scientist), it was not as popular as some of its successors, many of which were lavishly illustrated (figure 18). This supposition is further supported by the fact that few if any tributes to the book are to be found in the autobiographical writings of chemists who received their education during this period. Indeed, the only mention I have been able to locate occurs in the autobiography of Sir Oliver Lodge, who was a physicist rather than a chemist, and by the time Lodge stumbled on the book, as a young boy in the 1860s, much of it was rather outdated (42):

> ... at some stage I studied his [Faraday's] book on *Chemical Manipulation*, admiring the deftness with which he evidently manipulated his apparatus, and the ingenuity which he showed in constructing all manner of little appliances that then had to be made on the spot, though now they can bought in a shop. Even such a thing as india-rubber tubing for joining quilled glass together was not then available, or was only then beginning. Faraday had to wrap his junction-pieces around the tubes and tie them with tread. When I tried to do chemical manipulations at home at odd times, Faraday's example represented an ideal which I never even approached.

By the 1830s the tradition of single-volume speciality books on chemical manipulation had largely displaced the less detailed accounts of chemical apparatus and operations typical of 17th and 18th-century textbooks and, as can be seen from the absence of later dates in Table 5, this tradition, in turn, began to decline in the 1880s. The speciality volume on chemical manipulation had originally been designed to train chemical amateurs in a period when formal university-level laboratory training was largely nonexistent, and in Faraday's case there is a certain element of the Samuel Smiles' "Self-Help" mentality which reflects Faraday's own route into science. By the 1880s, however, the situation had changed. Laboratory training was now part of an integrated course of instruction and the contents of the average manipulation book were now spread throughout the curriculum, from the introductory Freshman laboratory course, on the one hand, to advanced laboratory courses in organic and physical chemistry, on the other, though the Germans continued to generate multi-volume "Handbuch der Arbeitsmethoden" in advanced areas such as organic (43), inorganic (44) and biochemistry (45) well into the second decade of this century. With this change, the tradition of the single-volume introductory chemical manipulation book splintered into a profusion of laboratory manuals.

Our present day knowledge of the pervasive impact of Faraday's scientific legacy makes it very difficult to assess objectively the true significance of *Chemical Manipulation*. There is a tendency to hero worship in science as in other areas of human culture, and the compulsion to retrospectively clothe every aspect of a famous scientist's activities with the gloss of genius is a strong one. There is no doubt that *Chemical Manipulation* is a useful book that gives us valuable insight into the details of chemical laboratory practice in the early 19th century. But it is also certain that, however unbounded our admiration for Faraday, *Chemical Manipulation* is not, and was never intended to be, a classic of Western scientific thought.

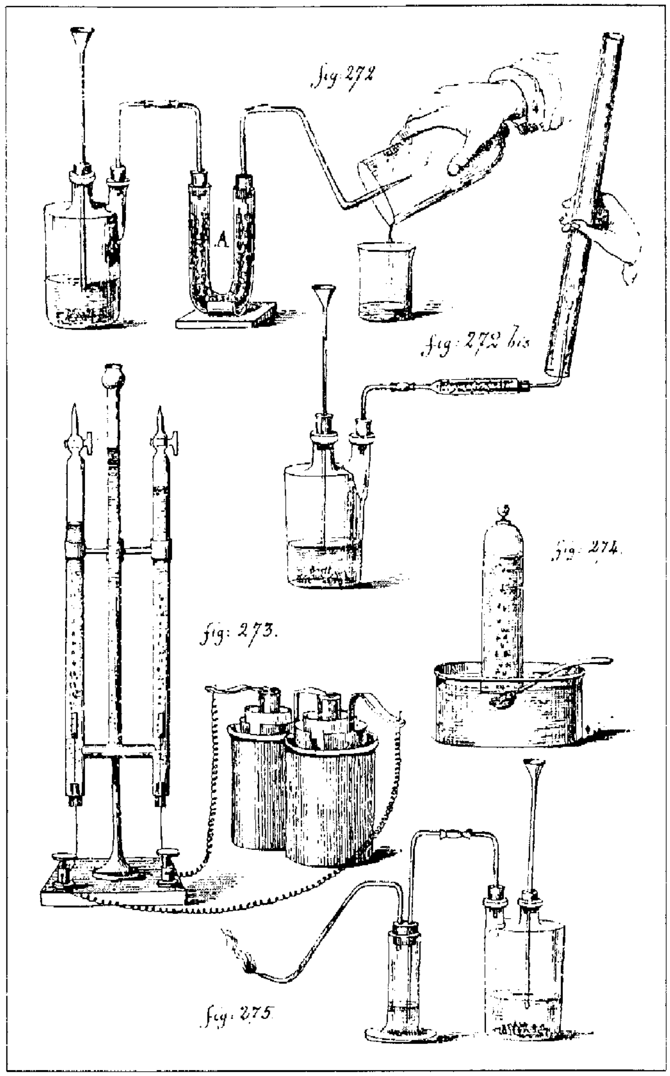


Figure 18. A typical plate from the 1882 edition of Rivière and Rivière's *Traité de manipulations de chimie*.

References and Notes

1. M. Faraday, *Chemical Manipulation; Being Instructions to Students in Chemistry on the Methods of Performing Experiments of Demonstration or of Research with Accuracy and Success*, W. Phillips, London, 1827. An earlier discussion of this book has been given by F. Bei, "Il *Chemical Manipulation* nell'opera di Michael Faraday", in F. Calascibetta and E. Torracca, eds., *Atti del II Convegno Nazionale di Storia e Fondamenti della Chimica*, Accademia Nazonale delle Scienze, Rome, 1988, pp. 215-223.

2. T. Martin, ed., *Faraday's Diary*, 7 Vols. + Index, Bell, London, 1932-1934.

3. M. Faraday, *Experimental Researches in Electricity*, 3 Vols., Quaritch, London, 1839-1855

4. M. Faraday, *Experimental Researches in Chemistry and Physics*, Taylor and Francis, London, 1859.

5. M. Faraday, *A Course of Six Lectures on the Forces of Matter and their Relation to Each Other*, Harper, New York, NY, 1860, edited by W. Crookes.

6. M. Faraday, *A Course of Six Lectures on the Chemical*

History of a Candle, Harper, New York, NY, 1861, edited by W. Crookes.

7. M. Faraday, *The Subject Matter of a Course of Six Lectures on the Non-Metallic Elements*, Longman, Brown, Green and Longmans, London, 1853, edited by J. Scoffern.

8. There seems to an incredible amount of variation among Faraday's biographers as to some of these dates. Davy's resignation as Professor of Chemistry is variously reported as 1812 and 1813. Based on the biography by T. E. Thorpe (*Humphry Davy, Poet and Philosopher*, Macmillan, New York, 1896, pp. 175-176), who quotes the minute book of the Royal Institution, I have chosen the latter. Likewise, 1813 and 1815 are variously given as the date when Brande was appointed to succeed Davy. Based on the study of Chilton and Coley (9), I have chosen 1813. Finally, Thompson (12) reports that Faraday was named "Superintendent of the House and Laboratory" in May of 1821 (p. 49), whereas H. Bence Jones (11) states that Faraday was appointed as "Director of the Laboratory" in February of 1825 (p. 346). I am assuming that these are two separate positions.

9. D. Chilton and N. G. Coley, "The Laboratories of the Royal Institution in the Nineteenth Century", *Ambix*, **1980**, *27*, 177-203.

10. J. Agassi, *Faraday as a Natural Philosopher*, University of Chicago, Chicago, 1971, p. 10. Dr. Derek Davenport has informed me that the manuscript lecture notes to the introductory chemistry course given by Brande and Faraday are still in existence in the library of the Royal Institution.

11. H. Bence Jones, *The Life and Letters of Faraday*, Vol. 1, 2nd ed., Longmans, Green, London, 1870, p. 354.

12. S. P. Thompson, *Michael Faraday, His Life and Work*, Macmillan, New York, 1898, p. 233-234, p. 101.

13. *Ibid*., p. 233.

14. L. P. Williams, R. FitzGerald, and O. Stallybrass, eds., *The Selected Correspondence of Michael Faraday*, Vol. 1., Cambridge University Press, Cambridge, 1971, Letter 85, pp. 165-166.

15. M. Faraday, *Chemical Manipulation; Being Instructions to Students in Chemistry on the Methods of Performing Experiments of Demonstration or of Research with Accuracy and Success*, 2nd ed., Murray, London, 1830.

16. M. Faraday, *Chemical Manipulation; Being Instructions to Students in Chemistry on the Methods of Performing Experiments of Demonstration or of Research with Accuracy and Success*, 3rd ed., Murray, London, 1842.

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18. M. Faraday, *Chemische Manipulation; oder das eigentlich practische der sichern ausführung chemischer arbeiten und experiments*, Verlage des Grossn. s. pr. Landes-Industrie-Comptoirs, Weimer, 1828.

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20. M. Faraday, *Chemical Manipulation; Being Instructions to Students in Chemistry on the Methods of Performing Experiments of Demonstration or of Research with Accuracy and Success*, Carey and Lea, Philadelphia, PA, 1831, edited by J. K. Mitchell.

21. A. Libavius, *Die Alchemie des Andreas Libavius*, Verlag Chemie, Weinheim, 1964. The first German translation of the 1597 Latin edition.

22. O. Hannaway, *The Chemists and the Word. The Didactic Origins of Chemistry*, Johns Hopkins, Baltimore, MD, 1975.

23. Discussed in F. Ferchl and A. Süssenguth, *A Pictorial History of Chemistry*, Heinemann, London, 1939. pp. 117-119. Süssenguth was the founder and director of the Chemical Section of the Deutsches Museum from 1905-1935 and this book, despite its misleading title, deals largely with the evolution of chemical apparatus. For a study of 18th century laboratory practice, see also J. Eklund, *The Incompleat Chymist*, Smithsonian, Washington, DC, 1975.

24. A. Lavoisier, *Elements of Chemistry*, Creech, Edinburgh, 1790, Part III and plates.

25. H. Bolton, *A Select Bibliography of Chemistry, 1492-1892*, Smithsonian, Washington, DC, 1893 and the *First Supplement*, Smithsonian, Washington, DC, 1899.

26. Reference 1, p. 84.

27. *Ibid*., p. 107.

28. H. Roscoe, *Ein Leben der Arbeit*, Akademische Verlag, Leipzig, 1919, pp. 41-42.

29. G. Lockemann, *Robert Wilhelm Bunsen*, Wissenschaftliche Verlag, Stuttgart, 1949, pp. 123-124.

30. P. Dolch, "100 Jahre Bunsenbrenner - einer chemigeschichtlich Studie", *Österreich. Chem. Zeit*., **1955**, *56*, 277-285. For a more accessible but much less thorough account, see M. Kohn, "Remarks on the History of Laboratory Burners", *J. Chem. Educ*., **1950**, *27*, 514-516. Also of interest is T. E. Thorpe, "On the Theory of the Bunsen Lamp", *J. Chem. Soc*., **1877**, *31*, 627-642. The author would like to thank Dr. Derek Davenport for bringing the last two references to his attention.

31. Reference 1, p. 178.

32. *Ibid*., p. 178.

33. *Ibid*., p. 391-392.

34. I am referring specifically to the set designed by the German chemist, Johann F. A. Göttling, (1789) and the set designed by the American chemist, James Woodhouse (1797). See W. B. Jensen, "Two Centuries of the Chemistry Set", to be published.

35. See F. S. Taylor, *An Illustated History of Science*, Praeger, New York, NY, 1968, p. 164.

36. J. T. Stock, "The Pathway to the Laws of Electrolysis", *Bull. Hist. Chem*., **1991**, *11*, 86-92.

37. Reference 1, p. 546.

38. *Ibid*., p. 549.

39. *Ibid*., p. 551.

40. *Ibid*., pp. 550-551.

41. S. Ross, "The Chemical Manipulator", *Bull. Hist. Chem*., **1991**, *11*, 76-79.

42. O. Lodge, *Past Years, An Autobiography*, Scribners, New York, NY, 1932, p. 75.

43. J. Houben, *Die Methoden der organischen Chemie. Ein Handbuch für die Arbeiten in Laboratorium*, 3rd ed., 4 Vols., Theime, Leipzig, 1925.

44. A. Stähler, *Handbuch der Arbeitsmethoden in der anorganischen Chemie*, 5 Vols., Veit, Leipzig, 1913-1914.

45. E. Abderhalden, *Handbuch der Biochemischen Arbeitsmethoden*, 10 Vols., Uban and Schwarzenberg, Berlin, 1910-1919.

46. F. A. Abel and C. L. Bloxam, *Handbook of Chemistry: Theoretical, Practical and Technical*, Blanchard and Lea, Philadelphia, PA, 1854, p. 103.

William B. Jensen is Oesper Professor of the History of Chemistry in the Department of Chemistry, University of Cincinnati, Cincinnati, OH 45221. He is interested in the history of 19th and early 20th century inorganic and physical chemistry and in the history of chemical education.

THE CHEMICAL MANIPULATOR

Sydney Ross, Rensselaer Polytechnic Institute

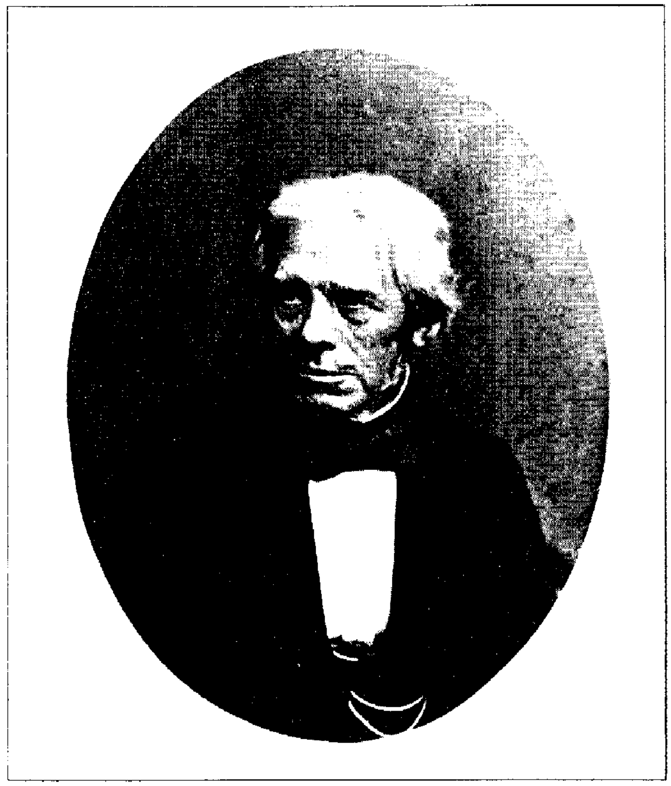
Faraday's *Chemical Manipulation* was published in 1827 (1). It was Faraday's first book; no doubt after the tedious work of its preparation he was proud to see it in print. He took a copy, divided it into three parts, placed a large (quarto) sheet of writing paper between each page, and rebound it into three volumes.

The binding was examined by Mrs. Fiona Anderson, bookbinder, who furnished me with the following technical description (2):

This quarto book has been made up from an octavo. The original book has been split into single sheets and these are tipped in between blank sheets. The blank sheets are made up from folio sheets of laid paper folded down the middle to form quarto sheets. The sections are made up from four folio sheets (making a quarto gathering of eight) and four printed pages. B = blank; P = printed. B/P/BB/P/BB/P/BB/P/B. The binding is 3/4 roan with green French shell marbled sides. Headbands are flat-silk over parchment strips. The sewing is on six sawn-in cords.

The three quarto volumes of Faraday's interleaved copy of *Chemical Manipulation* were part of the Honeyman collection of early works of science, which was sold at auction by Sotheby on 1983, when I acquired it. Sir George Porter (now Lord Porter), at that time the Director of the Royal Institution, told me that the Royal Institition was the runner-up at the bidding, and that my final bid was successful only because it exceeded the limit he had assigned for the purchase. "But", he said, "I don't mind too much for after all we have the whole of Faraday's original manuscript of the book, so perhaps we can do without his later emendations." With such a wealth of Faraday material in its archives, the Royal Institution should not grudge a few crumbs to private collectors.

Clearly Faraday's intention was to use the interleaves as the repository of additional material, although most of it never appeared in any later edition. As it turned out his interest in the subject was destined to make way for more pressing concerns after his discovery of electromagnetic induction in 1831, when he became preoccupied with his experimental researches in electricity. So the ambitious provision of so many blank pages,



Faraday in later life.

if intended for the revision of *Chemical Manipulation*, had only limited fulfillment. A second and revised edition was published in 1830, but it contained only a few of the revisions included in Faraday's interleaved copy. Most of these notes are references to periodicals containing information on topics already discussed in the printed text, which often lacked acknowledgments to the source of the information, or they are references to articles that brought that information up to a later date.

Obviously such an undertaking is open-ended and once commenced has to be kept up until the time when a new edition is in active preparation. After a promising start in which he probably copied his outstanding notes on to the interleaves, he seems to have abandoned the project (if he ever entertained it) of providing his readers with a complete set of references, for only a few of those written on his interleaves were included in later editions. The interleaves contain some 575 references. Far from including this large store of references in a later edition, Faraday actually reduced the number originally present from 78 foot-noted references in the first edition to 57 in the third. In the introduction, Faraday declared that his book was principally for beginners, and that he disclaimed any scientific character for it. He may well have thought that it was inappropriate to load it with references. In that case, the collection on the interleaves would have been entirely for his own private purposes, in a convenient form and location,