

BULLETIN FOR THE HISTORY OF CHEMISTRY

Division of the History of Chemistry of the American Chemical Society

VOLUME 29, Number 2

2004



Gough Square

BULLETIN FOR THE HISTORY OF CHEMISTRY
VOLUME 29, CONTENTS

NUMBER 1

THE 2003 EDELSTEIN AWARD ADDRESS MAKING CHEMISTRY POPULAR	
<i>David Knight, University of Durham, England</i>	1
THE DISCOVERY OF LECITHIN, THE FIRST PHOSPHOLIPID	
<i>Theodore L. Sourkes, McGill University</i>	9
GABRIEL LIPPMANN AND THE CAPILLARY ELECTROMETER	
<i>John T. Stock, University of Connecticut</i>	16
KHEMYE: CHEMICAL LITERATURE IN YIDDISH	
<i>Stephen M. Cohen</i>	21
AN EARLY HISTORY OF CHEMISTRY AT TEXAS TECH UNIVERSITY, 1925-1970*	
<i>Henry J. Shine, Texas Tech University</i>	30
NOYES LABORATORY, AN ACS NATIONAL CHEMICAL LANDMARK: 100 YEARS OF CHEMISTRY AT THE UNIVERSITY OF ILLINOIS	
<i>Sharon Bertsch McGrayne</i>	45
BOOK REVIEWS	52

NUMBER 2

CHEMISTRY IN THE LIFE OF DR. SAMUEL JOHNSON	
<i>Frederick Kurzer, Royal Free Hospital School of Medicine, University of London</i>	65
RUTHERFORD, THE "TRUE DISCOVERER OF RADON"	
<i>Marelene F. Rayner-Canham and Geoffrey W. Rayner-Canham, Sir Wilfred Grenfell College</i>	89
REPLY	
<i>James L. Marshall and Virginia R. Marshall</i>	90
FREDERICK GEORGE DONNAN AND THE RELATIONSHIP BETWEEN ELECTROLYTIC DISSOCIATION AND LIGHT ABSORPTION	
<i>John T. Stock, University of Connecticut</i>	91
CAMBODIA'S FOUR ELEMENTS	
<i>Fathi Habashi, Laval University</i>	97
THE HISTORY OF OZONE. IV. THE ISOLATION OF PURE OZONE AND DETERMINATION OF ITS PHYSICAL PROPERTIES	
<i>Mordecai B. Rubin, Technion- Israel Institute of Technology</i>	99
HIST Citations for Chemical Breakthroughs	107
BOOK REVIEWS	108
CALL FOR NOMINATIONS FOR THE EDELSTEIN AWARD FOR 2005	119

The Cover.....See page 71.

CHEMISTRY IN THE LIFE OF DR. SAMUEL JOHNSON

Frederick Kurzer, Royal Free Hospital School of Medicine, University of London

Introduction

Our acquaintance with Samuel Johnson, LL.D., the dominating figure of the London literary scene of the mid-eighteenth century, surpasses in a remarkable way the usual knowledge and appreciation of the life of a notable author and scholar. Thanks to his contemporary biographers who wrote from close personal knowledge—the candid James Boswell foremost among them—(1, 2) we possess a portrait well-nigh unique in the annals of literary biography (3, 4): Johnson appears before us with all his personal strengths and weaknesses, habits and foibles, opinions, prejudices and wit. His pungent and penetrating pronouncements continue to suffuse the consciousness of the English-speaking world to this day (Fig. 1) (5).

A vast corpus of literary criticism and social, moral, and religious comment has grown around Johnson, un-

til every aspect of his existence has been subjected to the minutest scrutiny (6). This extends from his literary and scholarly achievements and famous conversational powers to his manifold other interests, not least among them his fascination with medicine (7), and his aware-

ness of the importance of the rise of science and technology, and its impact on society.

In modern scholarly inquiries into Johnson's medical and scientific interests, chemistry has occupied a subordinate position: of 42 relevant abstracts that appeared in the authoritative *Isis Bibliography* between 1913 and 2000 (8), 20 referred to medicine, 19 to science in general, but only

two dealt specifically, albeit briefly, with chemistry (9). In his comprehensive general study of Johnson's manifold involvement with science, Schwartz (10) has analysed Johnson's interest in the emerging sciences in all their technical, philosophical, and more particularly



Figure 1. Johnson and Boswell walking by Temple Bar, Fleet Street. Drawing by Charles Green (Courtesy of Guildhall Library, Corporation of London)

social and religious ramifications, and devoted such attention to chemistry as was relevant to his central theme. The present essay attempts to focus on Johnson's pre-occupation with this, his favorite scientific subject.

Johnson's Chemistry, Philosophical and Practical His Biography of Boerhaave

Johnson is likely to have had his first occasional encounters with 'natural philosophy' of one form or another in his father's bookshop, where he read widely, and while an undergraduate at Oxford. A deeper and lasting attachment to chemistry was awakened by his writing a biography of Herman Boerhaave for the *Gentleman's Magazine* in 1739 (11), shortly after the death of the celebrated Dutch physician and chemist. The task required but little research on his part, ample material being available in the *Memorial Oration* (12) delivered in Latin by Boerhaave's friend, the eminent scholar Albert Schultens (Fig. 2) (13). Johnson dwelled on Boerhaave's scientific achievements as a physician, botanist, and chemist, as well as his exemplary modesty and piety (14). However, chemistry emerged in particularly favorable light: Johnson clearly admired Boerhaave's treatment of that science 'with an elegance of style not often found in chemical writers,' and was impressed by 'his theory, more philosophical, exact and full, and his processes more methodical and regular than those of any preceding author on the subject.' The biography was reissued in an expanded form in Robert James' *Medicinal Dictionary* (15). Boswell's assertion (16) that

Johnson's 'love of chymistry which never forsook him' was inspired by his admiration of Boerhaave may well have been near the truth (17). Again, in his short account of the life of Sarpi (18), Johnson stressed the part that natural philosophy and especially chemistry played in the education of this theologian, 'which enabled him to converse with chemists upon the analysis of metals not as a superficial enquirer, but as a complete master' (19).

Johnson, the Chemical Operator

Against this background, Johnson's scientific interest gravitated particularly towards chemistry. His fondness of performing chemical experiments repeatedly aroused the curiosity of his friends; but, being themselves unfamiliar with scientific matters, they could not fully appreciate and describe his chemical preoccupation. Boswell, being admitted to the garrets above Johnson's chambers in the Inner Temple, noticed 'an apparatus for chymical experiments, of which Johnson was all his life very fond' (20). It was likely to be of the simplest form, probably of the kind alluded to in his tale of Mr. Sober (with whom he identified himself (21)). After failing to overcome his ennui by various distractions, Sober finds comfort in chemical experiments (22):

His daily amusement is in chemistry. He has a small furnace, which he employs in distilla-

tion, and which has long been the solace of his life. He draws oils and waters and essences and spirits . . . and counts the drops, as they come from his retort.

Arthur Murphy (23), on his first visit to Johnson in 1754 (24), found him in a little room, intent on making ether

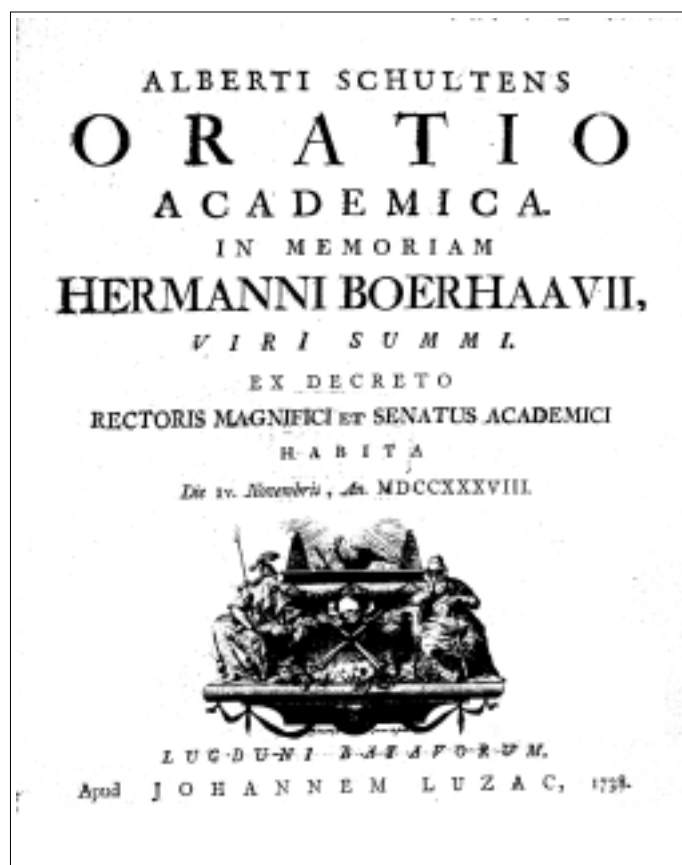


Figure 2. Title page of Albert Schultens's Memorial Oration on the life of Herman Boerhaave (Ref. 12).

'covered with soot like a chimney-sweeper, . . . as if he had been acting Lungs in *The Alchemist*' (25).

Producing ether by distilling a mixture of alcohol and concentrated sulfuric acid was one of Johnson's favorite experiments, in which he followed the detailed directions of Boerhaave (26) or Lewis (27) for the safe management of this somewhat hazardous reaction. Heeding their warnings, he operated on a small scale, using no more than one ounce of sulfuric acid at a time. On one recorded occasion, he sent Mr. Peyton, his amanuensis, to procure it, taking care by the politeness of his request not to offend the sensibility of his literary assistant (28):

Mr. Peyton, Mr. Peyton, will you be so good as to take a walk to Temple Bar? You will there see a chymist's shop: at which you will be pleased to buy for me an ounce of oil of vitriol; not spirit of vitriol, but oil of vitriol. It will cost three half-pence.

Peyton immediately went and returned with it, and told him it cost but a penny. When during the last 20 years of his life Johnson was a family friend of the Thrales and enjoyed their hospitality at their country mansion at Streatham, his enthusiasm for 'chemical operating' was so far indulged as to establish a simple laboratory, prudently set up in the grounds at some distance from the house. Its central feature was a furnace constructed according to Johnson's detailed directions. Here, in the intervals between good dinners, animated conversation, and the composition of his last master-piece, the *Lives of the Poets*, Johnson would entertain Mrs. Thrale, her daughters, and servants with chemical demonstrations and distillations, 'withdrawing essences and coloured liquors' from various plant materials (29). His shortsightedness, coupled with the combustibility of his wig, was a constant anxiety to his friends, especially since ether continued to occupy a prominent place in the practical syllabus, as Mrs. Thrale recalled in after-years (30):

If you pour one Table-Spoonfull of [Aether] into a Copper Pot full of boyling Water, & then approach with a lighted Candle, the most vivid & verdant & beautiful Flash of Lightning possible is immediately produced; & you had best hold your Candle with a Pair of Kitchen Tongs, or evil Consequences may ensue from ye Experiment (31).

In the end, Mr. Thrale, alarmed over his guest's and household's safety, called a halt to all further chemical enterprise, ordering that 'nothing more should be done towards finding the Philosopher's stone' (32).

Apart from his own practical exercises, Johnson was keen to witness philosophical experiments, whenever

the opportunity offered, and took part in experiments of his friend Beauclerk at Windsor. His chemical efforts were sufficiently notorious among his friends to become the object of gentle raillery. When a friend suggested to him that Pope, seeing him at his distilling, might consider him "to have little to do," Johnson promptly retorted, "Sir, if Pope had told me of my distilling, I would have told him of his grotto" (34).

Johnson, the Student of Chemistry

More significant than Johnson's partiality to chemical experiments was his diligence in gaining wider information by his acquisition of a fairly complete collection of chemical treatises and in his sifting of chemical terms for his Dictionary. He attended lectures, visited manufactures, and sought information from instructed friends. At the Ivy Lane Club, Samuel Dyer (35), who attended Dr. Pemberton's chemistry course at Gresham College (36), occasionally entertained his fellow members with accounts of the lectures (37), to which Johnson listened attentively (38).

A welcome link to chemistry was forged by his acquaintance about 1757 with Robert Dossie (39), who had recently arrived in London from Sheffield (40). He was an accomplished chemist of wide experience, who had rapidly gained a high reputation, especially by the publication in quick succession of three excellent treatises on chemistry (41). Johnson said of him that 'he knew more than any man of the chymical effects of bodies operating on other bodies' and went to great lengths to secure his election to the recently founded (1754) Society of Arts (42), of which Dossie became a prominent member.

Even during Johnson's tour to the Hebrides late in life (1773), when the fatigues of travel and unaccustomed surroundings engrossed his attention, chemistry was not forgotten. Being shown the military installations of Fort George by two garrison officers, he met them on their own ground with a disquisition on the manufacture of gun powder, dwelling on the importance of the correct proportion of charcoal and saltpetre and the need for its granulation and giving it a gloss (43). Later, while staying as the guest of Lord Macleod at Dunvegan Castle, he discussed, in the course of the drawing room conversation, the process of tanning, the nature of milk, and the various operations upon it, thus astonishing if perhaps not delighting the company with the unexpected variety of his information (44).

On a journey with Boswell into Bedfordshire in 1781 (45), Johnson talked little to the other passengers in the carriage, being engrossed in the study of Watson's second volume of *Chemical Essays* just published (46). Only one year before his death he attended a lecture given by a physician in Salisbury on the 'different kinds of air' lately discovered by Priestley. Johnson, provoked by the repeated mention of the name of the scientist, whose radical political and doctrinal opinions were odious to him, inquired severely, "Why do we hear so much of Dr. Priestley?" Upon being properly answered: "Sir, because we are indebted to him for these important discoveries," he appeared mollified and observed, "Well, well, I believe we are; and let every man have the honour he has merited" (47).

Johnson and Alchemy

Remembering Johnson's robust common sense and distrust of all pretence, it is surprising that he did not reject the claims of alchemy as decidedly as might be expected. He was, on the contrary, much intrigued by its doctrines (48) and defined it, in his *Dictionary*, as 'the more sublime and occult part of chymistry, which proposes for its object the transmutation of metals and other important operations,' adding a quotation (49) to the effect that 'alchemy changes, or would do, the substance of metals.' According to Boswell (50), Johnson 'was not a positive unbeliever, but rather delighted in considering what near approaches there had been to the making of gold, . . . and that it was not impossible, but it might in time be generally known.'

In this attitude, Johnson may well have been influenced by his first contact with Boerhaave, who for all his chemical insight did not deny the possibility of transmutation (51). Such uncertainties were hardly dispelled by Boyle's surmise that all elements consisted of the same ultimate matter, differing from one another in the individual shapes and motions of the particles of this primary substance, an idea that seemed to make interconversions between metals feasible (52). Boyle's decided enthusiasm for alchemy has recently been underlined by the resurrection of his 'lost' *Dialogue on Transmutation* (53); Newton's preoccupation with its mysteries has also been minutely documented by modern scholarship (54).

Alchemists' claims and doctrines continued to linger into the early 18th century, though increasingly in an atmosphere of fraud and deception. George Wilson's *Chymistry* (1746), a book in Johnson's possession, still

included a serious discussion of the transmutation of the metals, describing a series of the author's attempts made between 1661 and 1704, to produce the 'universal solvent' and effect transmutations. Although Wilson reported honestly his invariable failure, his protracted efforts clearly implied a hope of eventual success. To these and similar causes may be ascribed Johnson's conclusion that 'among the numerous students of Hermetic philosophy, not one appears to have desisted from conviction of its impossibility, but from weariness of toil, or impatience of delay, a broken body or exhausted fortune' (56).

The overall picture of Johnson's commitment to chemistry that emerges from the contemporary anecdotal accounts, though authentic and colorful, is the product of chance, and necessarily lacks balance and precision. However, these shortcomings are largely redressed by a survey of the numerous chemistry books that formed part of Johnson's personal library—or were consulted by him elsewhere—and by a census of the chemical terms that he admitted to his *Dictionary*, and which he defined and illustrated by a judicious choice of references. This evidence is presented in the following discussion.

Johnson's Library and its Dispersal

It is hardly surprising that Johnson, the son of a bookseller, the co-author of the monumental catalogue of the *Bibliotheca Harleiana*, the companion of London publishers, and dedicated scholar, should accumulate a personal library, even in the face of early adversity and want. What is indeed exceptional is the inclusion in the library of this essentially literary figure of an impressive assembly of scientific books, testifying to their owner's devotion to the serious study of the natural sciences, medicine, and chemistry (57).

Johnson accumulated his books for use rather than ostentation and was indifferent to their condition or preservation. It was unsafe, as his friends knew to their cost, to lend him any fine or rare volume (58), for it was apt to be returned—if at all—the worse for rough usage. When Boswell obtained a sight of his library, stored in two garrets over his chambers in The Temple, he 'found a number of good books, but very dusty and in great confusion' (59). At the time of their dispersal after Johnson's death, they were, as one viewer noted, in a 'most woful condition' (60). This gave the auctioneer, James Christie, little incentive to bestow much care on the preparation of the Sale Catalogue, which has conse-

quently proved a very defective guide to later researches. We are nevertheless dependent on this list (61), whatever its shortcomings deplored by bibliographers (62), for our knowledge of the remarkable range of Johnson's library. This poorly printed 28-page pamphlet (Fig. 3), of which only very few original copies have survived (63), was reissued in facsimile for the Oxford Meeting of the Johnson Club in 1892; this limited edition of 150 copies has also long since disappeared. More recently, the original Harvard copy, interleaved with a list of prices and the names of buyers in a neat contemporary hand, has been reproduced (64) and supplemented with an annotated guide (65) to its contents.

As in all large library sales by auction, only the more valuable volumes were catalogued individually. By far the greater number of books were combined into parcels, of which only the leading item was identified by author and title. Although the academic standard of Johnson's collection was indeed distinguished, a large proportion of its books was relegated into this 'unnamed' category, partly because of their poor condition, partly because of the hurried cataloguing, which condensed some 3,000 volumes into 650 'lots,' so that three quarters of the books passed anonymously under the hammer. The financial outcome was correspondingly modest, the total sum realized amounting to £242 (66). The material on chemistry and the sciences realized even lower prices than that of the humanities; appealing to a narrower section of the public, it was mostly acquired by booksellers for stock, for derisory sums.

Johnson's Collection of Chemistry Texts

The sale catalogue identifies some 40 named works on chemistry, including some general encyclopaedias. Another 20 titles familiar to Johnson are traceable through quotations in his Dictionary or miscellaneous writings. A consolidated list of titles from all available sources is given in Appendix 1.

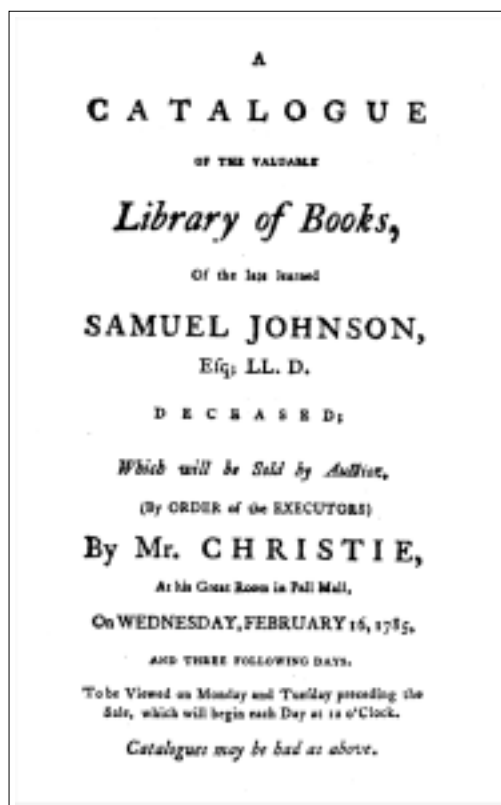


Figure 3. Title page of the Sale Catalogue of Johnson's Library (Ref. 61)

Discounting the large cyclopædias containing incidental chemical information, which might have been found in any large private or academic library, Johnson had assembled a very respectable, specialized collection of chemistry texts by the leading authors. Classical antiquity was represented by Pliny and Lucretius, the mystic and alchemical phase by Roger Bacon and van Helmont, the iatrochemical and spagyric interlude by Paracelsus, and the reign of the phlogiston doctrine by Becher and Stahl. The increasingly rational approach to chemical philosophy was to be found in the works of Boyle, Newton, and Boerhaave. Treatises of more recent date containing sound practical information, such as those of Lewis, Marggraf, and Macquer were also on hand, as were more specialized texts on mineralogy, mining, metallurgy, and the manufactures (e.g. glass, nitre, etc.).

That Johnson's chemical library was, by contemporary standards, reasonably complete, may be concluded by reference to Spielmann's chemical bibliography of 1762 (67), which catalogued the total chemical literature of the mid-18th century. According to this listing, Johnson's collection lacked relatively few major works; among these, the renowned textbooks of Nicolas Lemery and of Jean Beguin were probably the more conspicuous examples. Joseph Black's celebrated lectures, published posthumously (68), were as yet not available, but the absence of Priestley's pioneer accounts on the 'different kinds of air' (1774-7) (69) may have been due as much to their late appearance in Johnson's life, as to his deep suspicion of Priestley's radical political views, which clouded his opinion of their author's scientific merits. Treatises of the leading Swedish and German chemists, such as Torbern Bergmann, Andreas Libavius, Johann Glauber, Christlieb Gellert and Kaspar Neumann found apparently no favor with him, in spite of the existence of Latin or French translations, and in the case of Neumann, of an excellent English version

(70). It will be understood that some of these works may indeed have been among the 'hidden' items of the sale: its catalogue was designed to appeal to British readers, whose interest in foreign, especially German, titles might be expected to be limited.

The Thrale Library at Streatham Park

The account of Johnson's chemistry books would be incomplete without a brief reference to his 'branch library' at the handsome country mansion of the Thrales at Streatham, South London, in what was then still a pleasant rural retreat (Fig. 4). During his long friendship with the family, a comfortable room at Streatham Park was permanently set aside for his reception; it adjoined the library, in which he took a watchful interest (71).

Once again, an approximate inventory of this collection has been preserved in the form of its sale catalogue (72). When in 1816, seven years after the death of Mrs. Thrale's second husband Gabriel Piozzi, the house at Streatham was given up, its contents, including the library of some 3,000 volumes, were dispersed by auction. Johnson's influence is evident not only in the gathering of the more ponderous classics, but once again, in the inclusion of an effective range of chemistry books, duplicating on a smaller scale his own town collection (see Appendix II). Mr. Thrale's brewing interests were reflected in two specialist treatises and by a collection of tracts on distilling. The maintenance of a cross-section of the standard chemical works at Streatham confirms Johnson's sustained interest in the science, long after the Dictionary had first been printed in 1755 (73).

Through his acquaintance with F. A. Barnard, the King's librarian, Johnson enjoyed in later life the privilege of access to the extensive royal collections. A revealing illustration of his attitude toward the effective use of books occurred at a dinner given by R. O. Cambridge (74). As soon as it was decently possible, Johnson ran eagerly to the shelves of the library, surveying the

rows upon rows of books. Being teased by Sir Joshua Reynolds, another guest at the dinner, about his 'enjoying the sight of their backs,' he replied without hesitation, "Sir, the reason is very plain, knowledge is of two kinds: We know a subject ourselves, or we know where we can find information upon it. When we enquire into any subject, the first thing we have to do is to know what books have treated of it. This leads us to look at catalogues, and at the backs of books in libraries" (75).

Chemistry in Johnson's Dictionary

A second important key to estimating Johnson's sympathy towards chemistry is his treatment of the subject

in his Dictionary (76). Speaking eloquently, in its Preface, of the difficulties and tribulations that fall to the lot of the lexicographer, he dwelled on the impossibility of including all 'Terms of Art' of every technical field and admitted that 'many terms appropriate to particular occupations, though necessary and significant,

[were] undoubtedly omitted.' Yet the breadth of his coverage of chemical terms, their clear definition, and their apt illustration by well chosen references were obviously the work of a person having first-hand knowledge of the chemical usage of the time (Fig. 5).

Retrieval of Chemical Entries

For the present purpose, the chemical items among the 40,000 entries of Johnson's Dictionary were located with the aid of a standard list of chemical terms drawn from Nicholson's *Dictionary of Chemistry* (77), supported by supplementary sources (78). By the use of this more comprehensive listing as the working basis it was hoped to ensure that few of Johnson's less numerous Dictionary entries would be missed. In theoretical questions, Nicholson's work of 1795 inclined towards the new system of chemistry but did not exclude consideration of



Figure 4. Streatham Place, the Thrales' country mansion



Figure 5. The house at 17 Gough Square, Johnson's home, 1749-59. Its top floor was the scene, during six years, of his and his assistants' labors in the compilation of the Dictionary. The building, restored to almost its original state, now houses the Johnson Museum.

the phlogistic doctrine; nor had the new French nomenclature of 1787 (79) displaced the old names in its text, but was relegated to a separate discussion. Of the 600 monographs of Nicholson's compilation, only 300 were of a strictly chemical character, the remainder being devoted to mineralogy (ca. 150), materia medica (ca. 75), and technical subjects (e.g. silk, porcelain, etc.). Johnson's Dictionary dealt with 175 of these chemical items.

Johnson's Choice of Chemical Authorities

In illustrating his chemical terms, Johnson referred chiefly to the existing scientific bibliographic resources, but would occasionally introduce a felicitous literary allusion with agreeable effect.

The definition for chemistry itself was appropriately adopted from his first mentor Boerhaave as:

an art, whereby sensible bodies . . . are so changed, by means of certain instruments, and principally fire,

that their several powers and virtues are thereby discovered, with a view to philosophy, or medicine.

The severe proposition was softened by the addition of Pope's couplet of the happy man who (80):

With *chymic* art exalts the min'ral pow'rs
And draws the aromattick souls of flow'rs.

Too high an expectation of the powers of chemistry was guarded against by Arbuthnot's caution that 'Operations of *chymistry* fall short of vital force: no chymist can make milk or blood of grass' (81).

In elucidating the terms 'principles and elements,' Johnson surprisingly relied on his favorite philosopher Isaac Watts (82) rather than a chemist, quoting from his *Logick* (83), that 'the first principles of bodies, usually called *elements*, [are the simple substances], of which other bodies are compounded,' a definition falling short in precision of that of the *Sceptical Chymist* (84). 'Air' was defined, again somewhat vaguely after Watts, as 'that invisible matter which fills all places near the earth, or which immediately encompasses the globe of earth and water.' If Watts' chemical definitions left room for improvement, his book has fortuitously proved of singular bibliographical interest: The copy, used personally and annotated by Johnson in the preparation of the Dictionary, has survived in an excellent state of preservation and clearly illustrates his method of collecting and arranging his material (85). When searching for words and quotations from a particular book, Johnson read it through, underlining in pencil all the words to be extracted, indicating by vertical lines the limits of the context to be quoted, and boldly marking the initial letter of the selected word in the margin. His amanuenses thereupon copied the selected passages on separate slips and pasted them in alphabetic order on quarto sheets of paper, leaving space for Johnson to supply the definition and etymology. Watts' *Logick* contains on its 365 pages over 900 marginalia in Johnson's hand, but only a few of them refer to scientific matters (Fig. 6).

In Johnson's roll of the 'best writers' whose aid he enlisted, the most renowned natural philosophers were undoubtedly Bacon, Boyle, and Newton, even though their writings were somewhat archaic even in his own days. Francis Bacon was a favorite authority of Johnson's, but was apparently discovered by him only when compiling the Dictionary (86). Among the very numerous general quotations extracted from his extensive writings, chemical references are drawn chiefly from his *Natural History* (87) and *Apophthegms* (88) and are characteristic of his style and penetration.

Boyle's Works, a collected edition of which (89) was in Johnson's possession, yielded some 30 citations on all aspects of chemistry, ranging from theoretical concepts (combination, compound, element, earths, salts), practical operations (distillation, rectification, incineration), individual substances (oil, saltpetre, sugar of lead) to laboratory apparatus (alembic, cucurbite) (90). Newton's chemical reflections, though remaining largely unpublished (91), emerged intermittently in his *Optics* (92), from which Johnson gleaned a number of quotations. They referred mostly to physical phenomena encountered in chemical processes, such as flame, vapor, volatility, sublimation, and explosion. Newton's allusion to cinnabar, in which 'the particles of mercury are united to the particles of sulphur' underlined his familiarity with the favorite substances of the alchemists and his remarkable intuitive perception of chemical combination.

On the whole, Johnson preferred to use encyclopaedic manuals rather than individual textbooks. Five authors provided him with no less than three-quarters of his 200 core-quotations (see Appendix III), viz., Boyle, Quincy (93), Arbuthnot (94), Hill, (95), and Chambers (96), all except Boyle writing recently, during the earlier part of the current century.

The largest contribution was that of Quincy's popular *Lexicon Physicomedicum* (97), which, ultimately based on the cyclopaedia of Bartholomew Castellus (98), was issued twelve or more times between 1717 and 1811. Its plain and succinct chemical entries were suitable for direct transfer to the Dictionary, often without change or abridgement. Its more serviceable quotations dealt with concrete rather than abstract matters, especially with laboratory apparatus such as aludels, mattresses, sand

and water baths, Mr. Papin's pot, and the ancient 'athanor' beloved by the alchemists:

[Athamor], A digesting furnace, to keep heat for some time; so that it may be augmented or diminished at pleasure, by opening or shutting some apertures made on purpose with slides over them, called registers.

The lexicon also described chemical processes and miscellaneous substances, such as bismuth, glass, spermaceti, sugar, and tartar, but was not free from an occasional blunder, carrying Johnson with it, as in the case of borax:

An artificial salt, prepared from sal ammoniac, nitre, calcined tartar, sea salt, and alum, dissolved in wine. It is principally used to solder metals.

A similar work extensively consulted by Johnson was Arbuthnot's *Nature of Aliments* (99). Addressing a wider public, the author was careful to explain the chemical terms that the reader would encounter. Here again was a ready stock of definitions that could be incorporated almost unchanged into the Dictionary. Quincy's and Arbuthnot's works complemented one another, in that the latter paid greater attention to the living organism with such entries as fat, wax, jelly, oils, sugar, blood, serum,

and urine. One of the references alluded to Boerhaave's process of producing the 'native salt of urine,' probably the first account of the isolation of urea (100).

In both these and other contemporary works, the concept of acids, alkalis, salts, earths, and the nature of chemical change inevitably presented serious difficulties; but creditable approaches were sometimes achieved. Thus, under the heading 'alkali,' the manufacture of potash is readily recognized:

The Egyptians burn the herb 'ka'i' to ashes, boil them in water, and after having evaporated the water, there remains at the bottom a white salt; this they call '*sal kali*' or '*alkali*'.

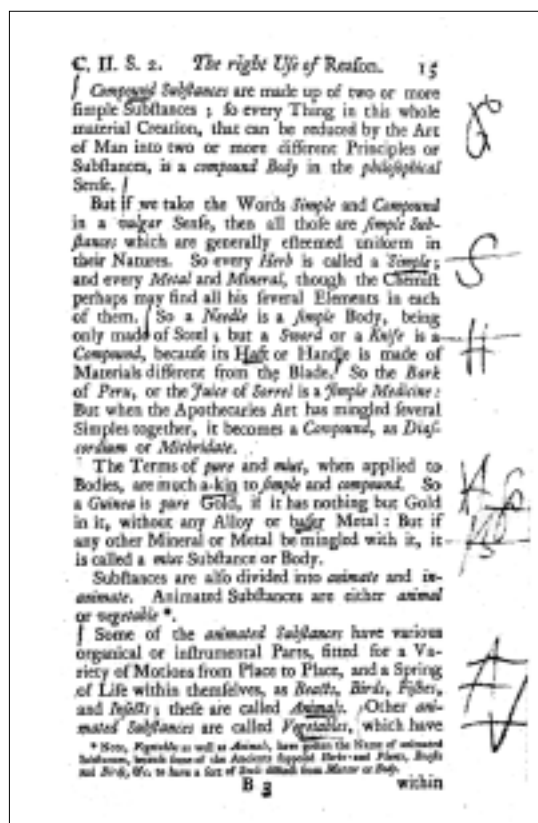


Figure 6. A page of Watt's Logick (Ref. 83), annotated by Johnson in the preparation of the Dictionary

Johnson was on firmer ground when dealing with plain mineral chemistry. Long traditional practice in mining and metallurgy, as well as the experience gained in the rudimentary chemical manufactures, had stripped away much of the mystery surrounding the metals, the smelting of their ores, and the properties of some of their compounds. This information was beginning to be collected systematically in the large universal encyclopaedias that made their appearance in the early 18th century. Chambers' *Cyclopædia* (1738) (101), published in two massive folios in 1738, one of the first, supplied Johnson with many of his chemical and technical entries. Curiously, after the completion of the first few letters of the alphabet, he largely neglected it in favor of Hill's *Materia Medica* (102) and illustrated *Natural History* (103). Their substantial chemical sections yielded notices on metals (cobalt, copper, gold, lead, iron, mercury, steel), individual chemicals (nitre, lime, potash, opium) and natural products (ivory, isinglass, naphtha). The same ground was gone over, though more narrowly, by J. Woodward (104), who described and classified his own extensive cabinet of minerals and fossils in a useful catalogue (105). Quotations for the remaining items not covered by Johnson's chief authorities were culled from a miscellany of books, several of them of a specialized character (see Appendix III).

In accord with the general plan of the Dictionary, the chemical entries were concise and closely targeted, amounting in each case to no more than three or four lines. It seems, however, that Johnson considered certain subjects, particularly those of general usefulness, to demand closer attention. Thus, accounts of 200-250 words were devoted to such topics as aqua fortis, sal ammoniac, diamond, naphtha, oil, potash, and iron (106).

As a consequence, a certain unevenness in the overall treatment has occasionally crept in: the 750-word monograph on 'nitre,' occupying nearly a whole folio-column of print, enters into technicalities in greater detail than literary critics might consider appropriate in a dictionary of the English language. Silver, by contrast, surely of the highest historical, economic, and cultural importance, is dismissed in one line, surprisingly selected from Watts' *Logick* (107) ('a white and hard metal next in weight to gold'), while the ancient metal zinc is overlooked entirely. The meager reference to phlogiston as 'the inflammable part of any body, a chemical liquor extremely inflammable,' is understandable, in view of the difficulty it posed to the comprehension of the non-expert.

The fourth edition of the Dictionary, published in 1773, again in two volumes folio (108), was the last to be revised personally by Johnson. Among the numerous corrections that he introduced (109), the chemical entries remained essentially unaltered apart from occasional abridgements. The composition of gunpowder appears to have fascinated him, for he changed the proportions of its constituents, nitre, sulphur, and charcoal from the original 20:3:3 to 15:3:2. Nothing of true importance was added. The great discoveries of pneumatic chemistry of the 1770s by Scheele, Black, Cavendish, and Priestley, culminating in the detailed study of the gaseous elements (inflammable, dephlogisticated, and phlogisticated airs, i.e., hydrogen, oxygen, and nitrogen), as well as gaseous compounds (carbon dioxide, ammonia) were either too recent or indeed too late to be incorporated even in the 1773 edition of the Dictionary.

With his vast literary background, Johnson could not help but supplement his chemical references with occasional quotations from the realm of letters. If sufficiently apt, they superseded technical comment altogether, as did the stern warning of Scripture:

They that touch *pitch* will be defiled. Ecclesiasticus, 13, 1.

Milton's powerful image of the infernal regions served to illustrate the chemical effects of sulfur on metals:

A hill not far
Shone with a glossy surf, undoubted sign
That in his womb was hid metallick ore,
The Work of sulphur.' . *Paradise Lost*.
In a lighter mood, the use of lime in building was alluded to in Swift's satire:
As when a lofty pile is rais'd
We never hear the workmen prais'd
Who bring the *lime* and place the stones,
But all admire Inigo Jones!
The term 'alloy' appeared, with sober precision, in the context of the debasement of the coinage:
Let another piece be coined of the same weight,
wherein half the silver is taken out, and copper, or
other *alloy* put into its place, every one knows it
will be worth but half as much; for the value of
the alloy is so inconsiderable as not to be
reckoned. Locke.

Numerous other examples were in a similar vein.

Johnson and Hill. It is disappointing to discover that Johnson, having found Hill's compilations highly acceptable for his purpose, failed to render their author a service, when it was in his power to do so during his celebrated interview with King George III in 1767 (110).

The young king, himself a dedicated collector of books and scientific instruments, had heard of Johnson's visits to the library in Buckingham House (111), expressed a wish to meet him there, and one day went to him in the company of Frederick Barnard, his librarian (112), who presented the author to his sovereign. Although quite unprepared for this attention, Johnson conducted himself in a candid and confident manner. The king canvassed several literary topics, and at length asked his opinion of Dr. Hill. Johnson replied that he was an 'ingenious man, but lacked veracity,' mentioning one example of Hill's lapse from accuracy, that was in truth but a trifling matter. The king's unfavorable impression was hardly lessened when Johnson, realizing perhaps that he had gone too far, attempted to soften his verdict by adding that Hill was a curious observer who, 'if he would have been contented to tell the world no more than he knew, he might have been a very considerable man,' but by then the king turned the conversation to other matters.

It is true that Hill had led a checkered life as apothecary, botanist, journalist, and would-be playwright; and, being forever involved in quarrels, in which he was generally the loser, he commanded little respect from his contemporaries. He was nevertheless an indefatigable author of many books and bulky compilations of considerable merit (113), who, still living at the time, deserved a more generous commendation to the king.

Chemistry in Johnson's Miscellaneous Writings

Just as Johnson's erudition illuminated his scientific writing, so was his chemical knowledge likely to diffuse into his literary creations. While the work on the Dictionary was steadily going forward, Johnson issued, between 1750 and 1752, *The Rambler*, a series of essays in which he discussed social and moral questions of the day (114). Their composition afforded him some intellectual relief from the seemingly endless lexicographic toil. Chemical notions originating in these labors overflowed occasionally into these essays; here they served to instruct and amuse a wider reading public, and to emphasize Johnson's general moral arguments. Thus, for example, when castigating vain projects, he compared them to those of 'the chemist, who employs the arts of separation and refinement upon ore in which no precious metal is contained to reward his operations' (115). His own fascination with alchemy notwithstand-

ing, he did not hesitate to mock the hopeful virtuoso, who sits 'whole weeks without sleep by the side of an athanor, to watch the moment of projection' (116).

Indeed, to Johnson's strong political and social instincts, chemists as a class did not appear to great advantage. In his opinion, they could hardly be credited with liberal interests (such as the merits of different forms of government, or the reform of the legal system) having never accustomed their thoughts to any other subject but salt and sulfur (117), and the endless metamorphoses of their darling mercury (118). On the other hand, his general readership did benefit from gaining certain ideas of chemical doctrine, such as the principle that 'all bodies are resolvable into the same elements, and that the boundless variety of things arises from the different proportions of very few ingredients' (119). Other chemical allusions related to mineral springs, the distillation of herbs and spices, and similar subjects of popular concern (120). Johnson resumed publication of another collection of essays, *The Idler*, in the *Weekly Gazette* in 1758-60. His own appearance in these papers in the guise of 'Mr. Sober,' with his chemical amusements, has already been mentioned (121).

After the completion of the Dictionary, Johnson's livelihood continued to depend on the employment of his pen (122). In 1756 he participated in the conduct of the newly founded *Literary Magazine* (123), writing the Introductory Plan for its first number (124) and contributing numerous essays and book reviews to its pages (125). These dealt chiefly with political, moral, and literary questions, but included several reviews of books with a chemical background.

In reviewing Dr. Lucas' (126) *Essay on Waters* (127), Johnson faced a massive tome of some 900 pages that aimed at encompassing all existing knowledge concerning fresh, sea, and mineral waters. He commended the author's diligence in collecting and methodizing the large body of information, and his personal experimental contributions, especially the careful chemical analyses of more kinds of water and springs than anyone had attempted before. His own conviction 'that the natives of this island have little interest in foreign waters (more commonly visited by voluptuousness or curiosity than sickness)' absolved him from the need of reviewing the Continental mineral springs, which Lucas had studied minutely on his travels (128). In contrast, the waters of Bath, 'deserved to be considered with particular attention,' in all their chemical, medical, and social aspects (129).

In selecting Home's (130) *Experiments on Bleaching* (131) as a work worthy of the public's attention, Johnson stressed the scientific and economic interest of this important technical trade, but warned the reader that the book was intended to instruct rather than delight. He supported the author's argument, that improvements in the art of bleaching depended on a close understanding of its chemical processes, requiring systematic research. For once, Johnson's complaint of the use of terms that 'none but a bleacher understood' was hardly justified, for all such operations as steeping, bucking, souring, etc. were clearly explained in the account of the progress of a piece of cloth from the loom to the finished article. More reasonably, Johnson censured the author for measuring reagents 'by the spoonful,' declaring from his own experience, that 'accuracy is always desirable, even if the error cannot be great or significant' (132).

S. Hales (133), distinguished for his pioneer work on the movement of fluids through plants and blood vessels (134), issued, at the age of 80, a pamphlet that described useful inventions he had perfected over many years (135). The chief among these was an improved distillation procedure for converting sea water into fresh water by blowing a rapid stream of air through the boiling sea water in the still. The rate of distillation and the supply of potable water was thereby doubled, a factor of no small importance on long sea voyages at the time. Johnson—no stranger to the management of distillations—sensed a fallacy in the claimed saving of fuel in the modified process but, conceding that Hales understood these matters better than himself, would rather dwell on the merits of the modest author's 'life spent in the service of mankind' (136).

Scientific Societies

Although not a Fellow himself, Johnson maintained links with the Royal Society at various levels (137), cultivating friendly relations with its Secretary, Dr. Birch, whose *History* (138) of the Society he reviewed in the *Literary Magazine* (139). Anxious to promote the public appreciation of the Society's important role in the scientific life of the country, he advocated the wider circulation of its *Philosophical Transactions*, whose high standards 'did so much honour to the English nation.' Characteristically, he tempered his tribute with a literary homily, charging the editor 'to have some regard to the purity of the English language, which was too frequently assailed by the correspondents and translators.'

In his successive clubs (the Ivy Lane, the Literary, and the Essex Head Club, established in 1749, 1764 and 1783, respectively) and elsewhere, he made the acquaintance of at least 36 Fellows of the Royal Society, among them two of its presidents (Sir John Pringle and Sir Joseph Banks) and four secretaries (Dr. Thomas Birch, Sir Charles Blagden, Samuel Horsley, and Matthew Matey). Under these circumstances, his election to the Fellowship should have presented no difficulties—the less so, since professional eminence in a particular scientific discipline was at the time not essential—but Johnson does not appear to have aspired to this honor (141). The fellowship of the close circle of friends within his own clubs, where he played a leading rather than a subordinate role, and his enjoyable social life in his later years presumably met all his wishes (142).

For a short period, Johnson was a member of the Society of Arts (143) and served on several of its *ad hoc* committees, in the company of Dr. Fordyce, Benjamin Franklin, and his protégé Robert Dossie, who examined and evaluated technical proposals submitted to the Society (144). Whereas Dossie was to become one of the mainstays of the Society (145), Johnson's name disappeared from its records after 1762. The Society was nevertheless proud to proclaim its association with him in its annals, and more visibly in its house: when it commissioned (1777) the artist James Barry (146) to embellish its Great Room with a painting running uninterruptedly around its upper walls (147), he incorporated a portrait of Johnson in one of the allegorical compositions. The familiar likeness of his mature years appears near that of Mrs. Montagu (148), the notable intellectual, and between the Duchesses of Rutland and Devonshire, perhaps as a subtle allusion to his being by no means averse to the company and conversation of accomplished and attractive women (149).

Conclusion

Samuel Johnson is widely accepted as the dominating figure of the literary scene of his time. Such has been his influence on the imagination of literary historians, that the period which produced such brilliant novelists and poets as Fielding (1707-54), Sterne (1713-68), Smollet (1721-71), Goldsmith (1728-74), and Gray (1716-71), has nevertheless been called the Age of Johnson (150). Inevitably, his literary preeminence has overshadowed and all but extinguished the recognition of his life-long interest in the phenomena of the physical world, especially as they affect the life and condi-

tion of man. He had a more intimate acquaintance with the chemistry of his day, and a sounder understanding of its role in the manufactures, arts and medicine than could fairly be expected of a scholar of the humanities. Not surprisingly, commentators and critics have long neglected, if not actually denied, his scientific credentials, asserting, for example, that his esteem of scientific talent was low (151), or that he seldom showed more than a passing interest in science (152).

On the strength of a few selected passages from Johnson's writings, one critic (153) has gone so far as to represent him as an 'antiscientist,' who scorned as idle the pursuit of natural philosophy, in comparison with inquiries concerning fundamental moral and ethical issues. It is true, as was urged, that Johnson placed moral and religious values above mere worldly knowledge. This conviction emerges in numerous passages of his writings, probably most famously in his *Life of Milton* (154):

The knowledge of external nature, and the sciences which that knowledge requires or includes, are not the great or the frequent business of the human mind . . . the first requisite is the religious and moral knowledge of right and wrong; the next is an acquaintance with the history of mankind, and with those examples which may be said to embody truth and prove by events the reasonableness of opinions. Prudence and justice are virtues and excellences of all times and of all places; we are perpetually moralists, but we are geometricians only by chance. Out intercourse with intellectual nature is necessary; our speculations upon matter are voluntary and at leisure.

Johnson was not above mildly satirizing—in pity rather than contempt—the vain efforts of misguided dilettanti (155) and even insinuating certain shortcomings of the Royal Society (156). However, none of these opinions interfered with his genuine interest in the advancement of science, his appreciation of its universal utility, or his ability to comment incisively on a wide range of technical subjects. In Johnson's world, moral, literary, and scientific endeavors in no way excluded one another. Schwartz's acute analysis probably comes nearest the truth in its conclusion that Johnson was (157):

... a commentator, not a serious experimenter or professional 'philosopher,' but his role as such is justified by his personal scientific learning, and enhanced by his knowledge of the human issues, explicitly related to scientific methods and advances . . . The quality of his commentary on scientific matters often surpasses the writings of the scientists themselves, because of the reserves of intellectual sophistication,

rhetoric skill and personal experience on which he was able to draw.

Similarly, in critical assessments of Johnson's personal library, its scientific components have at times been ignored (158), or represented as mere tools for use in the compilation of his Dictionary. However, as is now shown, Johnson used in fact less than half of his chemistry books as sources of dictionary quotations, having clearly acquired the others for their intrinsic interest. Indeed, he regarded as superfluous the inclusion of technical works in the private library of a gentleman, unless they served the owner's special interests. Thus when, in 1768, the King's librarian was about to embark on a tour of the European Continent in search of rare books for the royal collection, Johnson, having apparently been approached for advice, gave his considered opinion regarding the most desirable categories of books to be procured: science books were not among them (159).

As for himself, he continued to collect chemistry books; he studied them, reviewed them, and with his fabulous memory, made much of their contents his own. When Murphy, his faithful friend (160), visited him during one of his last illnesses, he found him reading Watson's *Chemical Essays* with evident satisfaction, and expressing his approbation in his usual forceful way: 'From this book, he who knows nothing may learn a great deal, and he who knows will be pleased to find his knowledge recalled to his mind in a manner highly pleasing' (161).

Turning to Johnson's love of performing chemical experiments, a more favorable estimate of their benefit to him than has hitherto been allowed may justifiably be claimed. Modern opinion (162) has deviated little from the view of his contemporary friends, that his chemical 'operating' was a harmless amusement. Literary critics with little scientific background have regarded his experimenting, at best, as yet another engaging idiosyncrasy of their hero (163), or at worst a trivial pursuit to be dismissed with near contempt (164). Yet it is an established fact that interest in the study of chemistry is most effectively sustained by the personal performance of laboratory experiments, however modest and elementary: the management of apparatus, familiarity with chemical substances, and close attention to phenomena, afford first hand insights that no amount of reading can provide. Johnson's experiments were by no means all routine exercises which—barring accidents—gave predetermined results. They did not lack variety and a measure of originality, as when he "drew" the essences from different plants by distillation. He gave detailed directions for the construction of a chemical furnace and

was emphatic about the need for accuracy in weighing and measuring the substances used in chemical operations. All in all, Johnson's personal experience of chemical work was undoubtedly of no small service to him, rendering dry textbook descriptions familiar territory that could be entered with ease.

Although Johnson was not the only literary figure of his time having a predilection for the chemical and physical sciences, he pursued these studies more resolutely than others. Gibbon and also Rousseau, for example, are credited with an interest in chemistry; and Adam Smith, whose favorite study at Glasgow University was that of mathematics and natural philosophy, left an unpublished manuscript on the history of astronomy. Swift was sufficient familiar with science to satirize its disciples unmercifully. It was only in the next generation, in another country, that a great man of letters exceeded Johnson in scientific competence: the poet, author, and philosopher J. W. Goethe (1749-1832) combined in his person the highest literary genius with scientific talents of an order that enabled him to make original contributions to such divergent fields as geology, chemistry, optics, and botany (165). By the turn of the century, the rapid advance of science restricted its serious study inevitably to the domain of the professional specialist; henceforth the educated enthusiast might still take an informed interest in scientific progress, but had to be content with the role of the spectator.

It must remain a matter for regret that Boswell's attainments in science were decidedly limited. Although he recorded faithfully occasional anecdotes arising from Johnson's contacts with physicians and men of science, his own scientific naïveté was clearly apparent from his artless astonishment, each time Johnson gave an example of his scientific expertise. Had Boswell been able to enter this sphere of Johnson's interests, he would no doubt have elicited—and recorded with his accustomed minuteness—a great deal of Johnson's opinions of the state of contemporary chemistry and its protagonists. As it is, the existing solid evidence of Johnson's writings and known activities firmly establishes him as a committed student of chemistry and the natural sciences in the Baconian tradition. True to its philosophy, and following in the footsteps of his admired mentor Boerhaave, he relied not solely on book learning, but advocated critical study, personal observation and trial, and was as concerned with the elucidation of principles as with their practical application. He maintained that (166):

A man [may find] in the productions of nature an inexhaustible store of materials upon which he can employ himself . . . He has always a certain prospect of discovering new reasons for adoring the sovereign author of the universe, and probable hopes of making some discovery of benefit to others, or of profit to himself. [This requires not] much force of penetration . . . but only frequent experiments, and close attention. What is said by the chymists of their darling mercury is, perhaps, true of every body . . . that, if a thousand lives should be spent upon it, all its properties would not be found out.

With his high intellectual integrity and ripe scholarship, Johnson was as ready to explore religious, moral, and social problems as scientific questions, always with the ultimate aim of recognizing the true nature of things. His endeavors in the realm of chemistry were an integral part of this pattern and merit their due acknowledgment of posterity.

REFERENCES AND NOTES

1. J. Boswell, *The journal of a Tour to the Hebrides with Samuel Johnson, LL.D., containing some poetical pieces by Dr. Johnson relative to the tour, and never before published; a series of his conversations, literary anecdotes, and opinions of men and books*, Charles Dilly, London, 1785, and subsequent editions; For a bibliographical comment, see Ref. 2.
2. J. Boswell, *The Life of Samuel Johnson, LL.D., comprehending an account of his studies and numerous works . . . never before published*, Charles Dilly, London, 1791, 2 vol. and subsequent editions. The third edition issued under the superintendence of Edmond Malone in 1799 (which retains Boswell's spelling and punctuation) is readily accessible as an Oxford University Press reprint (1904, 2 vol., 1946, 2 vol. in one), and is the one referred to throughout the present text. A large authoritative edition, incorporating both the *Journal* (Ref. 1) and the *Life*, is the following: G. B. Hill, Ed., rev. by L. F. Powell, *Boswell's Life of Johnson*, Clarendon Press, Oxford, 1934-64, 6 vol. It is an indispensable tool for literary and textual research but is less readily available to the nonspecialist reader.
3. H. L. Piozzi (Mrs. Henry Thrale), *Anecdotes of the Late Samuel Johnson, LL.D., during the last twenty years of his life*, T. Cadell, London, 1786; W. Shaw, Ed., *The same*, with an introduction by A. Sherbo, Clarendon Press, Oxford, 1974.
4. Sir John Hawkins, *The Life of Samuel Johnson, LL.D.*, J. Buckland, London, 1787.
5. It is recalled that the intimate anecdotal and detailed accounts refer to Johnson in his mature years. The young Boswell first met Johnson, then aged 53, in 1763, and

- Johnson's friendship with the Thrales was formed one year later. Much less is known about his earlier life, though biographies focusing on these years have appeared (see Clifford, Ref. 6).
6. Within the scope of the present article, the following signposts to the extensive material must suffice: R. W. Chapman, *Two Centuries of Johnsonian Scholarship*, Glasgow University Publications, Glasgow, 1945; J. L. Clifford and D. J. Greene, *Samuel Johnson. A Survey and Bibliography of Critical Studies*, University of Minnesota Press, Minneapolis, MN, 1970; J. L. Clifford, *Young Samuel Johnson. A Biography*, Heinemann, London, 1981; J. L. Clifford, *Dictionary Johnson. Samuel Johnson's Middle Years*, Heinemann, London, 1979; D. J. Greene and J. A. Vance, *A Bibliography of Johnsonian Studies, 1970-1985*, University of Victoria, Victoria, B.C. 1987; J. Lynch, *A Bibliography of Johnsonian Studies, 1985-1998*, AMS Press, New York, 2000.
 7. H. D. Rolleston, "Medical Aspects of Samuel Johnson," *Glasgow Medical Journal*, **1924**, *10*, 173-91; H. D. Rolleston, "Samuel Johnson's Medical Experience." *Annals Med. Hist.*, **1929**, *11*, 540-52; J. Wiltshire, "Samuel Johnson in the Medical World," Cambridge University Press, Cambridge, 1991. See also Ref. 15.
 8. M. Whitrow, and J. Neu, Ed., *Isis Cumulative Bibliography*. Collective volumes 1913-65, 1966-75, 1976-85 and 1986-95, Mansell, London, 1971-97, and subsequent annual volumes.
 9. P. Cooper, "An Unlikely Chemist, Samuel Johnson," *The Pharmaceutical Journal*, **1963**, *190*, 482; A. R. Ubbelohde, "Samuel Johnson, Amateur Chemist," *Chem. Br.*, **1976**, *12*, 130-1.
 10. R. B. Schwartz, *Samuel Johnson and the New Science*, University of Wisconsin Press, Madison, WI, 1971.
 11. S. Johnson (anon.), "Life of Boerhaave," *Gentleman's Magazine*, **1739**, *9*, 37-8, 72-3, 172-6.
 12. A. Schultens, Oratio academica in memoriam Hermanni Boerhaavii, viri summi, ex decreto Rectorie Magnifici et Senatus Academici habita, die IV Novembris MDCCXXXVIII, Lugduni Batavorum, 1738.
 13. A. Schultens (1686-1750), orientalist, professor of oriental languages in the University of Leyden.
 14. S. C. Roberts, *Dr. Johnson and Others*, Cambridge University Press, Cambridge, 1958, 81ff. R. Knoeff, "The Making of a Calvinist Chemist. Herman Boerhaave, God, Fire and Truth," *Ambix*, **2001**, *48*, 102-111; R. Knoeff, *Herman Boerhaave (1668-1738): Calvinist, Chemist and Physician*, Koninklijke Nederlandse Akademie van Wetenschappen, Amsterdam, 2002.
 15. R. James, M.D., *Medicinal Dictionary, including physic, surgery, anatomy, chemistry, and botany; with a history of drugs and their various preparations, combinations, and uses*, T. Osborne, London, 1743-5, fol., 3 Vol. This was the largest medical dictionary hitherto published. Johnson composed its dedication to Dr. Richard Mead and contributed several biographical articles, including that on Boerhaave. See also: O. M. Brack and T. Kaminski, "Johnson, James and the Medicinal Dictionary," *Modern Philology*, **1984**, *81*, 378-400; R. B. Schwartz (Ref. 10), Appendix B. J. Gray and T. J. Murray, "Dr. Johnson and Dr. James," *The Age of Johnson: A Scholarly Annual*, **1996**, *7*, 213-46.
 16. Ref. 2, Boswell, Vol. 1, p 96.
 17. A surmise, based on internal stylistic evidence, that Johnson, aged 22, was the anonymous first translator of the initial eight sheets of Boerhaave's *Elementa Chymiae* (F. W. Gibbs, "Dr. Johnson's First Published Work," *Ambix*, **1960**, *8*, 24-34) has not been sustained (see Ref. 10, Appendix A).
 18. P. Sarpi (1552-1623), Venetian patriot, scholar, and church reformer; author of the *History of the Council of Trent* (suppressed by Papal decree of November 22, 1619). Johnson's biography was a preliminary to a projected English translation of this work, which did not, however, materialize.
 19. S. Johnson (anon.), "Life of Father Paul Sarpi," *Gentleman's Magazine*, **1738**, *8*, 581-3.
 20. Ref. 2, Boswell, Vol. 2, p 291.
 21. K. C. Balderston, Ed., *Thraliana. The Diary of Mrs. Hester Lynch Thrale, Later Mrs. Piozzi, 1776-1809*, Clarendon Press, Oxford, 1951, 2 Vol., 162, 766; Ref. 3, Piozzi, p.48 or Ref. 3, Shaw, p76.
 22. S. Johnson, *The Idler* (in weekly parts 1758-60); also collected and published in 2 vol., London, 1761; No.31, November 18, 1758.
 23. Arthur Murphy (1727-1805), Irish actor, playwright and author, one of Johnson's closest friends, was responsible for his introduction to the Thrales; *Dictionary of National Biography* (DNB), *13*, 123-4.
 24. A. Murphy, *Essay on the Life and Genius of Dr. Johnson*, T. Longman, London, 1792, 79.
 25. Lungs : One who blows the fire, a chemist's assistant. See Ben Jonson's *Alchemist*, Act II,i. "That's his fire drake, his lungs, his Zephyrus, he that puffed his coals."
 26. H. Boerhaave, *A New Method of Chemistry . . . translated from the original Latin . . .* by Peter Shaw, MD.FRS., 2 vol., T. & T. Longman, London, 1753, Vol.2, 275-6.
 27. W. Lewis, *A course of practical chemistry. In which are contained all the operations described in Wilson's Complete course of chemistry*, J. Nourse, London, 1746, 149. (pp 406-28 treat of the transmutation of metals, with experiments).
 28. Ref. 2, Boswell, Vol. 1, p 441.
 29. Ref. 3, Piozzi, p 237; or Ref. 3, Shaw, p138.
 30. Ref. 21, Balderston, Vol.2, p 982 (October 6, 1797).
 31. Professor Ubbelohde (see Ref. 9) recalled witnessing this experiment on the occasion of an inaugural lecture at Queen's University, Belfast. It frightened the newspaper reporters sitting close to the demonstration.
 32. Ref. 3, Piozzi, p 238; or Ref. 3, Shaw, p 139.
 33. Ref. 2, Boswell, Vol.1, p 165.

34. Ref. 2, Boswell, Vol.2, p 339.
35. Samuel Dyer (1725-72), translator, friend of Burke, DNB, 6, 288-9.
36. Henry Pemberton, M.D. (1694-1771), Gresham professor of physic (1728), published a *Scheme for a course of chymistry to be performed at Gresham College*, London, 1731.
37. J. Wilson, M.D., *A course of chemistry, divided into twenty-four lectures, formerly given by the late learned Dr. Henry Pemberton*. Now first published from the Author's manuscript, J. Nourse, London, 1771.
38. Sir John Hawkins Ed., *The works of Samuel Johnson, LL.D. Together with his life and notes on the lives of the poets*, J. Buckland, etc., London, 1787, 11 vol., Vol. 1, 414-5.
39. F. W. Gibbs, "Robert Dossie (1717-77) and the Society of Arts" *Annals Sci.*, **1951**, 7, 149-72; F. W. Gibbs., "A Further Bibliographic Note," *Annals Sci.*, **1953**, 9, 191-3.
40. Ref. 2, Boswell, Vol. 2, p 341.
41. They were: *The laboratory laid open*, J. Nourse, London, 1758; *The handmaid to the arts teaching a perfect knowledge of the materia pictoria . . . glazings for earthen and stone ware*. 2 vol., J. Nourse, London, 1758; and *Institutes of experimental chemistry, being an essay towards reducing that branch of natural philosophy to a regular system*, 2 vol., J. Nourse, London, 1759.
42. To qualify as a sponsor, Johnson was required to pay to the Society two years' arrears of his subscription, at a time when such outlay was a serious difficulty for him.
43. Ref. 1, August 28, 1773.
44. Ref. 1, September 23, 1773.
45. Ref. 2, Boswell, Vol. 2, p 419.
46. R. Watson, *Chemical Essays*, T. Evans, London, 1781-7, 5 vol.
47. Ref. 2, Boswell, Vol. 2, p 507. In reporting this incident, Boswell chose to add an intemperate attack on Priestley, accusing him of publishing pernicious doctrines, holding absurd and impious opinions, and finally dismissing him as a 'Literary Jack of all trades.'
48. Ref. 2, Boswell, Vol.1, p 603.
49. R.Hooker, *Of the lawes of ecclesiastic politie eight bookes*, John Windet, London, 1594-97; Facsimile of Books I-V, fol. Scholar Press, Manston, 1969; Book V, para.58.
50. Ref. 48).
51. See, for example, E.v.Meyer's restrained censure of Boerhaave on this count, in his *Geschichte der Chemie*, Veit & Co., Leipzig, 1914, 4th ed., 57, 107.
52. R. Boyle, *The sceptical chymist, or chymico-physical doubts and paradoxes touching the Spagyrist's principles . . . defended by the generality of alchymists whereunto is praemis'd part of another discourse relating to the same subjects*, printed by F. Cadwell for F. Crooke, London, 1661, 333, 422.
53. L. M. Principe, *The Aspiring Adept. Robert Boyle and his Alchemical Quest*, including Boyle's "lost" Dialogue on the transmutation of metals, Princeton University Press, Princeton, NJ, 1998.
54. B. J. T. Dobbs, *The Foundations of Newton's Alchemy or The Hunting of the Greene Lyon*, Cambridge University Press, Cambridge, 1975; K. Figala, J. Harrison, and U. Petzold, "De scriptoribus chemicis: Sources for the Establishment of Isaac Newton's (Al)chemical Library," in P. M. Harman and A. F. Shapiro, Ed., *The Investigation of Difficult Things*, Cambridge University Press, Cambridge, 1992, Ch.6, 135-80; M. White, *Isaac Newton, the Last Sorcerer*, Fourth Estate, London, 1997, 122, 131-48.
55. Ref. 27, pp 406-28.
56. S. Johnson, *The Rambler*, appearing as a periodical in 208 numbers between 1750 and 1752, was originally published anonymously. Collected in book form, it reached 16 editions in Johnson's lifetime and many more thereafter; e.g. 2nd ed., 6 vol., 12°, London, 1752. Here: No. 63, October 23, 1750.
57. It is recalled that Charles Lamb, the gentlest of critics, denied scientific treatises the dignity of 'books' altogether: "I can read anything which I call a book. There are things in this shape, which I cannot allow for such: Court calendars, directories, scientific treatises . . . and generally all those volumes which no gentleman's library should be without." C. Lamb, "Detached Thoughts on Books and Reading," *Essays of Elia*, Taylor & Hesse, Edward Moxon, London, 1823 and 1833; World's Classics, Oxford University Press, Oxford, 1901, 222-28.
58. Ref. 2, Boswell, Vol.1, p 468. 'Considering the slovenly and careless manner in which books were treated by Johnson, it could not be expected that scarce and valuable editions should be lent to him,' a point aptly illustrated by Johnson's rough handling of Garrick's fine copy of Petrarch. See H. A. Dobson, "Johnson's Library" in *Eighteenth Century Vignettes*. Second Series, Chatto & Windus, London, 1894, 3 vol.
59. Ref. 2, Boswell, Vol.1, p 291.
60. J. D. Fleeman, Ed., *The sale catalogue of Samuel Johnson's library. A facsimile edition. Made from the annotated copy in Harvard University*, ELS Monograph Series, English Literary Studies No. 2, University of Victoria, B.C. 1975, 7.
61. J. Christie, *A catalogue of the valuable library of books of the late learned Samuel Johnson, Esq., LL.D., deceased; which will be sold by auction (by order of the Executors) by Mr. Christie, at his Great Room in Pall Mall, on Wednesday, February 16, 1785, and the three following days*.
62. D. Greene, *Samuel Johnson's Library. An Annotated Guide*, ELS Monograph Series. English Literary Studies No.1, University of Victoria, B.C. 1975.
63. According to Fleeman (Ref. 60, p5), an original copy of the catalogue was in 1818 in the possession of Will-

- iam Upcott, assistant librarian (1806-34) at the London Institution, given him by "William Bray, FSA." The latter was in fact undoubtedly Edward William Brayley, librarian for 36 years (1834-70) at this institution. Another original copy has returned, after some vicissitudes, to the Johnson Museum, at 17 Gough Square, City of London, Johnson's residence during 1749-56, the years of the compilation of his Dictionary (Fig. 5).
64. Ref. 60.
 65. Ref. 62.
 66. Ref. 62, p 6.
 67. J. R. Spielmann, *Institutiones chemiae praelectionibus academicis accommodatae*, Apud Johannem Godofredum Bauerum, Argentorati, 1763. Appendix: Syllabus auctorum, 27 pp.
 68. [J. Black], *Lectures on the elements of chemistry delivered in the University of Edinburgh by the late Joseph Black*. Now published from his manuscripts by John Robison, LL.D., Longman & Rees, W. Creech, London and Edinburgh, 1803, 2 vol.
 69. J. Priestley, *Experiments and Observations on Different Kinds of Air*, London, 1774-7. Subsequent volumes appeared entitled *Experiments and Observations Relating to Various Branches of Natural Philosophy*, J. Johnson, London, 1779-86, 3 vol.
 70. C. Neumann, *The chemical works of Caspar Neumann. Abridged and methodized. With large additions . . . by William Lewis, MB, FRS, W. Johnston, G. Keith, etc.*, London, 1759.
 71. R. W. Chapman, Ed., *The letters of Samuel Johnson. With Mrs. Thrale's genuine letters to him*, Clarendon Press, Oxford, 1952, 3 vol. Letter No. 1104, B. Redford, Ed., *The Letters of Samuel Johnson*, Princeton University Press, Princeton, NJ, 1992-94, 5 vol., Vol.5, 26-27.
 72. Streatham Park, Surrey. *A catalogue of the excellent household furniture of the best description . . . and the extensive and well-selected library, . . . the genuine property of Mrs. Piozzi; and will be sold by auction by Mr. Squibb on the premises on Wednesday 8 May 1816 and four following days.*
 73. A Sale, held in Manchester in 1823 of the 'effects of the property Bach-y-Craig, of Mrs. Piozzi, deceased,' once again included a library of books, many of them with Johnsonian associations, but chemistry had all but disappeared. The Catalogues of this and the foregoing sale (Ref. 72) were reprinted in: S. Parks, Ed., *Sale catalogues of libraries of eminent persons* (General editor, A. L. N. Munby), Vol. 5: *Poets and men of letters*, Mansell with Sotheby Parke Bernet, London, 1972.
 74. Richard Owen Cambridge (1717-1802), author. DNB, 3, 723-9.
 75. Ref. 2, Boswell, Vol.1, p 595.
 76. S. Johnson, A.M., *A Dictionary of the English language, in which the words are deduced from their originals, and illustrated in their different significations by examples of the best writers. To which are prefixed A history of the language and an English grammar*, W. Strahan for J. & P. Knapton, etc., London, 1755, 2 vol. Folio. A facsimile reprint of this first edition was issued by Longman (Harlow, 1990). The fourth edition was the last to be supervised by Johnson personally, London, 1773, 2 vol., folio. All the present quotations are taken from the first folio edition, unless otherwise stated.
 77. W. Nicholson, *A Dictionary of Chemistry*, G. G. and J. Robinson, London, 1795, 2 vol., 4to.
 78. E. J. Eklund, *The incomplete chymist. Being an essay on the 18th century chemist in his laboratory, with a dictionary of obsolete chemical terms*, Smithsonian Institution Press, Washington, DC, 1975
 79. L. B. Guyton de Morveau, *Méthode de nomenclature chimique, proposée par MM. de Morveau, Lavoisier, Bertholet (sic) et de Fourcroy. On y a joint un nouveau système de caractères chimiques, adaptés a cette nomenclature, par MM Hassenfratz & Adet*, Suchet, Paris, 1787. Outlined in Ref. 77, pp 519-29.
 80. Alexander Pope, "Windsor-Forest," composed 1704, first published, B. Lintott, London, 1713. Nelson Classics ed., London, 1954, 31-43.
 81. J. Arbuthnot, *An essay concerning the nature of aliments and the choice of them according to the different constitutions of the human body*, J. Tonson, London, 1731-2, 2 vol.
 82. Isaac Watts (1674-1748), author, hymn writer, and philosopher; DNB, 20, 978-81. Johnson included his biography in the *Lives of the Poets*, Ref. 154.
 83. I. Watts, *Logick, or the right use of reason in the enquiry after truth . . . in the affairs of religion and human life, as well as in the sciences*, J. Clark & R. Hett, London, 1725 and numerous subsequent editions.
 84. Ref. 52, (1680 London ed.), pp16, 354.
 85. The copy in the British Library (8th ed., London, 1745) annotated by Johnson bears Samuel Roger's bookplate and the following inscription on its flyleaf: 'Dr. Johnson's copy, marked for the quotations for his Dictionary. Bought at his sale by Mr. Rogers, and by him given to me, 30 October 1842. Samuel Sharpe. For S. Rogers (1763-1855) and S. Sharpe, FGS (1799-1881), his nephew, see DNB, 17, 139-42 and 17, 1363-5.
 86. Ref. 2, Boswell, Vol. 2, p 148. This assertion has been questioned by Schwartz, Ref. 10.
 87. F. Bacon, *Sylva sylvarum, or a Natural history in ten centuries, whereunto is added . . . the New Atlantis*, William Lee, London, 1685.
 88. F. Bacon, *Apophthegms, new and old, collected by the Rt. Hon. Francis Lord Verulam*, H. Barratt & R. Whittaker, London, 1625.
 89. T. Birch, Ed., *The works of the Hon. Robert Boyle (with life)*, A. Millar, London, 1744, 5 vol., folio (The first complete edition of Boyle's works).
 90. P. Shaw, M.D., Ed., *The philosophical works of the Hon. Robert Boyle, Esq. Abridged, methodized and disposed under general heads*, J. Osborne & T. Longman, London 1725, 3 vol., 4to.

91. Ref. 54, Dobbs.
92. I. Newton, *Opticks, or a Treatise of the reflexions, refractions, inflexions and colours of light. Also, two treatises on the species and magnitude of curvilinear figures*, S. Smith & B. Walford, London, 1704, 4to, and subsequent editions.
93. John Quincy (d.1722), medical writer, author of the *Lexicon physicomedicum* (Ref. 97), and the *English Dispensatory* (1721); DNB, 16, 555-6.
94. John Arbuthnot (1667-1735), medical man, author and wit, physician-in-ordinary to Queen Anne, friend of Swift, Pope, and Congreve; DNB, 1, 534-7.
95. John Hill, MD (?1716-1775), apothecary, author, compiler and translator of voluminous works on botany, materia medica, mineralogy, and chemistry. DNB, 9, 848-52.
96. Ephraim Chambers (?1680-1740), FRS (1729), encyclopaedist, DNB, 4, 16-7.
97. J. Quincy, *Lexicon physico-medicum, or a new physical dictionary, explaining the difficult terms used in the several branches of the profession, and in such parts of Natural Philosophy as are introductory thereto*, E. Bell, etc., London, 1719. Johnson used the 6th edition, 'with new improvements from the latest chymical and mechanical authors,' London, 1743.
98. B. Castellus, *Lexicon medicum Graeco-latinum. Ex Hippocrate et Galeno desumptum*, Apud G. Valentinum et F. Bolzettam, Venice, 1626, and later enlarged editions, e.g., Leipzig, 1713.
99. Ref. 81.
100. H. J. Backer, "Boerhaave's ontdekking van het ureum," *Nederlandsche Tijdschrift voor Geneeskunde*, **1943**, 1274-8; F. Kurzer and P. M. Saaderson, "Urea in the History of Organic Chemistry," *J. Chem. Educ.*, **1956**, 33, 492-9.
101. E. Chambers, *Cyclopaedia, or an Universal Dictionary of arts and sciences*, 2.ed., London, 1738, 2 vol., folio. Its French translation became the forerunner of Diderot and D'Alembert's *Encyclopédie*. Johnson used the 4th ed. (1741).
102. J. Hill, *A history of the materia medica, containing descriptions of all the substances used in medicine . . . and an account of their virtues, and of the several preparations from them now used in the shops*, T. Longman, A. Millar, etc., London, 1751, 4to. The first volume is devoted to the mineral kingdom.
103. J. Hill, *A general natural history, or Description of the animals, vegetables and minerals of the different parts of the world, including the history of the materia medica, pictoria and tinctoria of the present and earlier ages*, Thomas Osborne, London, 1748-52, 3 vol., folio.
104. John Woodward (1665-1728), FRS (1693), professor of physic at Gresham College (1692), author of several treatises on geology and mineralogy; DNB, 21, 894-6.
105. J. Woodward, *An attempt towards a natural history of the fossils of England, in a catalogue of the English fossils in the collection of J.W., J. Osborne & T. Longman*, London, 1728-9, 2 vol.
106. Ref. 102.
107. Ref. 83.
108. Ref. 76.
109. A. Reddick, *The Making of Johnson's Dictionary*, 1746-1773, Cambridge University Press, Cambridge, 1990; rev. ed., 1996.
110. J. Boswell, *A conversation between His Most Sacred Majesty George III and Samuel Johnson, LL.D., illustrated with observations by James Boswell, Esq.*, London, 1790; also Ref. 2, Boswell, Vol.1, pp 358-62.
111. E. L. MacAdam, *Dr. Johnson and the King's Library*, with a facsimile of Johnson's letter to the King's librarian, Grolier Club, New York, 1955.
112. Sir Frederick Augusta Barnard's portrait, painted by John Prescott Knight, RA, occupies a place of honor in the new British Library.
113. *The Dictionary of National Biography* (Ref. 95) credits Hill with 76 named works on botany, medicine, and a highly popular Herbal. His monumental *Vegetable System*, issued between 1759 and 1773 in 26 volumes, folio, illustrated with 1,600 copper engravings depicting 26,000 plants, earned him the Order of Vasa (1774) from the King of Sweden (the basis of his claim to a knighthood), but is said to have embarrassed him financially.
114. Ref. 56.
115. Ref. 56, No.139, 16 July 1751.
116. Ref. 56, No.199, 11 February 1752.
117. Ref. 56, No.99, 26 February 1751.
118. Ref. 56, No. 5, 3 April 1750.
119. Ref. 56, No. 68, 10 November 1750.
120. Ref. 56, Nos. 25, 51, 83, 103, 120, 142.
121. Ref. 22.
122. The total remuneration received by Johnson from the bookseller syndicate that had commissioned the Dictionary was £1575. Spread over seven years, it had to cover the wages of his amanuenses, the cost of paper and other materials, as well as his domestic expenses, and was spent by the time the Dictionary appeared in 1755. Some supplementary payments were apparently made subsequently. The award to him of the government pension of £300 p.a. was still seven years away (1762).
123. The *Literary Magazine or Universal Review* appeared monthly from May, 1756, but declined when Johnson ceased to write for it after its fifteenth number, and was discontinued in July, 1758.
124. In outlining the plan of the new periodical, Johnson expressed the editor's desire, apparently with an eye to the *Gentleman's Magazine*, 'to advance our interest without lessening that of any other.' Its purview would extend to 'all productions of science.'
125. Ref. 2, Boswell, Vol.1, pp 203-13, especially pp 205-6.
126. Charles Lucas, MD, MP (1713-71), apothecary and physician, Irish patriot; DNB, 12, 231-4.

127. C. Lucas, *An essay on waters. In three parts, treating I. of simple waters, II. of cold medicated waters, III. of natural baths*, A. Millar, London, 1756. The three parts separately paginated.
128. The minute description of the springs of Spa and Aachen (Aix-la-Chapelle) alone took up some 70 and 195 pages of the book, respectively.
129. S. Johnson (anon.), *The Literary Magazine*, **1756**, *1*, 167-8, 225-9, 288-92.
130. Francis Home (1719-1813), professor of materia medica at Edinburgh; DNB 9, 1122-3.
131. F. Home, *Experiments on Bleaching*, A. Kincaid & A. Donaldson, Edinburgh, 1756; see also F. G. Page, "Francis Home and Joseph Black: The Chemistry and Testing of Alkaline Salts in the Early Bleaching and Alkali Trade," *Bull. Hist. Chem.*, **2000**, *27*, 107-112.
132. S. Johnson (anon.), *The Literary Magazine*, **1756**, *1*, 136-41.
133. Stephen Hales (1677-1761), DD, FRS, physiologist and inventor. Perpetual curate at Teddington, clerk of the closet to the Princess Dowager (1751), and chaplain to her son, afterwards King George III; DNB 8, 916-20. See also A. E. Clark-Kennedy, *Stephen Hales, DD, FRS. An eighteenth-century biography*, Cambridge University Press, Cambridge, 1929.
134. S. Hales, *Statistical essays. Vol.1. Vegetable staticks; Vol.2. Haemostaticks*, W. & J. Innys, London, 1727 and 1733.
135. S. Hales, An account of a useful discovery to distil double the usual quantity of sea-water by blowing showers of air up through the distilling liquor . . . and an account of the great benefit of ventilators . . . in slave and other transport ships; also an account of the good effect of blowing showers of air through milk, thereby to cure the ill taste which is occasioned by some kinds of food of cows, Richard Manby, London, 1756. Reissued from *Philos. Trans. R. Soc.*, **1755**, *49 I*, 312-47. See also: "The Rev. Dr. Hales's method of obtaining plenty of fresh sea-water; Further improvements by the Rev. Dr. Hales," *Gentleman's Magazine*, **1756**, *26*, 78-9 and **1757**, *27*, 503.
136. S. Johnson (anon.), *The Literary Magazine*, **1756**, *1*, 143-5.
137. A. D. Atkinson, "Dr. Johnson and the Royal Society." *Notes and Records of the Royal Society*, **1953**, *10*, 131-8; A. D. Atkinson, "Dr. Johnson and Science," *Notes and Queries*, **1950**, *195*, No. 16, 24, 25, 26; pp 338-41, 516-9, 541-4, 561-3.
138. T. Birch, *The History of the Royal Society of London*, A. Millar, London, 1756, 4 vol., 4to.
139. S. Johnson (anon.), *Literary Magazine*, **1756**, *1*, 30-2.
140. S. Johnson (anon.), "Philosophical Transactions. Volume XLIX. For the year 1755," *Literary Magazine*, **1756**, *1*, 193.
141. The imposition by the Royal Society of an admission fee (of two guineas before 1753, raised to five guineas thereafter), and an annual subscription (of £2:12:0, see Ref. 142) may have been no small disincentive to Johnson of seeking election during his long years of straightened circumstances (see also Ref. 42).
142. C. R. Weld, *A History of the Royal Society*, John W. Parker, London, 1848, 2 vol., Vol.2, 524, 541; *Minute Book of the Royal Society*, 12 March 1752.
143. The signature 'Sam. Johnson' in the Society's membership book is followed by the promise to pay the subscription of 2 guineas.
144. J. L. Abbott, "Dr. Johnson and the Society," *J. R. Soc. Arts*, **1967**, *115*, 395-400, 486-90.
145. See Ref. 39.
146. James Barry (1741-1806), historical painter; DNB 1, 1241-4.
147. The impressive frieze paintings, 140 ft long and 11 ft tall, completely covering the upper four walls of the grand lecture room of the Society's mansion in The Adelphi have, with occasional cleaning and restoration, been preserved to this day. The artist has described the creation of the work, which seeks to illustrate, in six allegorical scenes, 'The Rise of Human Culture.' See, J. Barry, *An account of a series of pictures in the Great Room of the Society of Arts, Manufactures and Commerce at the Adelphi*, for the author, London, 1783.
148. Elisabeth Montagu (1720-1800), the original 'blue stocking;' DNB, *13*, 687-91.
149. Ref. 2, Boswell, Vol.2, p 537.
150. A. W. Ward and A. R. Waller, *The Cambridge History of English Literature*, Cambridge University Press, Cambridge, 1907-16, 1932, 15 vol.. Vol. is subtitled "The Age of Johnson;" G. Sampson, *Concise Cambridge History of English Literature*, Cambridge University Press, Cambridge, 1941, 1961, Chap. X, 502- 57.
151. P. Fussell, *The rhetorical world of Augustan humanism: Ethics and imagery from Swift to Burke*, Clarendon Press, Oxford, 1965, 17.
152. W. P. Jones, *The rhetoric of science. A study of scientific ideas and imagery in 18th century English poetry*, Routledge & Kegan Paul, London, 1966, 179.
153. J. R. Philip, "Samuel Johnson as Antiscientist," *Notes and Records of the Royal Society*, **1974-5**, *29*, 193-203.
154. S. Johnson in G. B. Hill, Ed., *Prefaces, biographical and critical to the works of the English poets*, Clarendon Press, Oxford, 1905, 3 vol., Vol.1, 99-100; see also Ref. 56, No. 24, 9 June 1750; No.137, 9 July 1751.
155. Ref. 56, No.199, 11 February 1752; Ref. 22, No. 31, 18 November 1758.
156. Ref. 140; also Ref. 22, No. 88, 22 December 1759.
157. Ref. 10, p 25 and Chap.V, pp 120-45
158. P. H. Houston, *Doctor Johnson—a Study of 18th-Century Humanism*, Harvard University Press, Cambridge, MA, 1923. For an unfavorable commentary thereon, see Ref. 62.
159. Ref. 111. Indebted to Barnard for his part in his recent interview with the King, and for other privileges, Johnson wrote a very courteous and diplomatic letter, offering his advice in terms that would give no offense to a man who was obviously himself an expert in this business.

160. Ref. 23.
 161. Ref. 24, p 121.
 162. Ref. 9.
 163. Ref. 58, Dobson.
 164. W. K. Wimsatt, in *Philosophic words. A study of style and meaning in The Rambler and Dictionary of Samuel Johnson*, Yale University Press, New Haven, CT, 1948, 36: 'what may by courtesy be called Johnson's experimental activities.'
 165. O. Krätz, *Goethe und die Naturwissenschaften*, Callway, Munich, 1992, 2nd ed.
 166. Ref. 56, No. 5, April 3, 1750.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the courtesy and help provided by the Staff of the British Library, the

Guildhall Library of the Corporation of London, and of the libraries of the Royal Society and the Royal Society of Chemistry.

ABOUT THE AUTHOR

Frederick Kurzer, Ph.D., D.Sc., FRSC, graduated in chemistry in the University of London. After 5 years' employment in a pharmaceutical research laboratory, he spent his working life teaching chemistry and biochemistry at the Royal Free Hospital School of Medicine. He is the author of numerous research papers and reviews dealing with synthetic organic chemistry and of several publications on historical aspects of science.

Appendix I. List of Johnson's Books on Chemistry and Cognate Subjects.

	Sale Cat.No.		
1.	346	-	Agricola, Georgius, <i>Opera</i> (Six named works), Frobenius, Basle, 1546.
2.	-	D	Arbuthnot, John. <i>An essay concerning the effects of air on human bodies</i> , J. & R. Tonson, London, 1733.
3.	-	D	Arbuthnot, John. <i>An essay concerning the nature of aliments</i> (Ref. 81).
4.	-	D	Bacon, Francis. <i>Apophthegms new and old</i> (Ref. 88).
5.	-	D	Bacon, Francis. <i>Sylva sylvarum</i> (Ref. 87).
6.	-	D	Bacon, Francis, <i>Philosophical Works</i> (Ref. 90).
7.	317	-	Bacon, Roger. <i>Opus majus ad Clementem Quartum</i> , fol., W. Bowyer, London, 1733.
8.	553	-	Béardé de l'Abbaye. <i>Essays in agriculture, or A variety of useful hints for its improvement, with respect to air, water, earth, heat and cold . . . for the improvement of natural knowledge</i> , 4to, T. Carnan, London, 1776.
9.	418	-	Becher, Johann Joachim, <i>Physica subterranea</i> (G. E. Stahl, Ed.), 4to, Weidmann, Leipzig, 1738.
10.	80	D	Boerhaave, Herman. <i>Elementa chemiae. Historia, artis theoria et 398 operationes chemicae</i> . 2. Vol. 4to, J. R. Imhof, Leyden, 1732. Two copies in Sale.
11.	562	D	Boyle, Robert. <i>Works</i> (T. Birch, Ed.) (Ref. 89).
12.	-	D	Boyle, Robert. <i>The sceptical chymist</i> . (Ref. 52.).
13.	-	D	Boyle, Robert. <i>Experiments and considerations touching colours</i> , 12mo, Henry Herringman, London, 1664.
14.	30	-	Boyle, Robert. (An unidentified single work).
15.	579	D	Browne, Sir Thomas. <i>Pseudodoxia epidemica</i> (Vulgar errors), Edward Dod, London, 1646.
16.	263	D	Butler, Samuel. <i>Hudibras</i> , D. Browne, London, 1726.
17.	417	-	Caesalpinus, Andreas, <i>De metallicis libri tres</i> , A. Zannetti, Rome, 1596.
18.	295	D	Celsus, Aurelius Cornelius. <i>De medicina libri octo</i> , with notes, Variorum, J. A. Langerak, Leyden, 1746.

19. 487 D Chambers, Ephraim. *Cyclopaedia* (The sale catalogue lists the 1741 edition), (Ref. 101).
20. 124 D Cheyne, George. *The English malady, or a treatise of nervous diseases of all kinds, with the author's own case*, G. Strahan, London, 1733.
21. - D Cowell, John. *A law dictionary, or the interpretation of words and terms. Now very much augmented and improved up to the year 1708*, folio, D. Browne, etc., London, 1708.
22. - D *Dictionnaire universel françois et latin* (vulgairement appelé Dictionnaire de Trévoux, 3 vol., folio, Trévoux, 1704).
23. - - Dossie, Robert. *The laboratory laid open*. 1758. (Ref. 41).
24. - - Dossie, Robert. *The handmaid to the arts*. 1758, (Ref. 41).
25. - - Dossie, Robert. *Institutes of experimental chemistry*, J. Nourse, London, 1759, (Ref. 41).
26. 488 - *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers*, par une société de gens de lettres. 7 vols Folio, M. Diderot et M. d'Alembert, Paris, 1751-9.
27. 225 - Galenus, Claudius. *Galenii opera*. 5 vol., Frobenius, Basle, 1538
- 470 - *Galenii opera*, 7 vol., Frobenius, Basle, 1542. Two copies in Sale.
28. 464 - Gerarde, John. *The Herball or generall historie of plantes, very much enlarged and amended by Thomas Johnson*, folio, A. Islip, J. Norton & R. Whitakers, London, 1633.
29. 358 D Grew, Nehemia. *Cosmologia sacra, or a discourse of the universe*, folio, W. Rogers, London, 1701.
30. 44 - Hales, Stephen. *Statical essays* (Ref. 134).
31. - - Hales, Stephen. *Account of distilling . . . sea-water* (Ref. 135).
32. - D Harris, John. *Lexicon technicum, or a universal English dictionary of arts and sciences*. 2 vol., folio, D. Browne, London, 1704-10.
33. 412 - Helmont, Johannes Baptista von. *Opuscula medica inaudita*. 4to, L. Elzevir, Amsterdam, 1648.
34. 272 D Hill, John. *A history of the materia medica* (Ref. 102).
35. - D Hill, John. *A general natural history*. (Ref. 103).
36. 592 - Hoffmann, Friedrich. *Opera omnia physico-medica*, 6 vol. +2 vol. Supplements, folio, de Tournes, Geneva, 1748-53.
37. - - Home, Francis. *Experiments on bleaching* (Ref. 131).
38. - - Hooker, Richard. *Of the lawes of ecclesiastic politie eight bookes* (Ref. 49).
39. 211 - James, Robert. *Medicinal dictionary* (Ref. 15).
40. 309 - Juncker, Johann. *Conspectus chemiae theoretico-practicae in forma tabularum . . . principia . . e dogmatibus Becheri et Stahlii potissimum explicantur . . . experimentis stabiliuntur*, 2vol. 4to, Impensis Organotrophei, Halle, 1730-8.
41. 615 - Lewis, William. *A course of practical chemistry* (Ref. 27).
42. 601 D Locke, John. *The works* (the first collected edition by J. LeClerk), 3 vol., folio, J. Churchill & S. Manship, London, 1714
43. - - Lucas, Charles. *Essay on waters* (Ref. 127).
44. 614 - Macquer, Pierre Joseph. *Elements of the theory and practice of chymistry* (translated from the French), 2 vol. 2nd ed., A. Millar & J. Nourse, London, 1764.
45. 62 - Macquer, Pierre Joseph. *Dictionary of chemistry. With full explanations of . . . the fundamental principles of the arts, trades and manufactures dependent on chemistry* (translated by James Keir, FRS), 2 vol., 4to, T. Cadell, London, 1771.
46. 260 - Marggraf, Andreas Siegmund, *Opuscules chymiques*, 2 vol. 12mo, Vincent, Paris, 1762.
47. - D Mead, Richard. *Mechanical account of poisons, in several essays*, Ralph Smith, London, 1702.
48. - D Miller, Philip. *A short introduction to the knowledge of the science of botany*, John Rivington, London, 1760.
49. - D Mortimer, John. *The whole art of husbandry, or the way of managing and improving of land*, 3rd ed., H. & G. Mortlock, R. Robinson, London, 1712.
50. 145 - Musschenbroek, Pieter van. *Elementa physicae conscripta in usus academicos*, Apud Samuelem Luchtmans, Leyden, 1734.
51. 624 - Neri, Antonio. *De arte vitaria libri VII, et in eosdem Christophori Merretti observationes et notae*, 18mo, Andreas Frisius, Amsterdam, 1668.
52. 58 D Newton, Sir Isaac. *Opticks* (Ref. 92).

- | | | | |
|-----|-----|---|---|
| 53. | 111 | - | Paracelsus, Theophrastus Bombast (ab Hohenheim). <i>Opera omnia</i> , 3 vol., folio, I. Antonius & S. de Tournes, Geneva, 1658. |
| 54. | 609 | - | Plinius, Secundus Caius. <i>Historiae mundi libri XXXVII</i> . Ex postrema ad vetustos codices collatione, cum (S.Galenii) annotationibus, Folio, Froben, Basle, 1539. |
| 55. | 306 | - | Plinius, Secundus Caius. <i>Naturalis historiae libri XXXVII</i> . Interpretatione et notis illustravit J.Harduinus in usum. Delphini. 5 vol., 4to, F. Muguet, Paris, 1685. |
| | 350 | - | Editio nova emendatior ac auctior, 3 vol., folio, Impensis Societatis, Paris, 1741 |
| 56. | - | D | Quincy, John. <i>Lexicon physico-medicum</i> (Ref. 97). |
| 57. | 354 | D | Savary des Bruslons, Jacques. <i>The universal dictionary of trade and commerce</i> , translated from the French . . . with large <i>additions</i> ... by M.Postletwayt, 2 vol., folio, J. & P. Knapton, London, 1751-5. |
| 58. | 132 | - | Schelhammer, Günther Christoph. <i>Tractatus de nitro, vitriolo, alumine et atramentis</i> , Apud Janssonio Waesbergios, Amsterdam, 1709. |
| 59. | 380 | - | Watson, Richard. <i>Chemical essays</i> (Ref. 46). |
| 60. | 262 | D | Watts, Isaac. <i>Logick</i> (Ref. 83). |
| 61. | - | D | Watts, Isaac. <i>The improvement of the mind, or a supplement to the art of logick</i> , James Brackston, London, 1741. |
| 62. | - | D | Woodward, John. <i>Fossils of all kinds, digested into a method</i> , suitable to the mutual relation and affinity, with the names by which they are known to the Ancients . . . and also several papers tending to the future advancement of the knowledge of <i>minerals</i> , William Innys, London, 1728. |
| 63. | 23 | D | Woodward, John. <i>Natural history of the fossils of England</i> (Ref. 105). |

Notes to Appendix I

The appended list is an attempt to register all works on chemistry and closely related subjects that can be shown to have been owned by, or known to Johnson. The books that formed part of his library, as recorded by its sale catalogue (Ref. 60, 61), are identified by their original catalogue number. All those cited by Johnson as sources of his Dictionary quotations, are marked D. Titles lacking either designation were traced through his miscellaneous writings.

Several major works of this list were primarily concerned with medicine but, according to the prevailing usage, included substantial sections on chemistry (and materia medica), as did the large encyclopaedias. Works on physics, botany, agriculture, and philosophy provided incidental chemical information. A few titles not obviously chemical or scientific (No. 16, 38, 60, 61) did contain suitable passages used by Johnson for his scientific entries.

Bibliographical details of volumes are not repeated in the Appendix, when they have already appeared in the footnotes of the text, to which reference is made instead. The very verbose titles of several of the early books are, except for the more obscure works, suitably abbreviated.

Appendix II. List of Books on Chemistry and Cognate Subjects in the Thrales' Library at Streatham

Sale Cat. No.	
1.	87 Barry, Sir Edward, FRS. <i>Observations historical, critical and medical</i> , on the wines of the ancients, and the analogy between them and <i>modern wines etc.</i> , 4to, T. Cadell, London, 1775.
2.	212 Becher, Johann Joachim. <i>Physica subterranea</i> (As No. 9, Appendix 1).
3.	79 Boerhaave, Herman (translated by Peter Shaw), <i>A new method of chemistry</i> , 2 vol., 4to, London, 1753 (Ref. 26).
4.	127 Boyle, Robert. <i>Works</i> (As No 11, Appendix 1).
5.	88 Combrune, Michael. <i>The theory and practice of brewing</i> , 4to, R. & J. Dodsley, etc., London, 1762.
6.	79 Experimental chemistry (unidentified work).
7.	229 Hoffmann, Friedrich. <i>Opera omnia</i> (As No. 36, Appendix I, but 4 vol., 4to, Genevae, 1740).
8.	117 Lucretius, T.Carus. <i>De rerum natura libri VI</i> . 2 vol., 4to, Apud Janssonios van der Aa, Leyden, 1725.
9.	79 Macquer, Pierre Joseph. Dictionary of chemistry (As No.45, Appendix 1).
10.	210 Newton, Sir Isaac. <i>Optice sive de reflexionibus . . . libri III</i> . Latine reddit Samuel Clarke DD, 4to, Sam. Smith & Benj. Walford, London, 1706.
11.	217 Plinius, Secundus C. <i>Naturalis historiae libri XXXVII</i> (As no.55, Appendix I, but folio, Leyden, 1606).
12.	98 Royal Society. <i>Philosophical Transactions. Abridgement</i> by Lowthorp et al., 7 vol.
13.	79 Miscellaneous texts on chemistry, unidentified (5 vol.).

Appendix III. List of Chemical Terms quoted in Johnson's Dictionary

The authors and cross references quoted refer to the works listed in Appendix I.

Absorbent	Arbuthnot 3; Quincy 56	Ambergris	Chambers 19; Trévoux 22
Acid	Arbuthnot 3; Quincy 56	Ammoniacal Salts	Chambers 19; Trévoux 22; Savary 57
Acidity	Arbuthnot 3	Analysis	No quotation
Adept	Boyle 11	Anodyne	Arbuthnot 3
Adulteration	Bacon 6	Antimony	Chambers 19
Agate	Woodward 62	Aqua Fortis	Chambers 19; Locke 42
Aggregate = Mixture	Woodward 62	Aqua Regia	Chambers 19
Air	Watts 60	Aqua Vitae	Chambers 19
Alcahest	Quincy 56	Ardent Spirit	Newton 5
Alchemy	Hooker (Ref. 49, b V, para.58)	Arsenick	Chambers 19
Alcohol	Arbuthnot 3, Boyle 11, Quincy 56	Asa Foedica	Chambers 19
Alembick	Boyle 11	Asbestos	Chambers 19
Alkali	Arbuthnot 3; Boyle 11; Newton 52	Asphaltum	Chambers 19
Alloy	Locke 42	Assay	Cowell 21
Aludel	Quincy 56	Athamor (a furnace)	Quincy 56
Alum	Boyle 11; Chambers 19	Attraction	No quotation
Amalgam	Bacon 6, Butler 16	Balance	Chambers 19
Amber	Chambers 19; Trévoux 22	Balloon	No quotation
		Bath	Quincy 56

Benzoin	Chambers 19; Trévoux 22	Enamelling	Woodward 62
Bismuth	Quincy 56	Essential Oils	Arbuthnot 3
Bitumen	Savary 57	Ether	Newton 52
Bleaching	No quotation	Evaporation	Boyle 11; Quincy 56
Borax	Quincy 56	Explosion	Newton 52
Calamine	Locke 42	Extract	Bacon 5, No.645; Boyle 12; Woodward 62
Calcination	Quincy 56	Fat	Arbuthnot 3; Quincy 56
Calx	No quotation	Fermentation	Harris 32; Quincy 56
Carmine	Chambers 19	Filtration	No quotation
Caustic, lunar	Arbuthnot 3; Quincy 56	Flame	Newton 52
Ceruse (White lead)	Quincy 56	Fulmination	Boyle 11
Chalk	Chambers 19; Mortimer 49	Furnace	Bacon 5
Chalybeate	Arbuthnot 3	Fusion	Newton 52
Charcoal	Bacon 5, No. 775	Gas	Harris 32
Chemistry	Arbuthnot 3; Boerhaave 10	Glass	Quincy 56
Cinnabar	Newton 52	Gold	Bacon 5; Boyle 11; Hill 35
Clays	Hill 35	Granulation	Quincy 56
Coagulation	Arbuthnot 3	Gun Powder	No quotation
Cobalt	Hill 35	Heat	Locke 42
Cochineal	Hill 35	Incineration	Boyle 11
Cohobation	Quincy 56	Indigo	Miller 48
Combination	Boyle 11	Inflammable (spirits)	Arbuthnot 3
Combustion	No quotation	Infusion	Bacon 6
Compound	Bacon 5, No.798; Boyle 12,	Inspissate	Arbuthnot 3
Concentration	Arbuthnot 3	Iron	Hill 34, 35
Congelation	Arbuthnot 2, 3	Isinglass	Hill 34
Copper, Copperas	Chambers 19; Hill 35	Ivory	Hill 35
Coruscation	Bacon 5, No.114; Newton 52	Jelly	Arbuthnot 3
Crucible	No quotation	Kali	Bacon 6
Crystal	Chambers 19; Hill 35	Laboratory	Boyle 13
Crystallization	Quincy 56	Lead	Grew 29; Hill 35
Cucurbite	Boyle 13; Mortimer 49	Levigation	Quincy 56
Cuppel, Cuppellation	Harris 32	Lime, Lime Water	Hill 34; Mortimer 49
Decantation	Boyle 11	Liquefaction	No quotation
Decoction	Bacon 5, No.308	Lixivium	Boyle 11
Decomposition	No quotation	Lute	Bacon 5
Decrepitation	Quincy 56	Maceration	Quincy 56
Deflagration	Quincy 56; Boyle 11	Madder	Hill 34
Deliquescence	Boyle 11	Magistery =Precipitate	Browne, 15; Quincy 56
Dephlegmation	Quincy 56	Manganese	Hill 35
Detonation	Arbuthnot 2; Boyle 11; Quincy 56	Matrass	Quincy 56
Diamond	Hill 35; Woodward 62	Menstruum	Newton 52; Quincy 56
Diaphoretick	Arbuthnot 3	Mercury	Arbuthnot 3; Hill 34, 35
Digestion, Digester	Bacon 5, No.326; Quincy 56	Metals	Hill 34
Distillation	Boyle 12; Newton 52	Muriatick	Arbuthnot 3; Quincy 56
Earths	Hill 34; Woodward 62	Naphtha	Hill 34; Woodward 62
Ebullition	Quincy 56	Nitre	Bacon 5; Hill 35
Effervescence	Arbuthnot 3; Grew 29; Mead 47	Ochre	Hill 34
Effluvia	Quincy 56	Oil (Dipple, ethereal)	Boyle 11; Harris 32
Electrum	Bacon 5	Opium	Hill 34
Element	Boyle 12; Watts 60	Ores	No quotation
Empyreuma	Quincy 56	Petrification	Boyle 11
Emulsion	Arbuthnot 3		

Pewter	Bacon 6	Solvent	Boyle 11
Phlogiston	No quotation	Spelter	Newton 52
Phosphorus	Cheyne 20	Spermaceti	Quincy 56
Pitch	Ecclesiasticus, 13, 1	Spirit	Arbuthnot 3; Boyle 11
Pneumatick	Boyle 11	Steel	Arbuthnot 3; Chambers 19; Hill 34
Potash	Hill 34; Woodward 62	Still	Arbuthnot 3; Newton 52
Precipitate	Grew 29; Bacon 6	Stones (Calculi)	Hill 34
Principle	Watts 60	Storax	Wyclif Bible, Ecclesiasticus 24, 21
Purification	Boyle 11	Sublimation	Bacon 6; Newton 52; Quincy 56
Putrefaction	Arbuthnot 3; Quincy 56	Sugar	Boyle 11; Quincy 56
Pyrites	Woodward 62	Sulphur	Newton 52; Woodward 62
Quartation	Boyle 11	Tartar	Boyle 11; Quincy 56
Quicklime	Hill 34	Tin, Tinning	Woodward 62
Quicksilver	Chambers 19; Hill 34	Tincture	Boyle 11
Quintessence	Boyle 11	Torrefaction	Boyle 13
Receiver	Arbuthnot 3	Touchstone	Bacon 4
Rectification	Boyle 11; Grew 29; Quincy 56	Trituration	Browne 15
Refrigeratory	Quincy 56	Urine	Arbuthnot 3
Regulus	Quincy 56	Vapour	Arbuthnot 3; Newton 52
Resin	Quincy 56	Verdigris	Bacon 5
Retort	Arbuthnot 3	Vinegar	Bacon 6
Salt	Boyle 11; Harris 32; Woodward 62	Vitriol	Bacon 6; Grew 29; Woodward 62
Saltpetre	Bacon 6	Volatility	Arbuthnot 3; Newton 52
Saponaceous	Arbuthnot 3	Water	Arbuthnot 3; Quincy 56
Saturation	Woodward 62	Wax	Arbuthnot 3
Scoria	Newton 52	Weld or Woald (dye)	Miller 48
Silver	Watts 60	Yeast	Butler 16
Smelting	Woodward 62, 63		
Soap	Arbuthnot 3		
Solubility	Arbuthnot 3		

Notes to Appendix III

The list of chemical terms cannot be claimed to be exhaustive, not having been compiled by an item-by-item scrutiny of the Dictionary itself but by the indirect approach described (see "Retrieval of Chemical Entries"). Relevant terms may therefore have occasionally escaped capture.

The references attached to the chemical terms listed in Appendix III link them to the works arranged alphabetically by author in Appendix 1. A few of the quoted terms lacking such cross references were defined or described without further illustrative quotations.

RUTHERFORD, THE “TRUE DISCOVERER OF RADON”

Marelene F. Rayner-Canham and Geoffrey W. Rayner-Canham,
Sir Wilfred Grenfell College

In an earlier issue of this *Bulletin* (1), Marshall and Marshall provide strong evidence that Ernest Rutherford was the “true discoverer” of radon. They report (p 78) that “By 1903 they [Rutherford and Soddy] could claim that the “emanation” must be matter in the gaseous state.” In fact, Rutherford was persuaded of the gaseous nature of emanation in 1901 as a result of research performed by his first graduate student, Harriet Brooks (2).

In an earlier paper of 1900 (3), Rutherford had suggested two possibilities for emanation: that it was “fine dust particles of the radio-active substance emitted by the thorium compounds” or “a vapour given off from thorium compounds.” Once experiments showed that emanation was not a dust, Rutherford concluded that, “The emanation may possibly be a vapour of thorium.”

It was in 1901 that Rutherford’s view changed. Rutherford and Brooks jointly authored a paper titled “The New Gas from Radium.” In their opening remarks, they comment (4):

The term “emanation” was applied to the substance thus emitted, as there was no evidence at the time whether the material emission was a vapour of the substance, a *radioactive gas* (our emphasis), or particles of matter each containing a large number of molecules.

Thus Rutherford and Brooks had now added this third possibility that was absent from the 1900 paper. They then described their efforts to identify the nature of emanation. No appreciable volume of a gas could be isolated nor could any new spectral lines be identified. As

a result, they concluded that the volume of any gas was small. They resorted to a gas interdiffusion apparatus as a means of not only confirming emanation to be a gas but also in order to obtain a rough value for its molecular weight. They reported (erroneously) that the gas had to have an atomic weight between 40 and 100. Nevertheless, the fact that the value was far less than that of thorium persuaded them that emanation was a previously unknown gas. They did not claim at the time that it was a new element, though this seems to be the implication left to the reader.

The title of the paper made a definitive claim of the gaseous nature of the substance; but, in their closing remarks, they were somewhat more diffident, stating (4):

We must therefore conclude that the emanation is in reality a heavy radioactive vapour or gas.

However, in the final sentence, they came out more strongly for the gas option:

... special experiments show that it diffuses rapidly, and is also gaseous in character.

Later in the year, Rutherford re-published the findings under his own name alone (5). This briefer account contained the comment, “In these experiments, I have been assisted by Miss H. T. Brooks, ...” He then repeated the statement from the earlier paper, “We must therefore conclude that the emanation is in reality a heavy radioactive vapour or gas.”

Thus we would courteously suggest 1901 as the year in which emanation was first identified by Rutherford–and Brooks–as a new gaseous element.

REFERENCES AND NOTES

1. J. L. Marshall and V. R. Marshall, "Ernest Rutherford, the 'True Discoverer' of Radon," *Bull. Hist. Chem.*, **2003**, 28, 76-83.
2. M. F. Rayner-Canham and G. W. Rayner-Canham, *Harriet Brooks—Pioneer Nuclear Scientist*, McGill-Queen's University Press, Montreal, 1992.
3. E. Rutherford, "A Radio-active Substance Emitted from Thorium Compounds," *Philos. Mag.*, **1900**, 49, 1.
4. E. Rutherford and H. T. Brooks, "The New Gas from Radium," *Trans. R. Soc. Canada*, **1901**, Section III, 21.
5. E. Rutherford, "Emanations from Radio-active Substances," *Nature*, **1901**, 64, 157.

RESPONSE TO RAYNER-CANHAM LETTER

Marlene Rayner-Canham includes an added dimension to the discovery process of radon in Rutherford's laboratory. The question is raised whether the actual discovery date should be earlier. We have found that identifying "the" discovery date of an element can be difficult, owing to uncertain criteria for the elements previous to modern times; this was briefly discussed in the beginning of our article. V. Karpenko (*Ambix*, **1980**, 27, 77-102) discusses this matter more fully and cites E. Rancke-Madsen (*Centarus*, **1976**, 19, 299), who suggests two criteria to be an "effective discoverer of an element," the first being the observation of a new substance recognized as being elemental (but may be in combination or may be impure), and the second being the announcement (publication or even professional lecture) of this discovery so that it has been noticed by persons outside the immediate circle. On this basis we

would tend to adhere to the "official" dates given in our article. (As we have noted in our article, we had contacted IUPAC, which has no official standing regarding the "true discovery of elements" except for the recent artificial elements.) However, we completely agree that the first recognition of a new element may precede the "official" date. Notable examples include einsteinium (whose first detection in a nuclear detonation was kept secret for a period of time) and oxygen (which was discovered by Scheele probably even before his work in Uppsala, actually during his previous stay in Stockholm). The Rayner-Canhams' excellent comments remind us that the "discover" phenomenon is a dynamic and unfolding process, and they breathe additional insight into the discovery process of radon in the laboratory of Rutherford. December 6, 2003.

James L. Marshall and Virginia R. Marshall

The 10th Biennial Chemical History Study Tour

The 10th Biennial Chemical History Study Tour will take place from October 7 - 19, 2005. Our itinerary will take us to Prague, Vienna, and Northern Italy where we will explore the work of Czech Nobel Laureate Jaroslav Heyrovsky, visit a medieval silver mine and one of the world's oldest alchemy museums, examine the work of Austria's most famous chemist, Auer von Welsbach, at a museum dedicated to his work, visit Galileo's academic digs in Padua, view the magnificent architecture of Palladio, the model for many of our buildings in Washington, DC, etc. There will be an optional four days in Rome for those who wish where we will visit the University of Rome's Physics Museum crammed with Fermi memorabilia, and the Chemical Education Museum. For more details of the itinerary and pricing, please contact Mary Virginia Orna at mvorna@cnr.edu or write to her at the Department of Chemistry, College of New Rochelle, New Rochelle, NY 10805.

FREDERICK GEORGE DONNAN AND THE RELATIONSHIP BETWEEN ELECTROLYTIC DISSOCIATION AND LIGHT ABSORPTION

John T. Stock, University of Connecticut

Donnan's Early Years

Although Frederick George Donnan (Fig. 1) grew up in Northern Ireland, actually he was born in Columbo, Ceylon (now Sri Lanka), on September 5, 1870 (1). He lost the sight of his left eye at the age of nine but did not allow this accident to handicap him. As a schoolboy, his main interest was in mathematics and physical science. He attended the Belfast Royal Academy from 1880 to 1889; and although he received instruction in physics and chemistry, this was confined to theory, because the Academy lacked laboratories. However, Donnan managed to get some practical training by attending evening courses elsewhere.

In 1889 Donnan entered Queen's College, Belfast, where one of his instructors was the organic chemist Edmund Albert Letts (1851-1918). His outstanding ability for chemistry and physics was recognized by the award of several scholarships. In 1893 he was granted an 1851 Exhibition Research Scholarship, which enabled him to study abroad. He went to the



Figure 1. Frederick George Donnan

University of Leipzig and, not surprisingly, studied for a year under Johannes Wislicenus (1835-1902), the professor of organic chemistry. No publication resulted, so the instruction was probably general. Eventually Donnan's natural interests in the physical sciences prevailed, and he decided to turn to physical chemistry.

At that time, this field was rapidly developing under the influence of Wislicenus's colleague, Wilhelm Ostwald (1853-1932), who became Donnan's dissertation advisor. Donnan's assignment was an experimental study of the relationship between dissociation and light absorption in solutions of violuric acid (2).

Physical Chemistry

Texts concerned with the general history of chemistry usually include a section on physical chemistry. An illuminating statement in one of them is (3):

Prior to about 1884 physical chemistry was the study of the physical properties of chemical substances.

There were of course exceptions to this very broad statement. One example was the question of *affinity*, or combining intensity, of

chemical substances. Attempts to measure, or at least to compare, affinities had been in progress since the 17th century. The concept that a reaction need not run to completion and could be reversible eventually led to the experimental formulation of the law of mass action (4). Jacobus Henricus van't Hoff (1852-1911) showed that this law could be deduced theoretically (5). He found that the gas equation, $PV = RT$ could be extended to solutions when osmotic pressure replaces gas pressure, P . However, when the solute is an electrolyte, the gas constant, R , had to be multiplied by an arbitrary factor, i , to make the observations fit the equation.

Early in his career, Ostwald had determined the relative affinities of acids by equilibrium methods and then by kinetic methods that involved catalysis by acids. This enabled him to list various monobasic acids in a numerically decreasing order of affinity. In 1884 Svante Arrhenius (1859-1927) sent a copy of his dissertation to Ostwald. This document contained the germ of the ionic theory, the development of which he described in 1887 (6). Arrhenius had studied the electrical conductivity of electrolyte solutions, and Ostwald realized that conductivity measurements should provide an alternative approach to the assessment of affinities. He found that the equivalent conductivities of his collection of organic acids were nearly proportional to the affinities obtained chemically. If a substance undergoes dissociation, the number of solute particles in the solution is increased, thus accounting for the factor i in van't Hoff's concept. The application of the law of mass action to ionization led to the *Ostwald Dilution Law*:

$$\frac{\alpha^2}{V(1-\alpha)} = k$$

where α is the degree of dissociation into ions at dilution V (*i.e.*, the reciprocal of concentration), and k is a quantity now termed the dissociation constant of the solute (7).

In 1887 Ostwald founded and became the principal editor of the *Zeitschrift für physikalische Chemie*. He thus had a vehicle for the rapid publication of research when he moved to the University of Leipzig in the same year. One of his assistants was Walther Nernst (1864-1941) who, by 1889, had developed the quantitative aspects of the electromotive force of galvanic cells (8). Ostwald kept in close contact with Arrhenius and van't Hoff. All four scientists eventually became Nobel laureates.

The announcement of the ionic theory did not lead to its wide acceptance. In fact, it was strongly opposed by some workers. That the indefinitely stable sodium chloride should break up (*i.e.*, dissociate into ions) when dissolved invited disbelief. Opponents could point out that the dilution law breaks down when applied to solutions of strong electrolytes, *i.e.*, those with equivalent conductivities that are high even in concentrated solutions. Several decades were to pass before the behavior of strong electrolytes in solution could be explained. Despite this anomaly, the theory accounted for some hitherto inexplicable relationships and was strongly supported by Ostwald. Donnan's project, which was to involve optical phenomena instead of those of conductivity, may have been chosen to obtain additional evidence for the validity of the theory. Certainly, developments were at an exciting stage when Donnan arrived in Leipzig.

Background to Donnan's Project

The project was probably initiated by the photometric studies of Gaetano Magnanini (1866-). He obtained his doctorate in 1888 and was assistant at the University of Padua in 1888. After the next year in Leipzig, he became professor of chemistry at the University of Messina. In 1892 he was appointed to simultaneous professorships at the Universities of Bologna and Modena (9). In 1892 Magnanini had claimed that the light-absorbing capacity of a solution of a colored electrolyte is independent of its dissociation but depends solely on the concentration (9). He had found that the light absorption of a solution of CuSO_4 was not changed by the addition of H_2SO_4 . Magnanini believed, as did all his contemporaries, that a salt like CuSO_4 was only partially dissociated in solution, and that the addition of H_2SO_4 would decrease its degree of dissociation. Hence, if Cu^{2+} is the light-absorbing species, a decrease in the absorbance should have occurred. Ostwald had stated that both ion and nondissociated salt were light absorbers, so that the changed ratio of the two species could leave the absorbance unchanged.

Magnanini then began the study of violuric acid (HV) (Fig. 2) and its salts (10). HV exhibits keto-enol tautomerism and acts as a pseudo acid. Magnanini

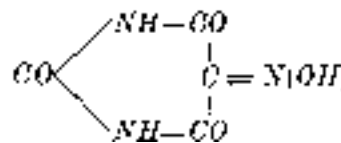


Figure 2. Violuric acid

claimed to have made solutions of HV that were colorless, but conductivity measurements showed the acid was appreciably dissociated. From this, he concluded that violurate ions (V) were colorless, *i.e.*, had practically no absorbance. However, a solution of potassium violurate (KV) is violet in color. He found that although the addition of KNO_3 did not change the light absorbance of such a solution, it considerably decreased the dissociation of KV.

Magnanini also prepared sodium and ammonium violurates. The solids differed in color from that of KV, but the three salts gave solutions of the same color. This could not be due either to the colorless cations or to the violurate ion, which he had stated to be colorless. He therefore assumed that the violet color of the salts depends on what happens to them when they are dissolved in water, or at least on the portions not split into ions.

Ostwald's assistant, Julius Wagner (1857-1924), in commenting on this assumption, stated that the color comes from "dissolved salt molecules," no matter what their state (11). Wagner felt that Magnanini had not correctly interpreted the significance of Ostwald's observation concerning solutions that contain a colored ion as a companion to a colorless one. Wagner then began his own examination of the behavior of HV and its salts. This involved the partial repetition of Magnanini's experiments, some results of which were found to be in conflict with the dissociation theory.

Despite Magnanini's claim, Wagner was unable to prepare a colorless solution of HV. In fact, as a preliminary to his study, Magnanini had obtained HV solutions that showed some color. He attributed this to the presence of alkali, dissolved from the glass-distilled water reservoir. Wagner found that water thus stored and that freshly distilled through a zinc condenser both

gave violet HV solutions, thus invalidating Magnanini's attribution.

Wagner used a colorimeter to compare the absorbance of a solution of HV with one of NaV. He found that the light path lengths required for equal absorbance were inversely related to the calculated concentrations of violurate ions. He then examined the effect of diluting a solution of HV. The intensity of color understandably decreased, but the effect was partially offset by the increased dissociation of HV as the solution became more dilute. Wagner found that, for a given solution and the same diluted fourfold, the color intensity ratio agreed with the ratio of the calculated ionic concentrations of the two solutions. Although he made no measurements, Wagner noted that the addition of HCl to a solution of HV diminishes the color. This can be explained as due to the suppression of the dissociation of HV by the additive. Overall, these experimental results are in harmony with the ionic theory. They show that the color of a solution of HV is due to the presence of the violurate ion. Later, Magnanini gave up his earlier ideas (12). Nevertheless, Donnan made use of Magnanini's conductivity data in his studies.

Donnan's Plan of Research

The first step of Donnan's plan was to determine optically the precise relationship between the concentration of HV and its degree of dissociation. He pointed out that although many others had examined light absorption in solutions, only one, Thomas Ewan (1868-1955), had determined electrolytic dissociation by colorimetric means (13). By use of a refined form of spectrophotometer, Ewan found that his results of the dissociation of dinitrophenol agreed very well with those calculated from conductivity measurements. If his first step was successful, Donnan planned to examine quantitatively the behavior of mixed solutions of HV and another acid.

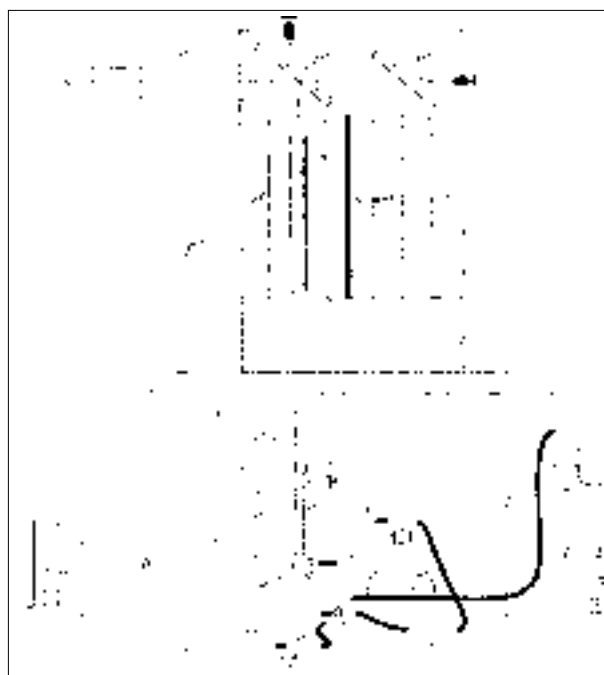


Figure 3. Colorimeter, side view at top, front view at bottom.

Donnan's Apparatus and Results

The simple but effective colorimeter designed by Donnan is shown as a side view at the top of Fig. 3 and as front view at the bottom. Light from the shielded incandescent gas burner *a* passes through tunnel *b* and is reflected upwards by the opal glass plate *c*. This is covered with a piece of frosted glass to diffuse the light, which is directed upwards through the approximately 20-cm high cylindrical cells *d*, *d*, which are shielded from one another by partition *s*. The rear cell (side view) contains a predetermined height of the solution to be examined, while the height of the reference solution in the other cell can be adjusted. After passage through the solutions, the light is reflected forward by mirrors *r*, *r*. An elliptical portion of the silvering of the front mirror is removed, so that light reflected by the rear mirror can pass through. Light from both mirrors passes through light filter cell *t*, which contains a solution of malachite green, of color complementary to the violet color of the solutions in cells *d*, *d* and then to the ocular *e*, which is merely a horizontal brass tube. The observer sees a circle of gray light in a similar background provided by the remainder of the front mirror. When the height of the reference solution is adjusted to achieve balance, *i.e.*, when the same amount of light is emerging from the two cells, the circle appears to have vanished; its illumination is the same as that of the background.

Pump *m* is used to compress the air in the large vessel *l*. Manipulation of cocks *g* and *p* allows the height of the reference column to be raised by air pressure, held constant, or lowered by relief of pressure. The height of the column in the reference cell is determined by reading the scale etched on tube *f*, the lower portion of which is sealed into the cell. Because of capillary action due to the difference in diameters of the cell and of the tube, the two levels are not the same. However, Donnan found that a constant correction could be applied. He also corrected for the fact that light from the rear mirror has to pass through the thickness of the glass of the front mirror, and also corrected for the absorbance caused by water in the differing column heights.

Donnan prepared violuric acid from hydroxylamine "hydrochlorat" and alloxan (14). After careful purification, he used it and carbonate-free NaOH to make the 1/1200-normal NaV that was used as the standard solution. Assuming that the degree of dissociation of NaV would be approximately the same as that found for KV by Magnanini, Donnan calculated that the dissociation

in his standard solution was 98.5%, *i.e.*, is practically complete.

The results obtained by Donnan for HV solutions are listed in Table 1. For each concentration (expressed as a fraction of normality), the percentages of dissociation of HV given are those obtained from conductivity, uncorrected colorimetry, and colorimetry corrected for solvent absorbance, respectively. It is obvious that the correction becomes important with the more dilute solutions. Donnan pointed out that these results were in harmony with the Ostwald dilution law.

TABLE 1

Percentage Dissociation of Violuric Acid in Solution

Concentration	Conductivity	Colorimetry	Colorim., corr.
1/32	2.90	2.89	2.88
1/64	4.08	4.07	4.14
1/128	5.75	5.54	5.74
1/256	8.06	7.61	7.97

Experiments with Violuric Acid Solutions that Contain Other Substances

If a solution of HV is acidified, the degree of dissociation, and hence the color, is decreased. The next section of Donnan's paper dealt with the examination of mixed solutions of HV and another monobasic acid (2). He wished to find out whether the decrease agreed with that indicated by the theory of equilibrium in electrolyte solutions. In such mixtures the concentration, dissociation constant, and degree of dissociation of each of the acids will be involved. The general approach for the calculation of α_1 , the degree of dissociation of HV, involves the solution of a complicated cubic equation. However, there are two cases in which this cubic equation can be simplified to a quadratic, namely, when the second acid is much stronger than HV and when the dissociation constants of the two acids are identical.

In the first case, the simplified equation is:

$$c_1\alpha_1^2 + (c_2 + k_1)\alpha_1 - k_1 = 0 \quad (1)$$

where α_1 is the degree of dissociation of HV at concentration c_1 and c_2 is the concentration of the strong acid.

According to Magnanini, the dissociation constant of HV, k_1 is 0.0000272.

As an example of this case, Donnan used solutions of HV that contained very low concentrations of HCl. He had found that, for 1/32-N HV solution itself, a_1 was 2.90%. However, when this solution was made 0.0003952-N with respect to HCl, a_1 had fallen to 2.47%. A similar experiment with 1/64-N HV gave corresponding percentages of 4.08 and 3.10. These results, along with another obtained at an HCl concentration of 0.0001976-N, agreed fairly well with those predicted by Eq. 1.

In the second case, the relevant equation is:

$$\frac{\alpha_2^1}{1 - \alpha_1} = \frac{k_1}{c_1 + c_2} \quad (2)$$

Donnan chose *p*-hydroxybenzoic acid (PAB, $k = 0.0000286$) and then levulinic acid (LA, $k = 0.0000255$) as solutes with dissociation constants close to that of HV. With PAB, both 1/32 N and 1/64 N HV solutions were used. As an example, a_1 was found to be 2.71% in a 1/32 N solution of HV that was also 0.005128 N with respect to PAB. The effect of PAB on a_1 was thus less than that produced by a much smaller concentration of HCl. Only 1/64 N HV solutions were used in experiments with LA. As an example, a_1 , found to be 4.14% with HV alone, fell to 3.14% when LA was added to a concentration of 0.01182 N. The results obtained with PAB were gratifying, those with LA less so. However, the LA results agreed very satisfactorily with those predicted by the general cubic equation.

This equation had to be used for 1/64 N solutions of HV that contained acetic acid (HA, $k = 0.0000180$), the dissociation constant of which differs considerably from that of HV. As an example, the addition to the HV solution of HA at a concentration of 0.0132 N caused a_1 to fall to 3.27%. Overall, the results were very satisfactory.

Arrhenius had examined the equilibrium in a solution that contained a weak acid and a strong acid, along with their potassium salts (9). He tested the theory by determining the hydrogen ion concentration through its specific effect on the velocity of the inversion of sugar (16). Donnan saw colorimetry as an alternative determinative method for solutions made from HV and a colorless alkali salt of a strong acid, for which he chose NaCl. Viewed on a molecular basis, equilibration will

result in the formation of NaV and of HCl, so that four solutes are involved. Further, these solutes dissociate to degrees that may differ greatly. Naturally, a rigid treatment of the resulting equilibrium state would be very complicated.

Donnan made the following assumptions: (i) the light-absorbing capacities of nondissociated NaV and of the violurate ion are the same; (ii) the concentration, x , of nondissociated NaV and the dissociation constant of HV are small compared with N , the concentration of NaCl. He showed that the concentration of the "light absorbing component" in a volume of V liters is given by:

$$\frac{(1 - x)\alpha_1 + x}{V} \quad (3)$$

Making use of his assumptions, Donnan was able to obtain expressions for a_1 and for x^2 (and hence for x) and could then evaluate expression (3). The considerable disagreement between the calculated values and those determined experimentally, e.g., 0.000688 N and 0.000762 N respectively, could not be explained, but was unlikely to be due to the difference in the light absorbing capacities of NaV and of its anion. Some experiments with mixed solutions of NaV and NaCl appeared to show that NaV was a better absorber than its anion, but the difference was too slight to affect the results.

Finally, Donnan tried his methods on *p*-nitrophenol and "commercial" dinitrophenol, which yield yellow ions. He found that his colorimeter lacked the necessary sensitivity. Ewan had been successful because of his more sophisticated instrumentation (7).

Donnan's Postdoctoral Career

In 1896, Donnan was awarded a Leipzig Ph.D. (*magna cum laude*). He then went to Berlin to work with van't Hoff (1852-1911) on the hydrates of salts and the vapor pressures of their solutions (1). Studying at home for a year, he wrote four papers on various aspects of theoretical physical chemistry. In 1898 he became a senior research student under William Ramsay (1852-1916) at University College, London. At that time, Donnan was the only person in the College who was well acquainted with Arrhenius-Van't Hoff-Ostwald concepts of physical chemistry, and he applied these vigorously to his studies. These led to publications on the Hall effect in electrolytes (17) and on the velocity of the iodide-ferricya-

nide reaction (18). Donnan's appointment as assistant lecturer in 1901 was his first academic post. In 1903 he moved to the Royal College of Science in Dublin, but his stay was short for he had become a leading scientist through his numerous publications on widely ranging physicochemical topics. In 1904 he became the first occupant of the new chair of physical chemistry at the University of Liverpool, where he continued to publish extensively.

His discovery of what is now known as the Donnan membrane equilibrium was announced in 1911 (19). Consider the simplest case: a solution of NaCl that is separated by a membrane from a solution of NaR, the anion R of which cannot pass through the membrane. The chloride ion concentrations become unequal, although the membrane is permeable to this ion. The Donnan effect has many ramifications, especially in biological systems.

Donnan succeeded Ramsay at University College in 1913 and remained there until his retirement in 1937. The outbreak of war in 1914 led him to become greatly involved in the national effort and, at the same time, brought him into close contact with leaders in the chemical industry. Donnan had become nationally and internationally famous, as indicated by his receipt of numerous awards and distinctions. He received eleven honorary doctorates, including those from Princeton and Johns Hopkins. He had been elected as a Fellow of the Royal Society in 1911 and received its Davy Medal in 1928. He was Foreign Secretary of the Chemical Society from 1925 until 1933, when he delivered the Ostwald Memorial Lecture to the Society.

Donnan's final papers, dated 1953, marked the 50th anniversary of the Faraday Society, of which he was a founding member. He died at Sittingbourne, Kent, on December 16, 1956.

REFERENCES AND NOTES

1. F. A. Freeth, "Frederick George Donnan. 1870-1956," *Biogr. Mem. Fellows R. Soc.*, **1957**, 3, 23-39.
2. F. G. Donnan, "Versuche über die Beziehung zwischen elektrolytischen Dissociation und der Lichtabsorption in Lösungen," *Z. Phys. Chem.*, **1896**, 19, 465-483.
3. W. H. Brock, *The Norton History of Chemistry*, W.W. Norton & Co., New York, 1993, 358.

4. E. W. Lund, "Guldberg and Waage and the Law of Mass Action," *J. Chem. Educ.*, **1965**, 42, 548-550.
5. Ref. 3, p 369-371.
6. S. Arrhenius, "Ueber die Dissociation der in Wasser gelöste Stoffe," *Z. Phys. Chem.*, **1887**, 1, 631-648.
7. W. Ostwald, "Zur Theorie der Flüssigkeiten," *Z. Phys. Chem.*, **1888**, 2, 36-37.
8. M. Archer, "Genesis of the Nernst Equation," in J. T. Stock and M. V. Orna, Ed., *Electrochemistry, Past and Present*, American Chemical Society, Washington, DC, 1989, 115-126
9. G. Magnanini, "Sul potere assorbente dei colorati in rapporto colla dissociazione elettrolitica," *Rend. d.r. Accad. Lincei*, **1892**, 22, 131-142.
10. G. Magnanini, "Ueber die Hypothese der Farben der Ionen," *Z. Phys. Chem.*, **1893**, 12, 56-62.
11. J. Wagner, "Ueber die Farbe der Ionen," *Z. Phys. Chem.*, **1893**, 12, 314-321.
12. G. Magnanini, "Elektrolytische Dissociation und Farbe," *Z. Phys. Chem.*, **1896**, 19, 190.
13. T. Ewan, "On the Absorption Spectra of Dilute Solutions," *Proc. R. Soc., London.*, **1894**, 57, 117-161.
14. Donnan does not state the source of his "Hydroxylaminhydrochlorat," an unusual and possibly explosive compound. Possibly, "Hydroxylaminhydrochlorid" was used.
15. S. Arrhenius, "Ueber die Gleichgewichtsverhältnisse zwischen Elektrolyten," *Z. Phys. Chem.*, **1890**, 5, 1-22.
16. J. T. Stock, "The Key Role Played by Sugar in Early Experiments in Kinetics and Equilibria," *Bull. Hist. Chem.*, **1999**, 23, 42-46.
17. F. G. Donnan, "Theory of the Hall Effect in a Binary Electrolyte," *Philos. Mag.*, **1898**, 45, 465-472.
18. F. G. Donnan and R. Le Rossignol, "Velocity and Measurement of the Reaction between Potassium Ferricyanide and Potassium Iodide in Neutral Aqueous Solution," *J. Chem. Soc.*, **1903**, 83, 703-716.
19. F. G. Donnan, "Theorie der Membrangleichgewichte und Membranpotentiale bei Vorhandensein von nicht dialysierenden Elektrolyten. Ein Beitrag zur physikalische-chemischen Physiologie," *Z. Elektrochem.*, **1911**, 17, 572-581.

ABOUT THE AUTHOR

John T. Stock, winner of the Dexter Award in the History of Chemistry in 1992, is Professor Emeritus of Chemistry, University of Connecticut, Storrs, CT 06269-3060.

CAMBODIA'S FOUR ELEMENTS

Fathi Habashi, Laval University

While on a trip to Siem Reap near Angkor (Fig. 1), the former capital of the tenth-twelfth centuries Khmer Empire, I was surprised when my young guide showed me around the Four Elements Temple, known locally as “Neak Pean,” founded by Buddhist King Jayavarman VII, who reigned from 1181 to 1220. The temple seems to have served as a place where pilgrims could go and take the waters, both physically and symbolically—the Khmer equivalent of a spa (1).

The temple is set in a large man-made square lake, 70 meters each side, bordered by steps and surrounded by four smaller square ponds (Fig. 2). A small circular island with a stepped base is in the center of the lake (Fig. 3). Each pond has a vaulted roof and is connected to the lake. The interior of the vault is decorated with panels of lotus and a central waterspout in the form of an animal or human in the center. The four buildings served a ceremonial function where pilgrims could meditate. They anointed themselves with lustral water, which flowed from the spout connected to the lake. Each waterspout is different: the elephant’s head symbolizes Water, the human head symbolizes Earth, the horse’s head for Air, and the lion’s head for Fire. Each pilgrim knows to which vault he belongs—

the priest had already assigned this to him at birth. The Cambodian four elements is said to be described in the Sanskrit books and is well known to the people. They also believe that on cremation, fire and air transform the body to water (vapor) and earth (ash). Rebirth is believed to be the reverse of cremation.

Neak Pean means in local language the “coiled serpents;” this refers to the two sculptured serpents encircling the base of the island whose tails entwine on the west side. The heads of the serpents are separated to allow passage on the east. Serpents are extensively represented in the ancient Egyptian *Book of the Dead*, which contains many illustrations of serpents that were considered to be the symbol of any force that was hostile to the dead and was usually represented by being attacked by the wise man Ani with a spear. Serpents are also represented in many alchemical texts. Ihde (2), for example, shows a page from a

Greek alchemical manuscript with a serpent. Partington (3) also shows the front page of the Latin translation of the Pseudo-Demokritos book *Abderita de Arte Magna*, published in 1572, in which a serpent is coiled on the anchor of a ship.

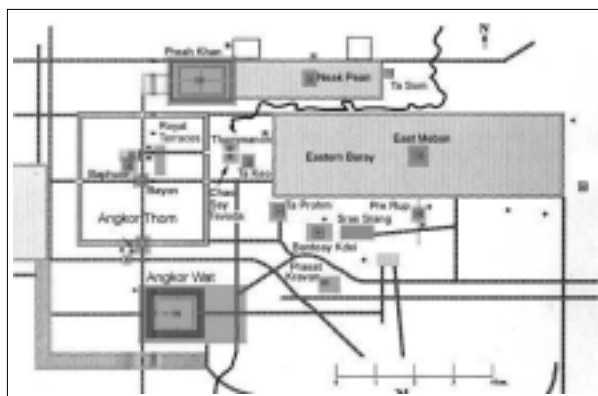


Figure 1. Plan of Angkor, the largest religious temple complex in the world showing the location of Neak Pean at the top.

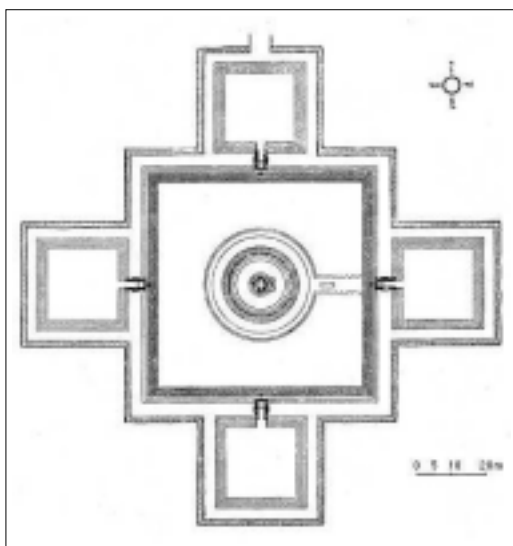


Figure 2. Plan of the Temple Neak Pean showing the central island and the four small lakes symbolizing the Four Elements: water, air, earth, and fire.

The fact that water, earth, air, and fire are the essential religious components of the temple recalls to the historians of chemistry the Theory of Four Elements, usually attributed to Aristotle (384-322 B.C.). In exploring this theory a few years ago, this author came to the conclusion that it originated in Persia from Zoroaster (630-553 B.C.), at least two centuries before Aristotle (4). According to Zoroaster air, water, earth, and fire are “sacred elements.” Humans and animals need air to breathe, water to drink, fire for cooking food, and earth for growing plants for their survival. Earth, air, and water are to be kept from defilement. To till the field and raise cattle are parts of one’s religious requirements. Rainwater, when it falls in abundance to irrigate the fields, is a blessing from God. When it is scarce, famine may result. Fire creates warmth and comfort



Figure 3. A view of the central island at temple Neak Pean showing the central sanctuary.

when the weather is cold, but when it burns uncontrolled it results in a catastrophe and loss of life.

The fact that Cambodian rulers were also familiar with these ideas suggests that the theory may have reached the Khmer kings from Persia via India by Buddhist monks who migrated to Cambodia to preach the new faith. Warder (5) mentions that, according to the Lokayata school in India which flourished during Buddha’s time (563-483 B.C.), the universe is composed of four elements: earth, water, air, and fire (6). All phenomena consist of combinations of these four. Further, when the Arabs conquered Persia in 636 A.D., they overthrew the religion of Zoroaster; and many of his followers escaped to Bombay, where they are known as the Parsees.

The theory of four elements was one of the most powerful in the history of science. It dominated the thought of scientists, philosophers, theologians, artists, poets, and others for about two thousand years. Although Robert Boyle in 1661 wrote a definition of an element in his *Sceptical Chymist*, yet a number of chemists continued to experiment with the four elements and propose theories about them (7). Studying Sanskrit texts with this in mind should be rewarding to historians of alchemy.

REFERENCES AND NOTES

1. D. Rooney, *Angkor. An Introduction to the Temples*, Odyssey Guides, Hong Kong 2002, 186-189.
2. A. J. Ihde, *The Development of Modern Chemistry*, Dover Publications, New York, 1984, 12.
3. J. R. Partington, *A Short History of Chemistry*, Macmillan, London, 1948, 21.
4. F. Habashi, “Zoroaster and the Theory of Four Elements,” *Bull. Hist. Chem.*, **2000**, 25, 109-115.
5. A. K. Warder, *Indian Buddhism*, Motilal Banarsidass Publishers, Delhi, 1980, 41, 115, 153, 308, 323.
6. In the text heat is mentioned instead of fire.
7. F. Habashi, *From Alchemy to Atomic Bombs*, Métallurgie Extractive Québec/Laval University Bookstore “Zone,” Québec City, 2002, 23-46.

ABOUT THE AUTHOR

Fathi Habashi is Professor Emeritus of extractive metallurgy at Université Laval, Faculté des Sciences et de Génie, Département de Génie de la Mines et Métallurgie et des Matériaux, Cité Universitaire, Québec City, G1K 7P4, CANADA.

THE HISTORY OF OZONE. IV. THE ISOLATION OF PURE OZONE AND DETERMINATION OF ITS PHYSICAL PROPERTIES (1)

Mordecai B. Rubin, Technion- Israel Institute of Technology

Introduction

Ozone is a devilish molecule, seemingly created specifically to validate the existence of the Law of Inanimate Malice (2). The procedures for its preparation give relatively low yields in admixture with the starting material, air, or oxygen. It is highly toxic even at very low concentrations and often violently explosive at high concentrations. It is thermally unstable, decomposing at a measurable rate at room temperature, and also extremely reactive. Its reactions include oxidation of many metals (including mercury) and of many organic compounds (including rubber) often with extreme rapidity at temperatures at or below that of Dry ice. Thus it combines difficulty in preparation and handling with hazardous behavior, instability and toxicity. Historically, even such a simple task as lubrication of stopcocks presented a problem; sulfuric acid was used in many cases as a lubricant until ozone-resistant fluorocarbon greases were developed many years later.

In view of the difficulties, it is not surprising that 25 years elapsed from the discovery of ozone by C. F. Schönbein (3) in 1840 to the determination of its molecular formula by Soret in 1865 and confirmation in 1868 (4). In 1845 Schönbein commented (5) that the problem of determining ozone's constitution would be enormously simplified if sufficiently low temperature could be achieved to permit its isolation in the liquid or solid state. This report describes the subsequent achievement of that goal, isolation of pure liquid and solid ozone, and the determination of their physical properties. It

should be noted, however, that the simplifications hoped for by Schönbein were not necessarily forthcoming as will be shown. The results of spectroscopic investigations and the long struggle to establish the structure of the ozone molecule will be presented in a separate article.

Liquid Ozone

Thomas Andrews, the discoverer of critical pressure of gases, attempted (6) to liquefy ozone by cooling an ozone-oxygen mixture with dry ice, but the temperature was not sufficiently low. The first successful experiment of this type was reported in 1882 by Hautefille and Chappuis (7) by using Cailletet's apparatus after the successful development in 1877 of techniques for liquefying low-boiling gases by Cailletet and by Pictet. In 1880 Hautefille and Chappuis had succeeded in obtaining ozone as a blue gas (8) and then as a liquid mixed with solid carbon dioxide (9). The blue color of ozone prompted Chappuis to continue with a detailed study (10) of its absorption spectrum in the visible region but no work was reported at that time on other properties of ozone.

Five years later, Olszewski reported (11) that ozone could be condensed from a mixture with oxygen by cooling at atmospheric pressure with liquid oxygen (bp -183° C). He estimated the boiling point of ozone to be -106° C. Attempts to crystallize ozone by further cooling were not successful. Olszewski's paper also included the first report of an explosion with ozone. When ozone

came into contact with ethylene (both at very low temperature), a violent explosion occurred shattering the apparatus and pulverizing the glass. Perhaps because of this experience, no further work on liquid ozone was reported from the Cracow laboratory. Eleven years elapsed before the next report appeared when Troost (12), in 1898, obtained liquid ozone by condensation with liquid oxygen. He redetermined the boiling point using a calibrated iron-constantan thermocouple in the headspace of a tube containing liquid ozone undergoing free warming. His value for the boiling point was -119°C , 13° lower than that of Olszewski; the currently accepted value (see below) is halfway between the two. Troost also encountered the explosion problem, in this case an explosion when the thermocouple, previously cooled in liquid oxygen, was immersed in the liquid ozone itself. Five years later, Goldstein (13) described a simple apparatus for producing small quantities of liquid ozone. An evacuated quartz apparatus with a cold finger cooled in liquid air was filled with a few mm pressure of oxygen and subjected to an external discharge from an induction coil. Within seconds the tube became luminous and the pressure sank to about 0.1 mm Hg; small quantities of liquid could be obtained by repeated operation.

The explosion hazard has dogged workers interested in the properties of liquid ozone through the years. In 1956 Hughes (14) wrote: "To prevent a possible serious accident in case of an explosion, only a few hundredths of a gram were produced at one time. Fortunately, there were no explosions." A. Ladenburg (15) prepared about 5 ml of apparently pure liquid ozone for boiling point determination and wrote that it was not possible to find a recognizable piece of the apparatus after the violence of the explosion which occurred; he abandoned his attempts. E. Ladenburg and Lehmann (16) reported a considerable number of violent explosions in their work on ultraviolet-visible spectra of liquid ozone. Explosions have even been observed (17) with solidified ozone at liquid hydrogen temperature (-250°C). Most workers have employed the precautions described by Hughes (14), namely working with small amounts of ozone, whatever preparative method was employed. The reasons for the frequent explosions are unclear. Some workers have attributed them to impurities, particularly traces of organic compounds, in the apparatus used or in the oxygen taken as starting material for preparation of ozone. Further, it seems essential to avoid any sudden changes in physical state or environment, such as rapid changes of temperature, physical shock, and so on.

Typical of the problems involved in working with ozone, it was necessary to prevent appreciable amounts of ozone from reaching mechanical vacuum pumps, otherwise explosions occurred in the pumps. Tubes containing soda lime were sometimes used to protect various sections of apparatus from ozone; sulfuric acid manometers were used alone or coupled with mercury manometers. Karrer and Wulf (18) used a water aspirator as vacuum pump, and another group (19) used a trap packed with sections of glass tubing and heated to 450°C to decompose any ozone before it reached the pumping system. Riesenfeld and Schwab (20) commented in 1922: "By avoiding even the slightest traces of catalysts for ozone decomposition (ether, for example), rapid increases in pressure, or warming, we have so far never had an explosion of liquid ozone;" it might further be noted that very small amounts of pure ozone were collected in their work. This was echoed later by Jenkins (21) in a 1959 article devoted to the handling of liquid ozone, which should be required reading for anyone dealing with this treacherous substance.

Given the considerable difference (about 70°C) in boiling points between oxygen and ozone, the above-mentioned scientists assumed that the deep blue liquid that they obtained consisted of pure ozone, and none of them seem to have made any attempt to establish the validity of this assumption. In the event, it turned out to be severely incorrect, and pure ozone was not obtained until 1922, over 80 years after Schönbein's discovery and 40 years after ozone was first liquefied. Moeller's 1922 book (22) gives only the two boiling points mentioned above and values, determined on gas mixtures, for the heat of formation, solubility in water, and density of ozone.

The first serious study in which pure ozone was prepared and a number of its physical properties determined came from the laboratory of E. H. Riesenfeld (17, 20, 23, 24, 25, 26, 30) at the University of Berlin during the period 1922-26. Karrer and Wulf (18) also reported pure liquid ozone in 1922 but were dogged by frequent explosions at various stages of their procedure. For example, while the system could be evacuated with a mechanical vacuum pump in the absence of ozone, the presence of ozone caused explosions in the pump making it desirable to use a water aspirator for pumping, as mentioned above. The vacuum was supplemented by a large reservoir which was evacuated to a high vacuum, then closed off, and opened when it was desired to reduce the vacuum obtainable with the aspirator. Probably because of these difficulties, Karrer and Wulf determined

only the molecular weight by the vapor density method obtaining a value of 47.3 ± 0.8 while Riesenfeld and Schwab (23, 26) obtained the value 47.9 ± 1.4 . Both groups confirmed the results of earlier work done with ozone in low percent ozone-oxygen mixtures. Karrer and Wulf only returned to liquid ozone research five years later.

Riesenfeld, who had been an active investigator of various aspects of ozone chemistry for about ten years, introduced his 1922 work on pure, liquid ozone by explaining that the recent availability of micro methods

trolysis (this would attack the mercury manometer following). It was then passed through a drying apparatus (D) containing conc. sulfuric acid and phosphorus pentoxide. The rates of flow and pressure were measured with flowmeter E and manometer F. The pure, dry oxygen at a small positive pressure was passed through three Berthelot tubes (J), operating at 8000 V and 500 Hz, which produced 10-15% ozone in oxygen. Samples of gas could be collected for analysis from vessel K, and excess gas could be vented to the atmosphere through tube M, which was filled with soda lime to destroy ozone before it entered the laboratory environment. A two-

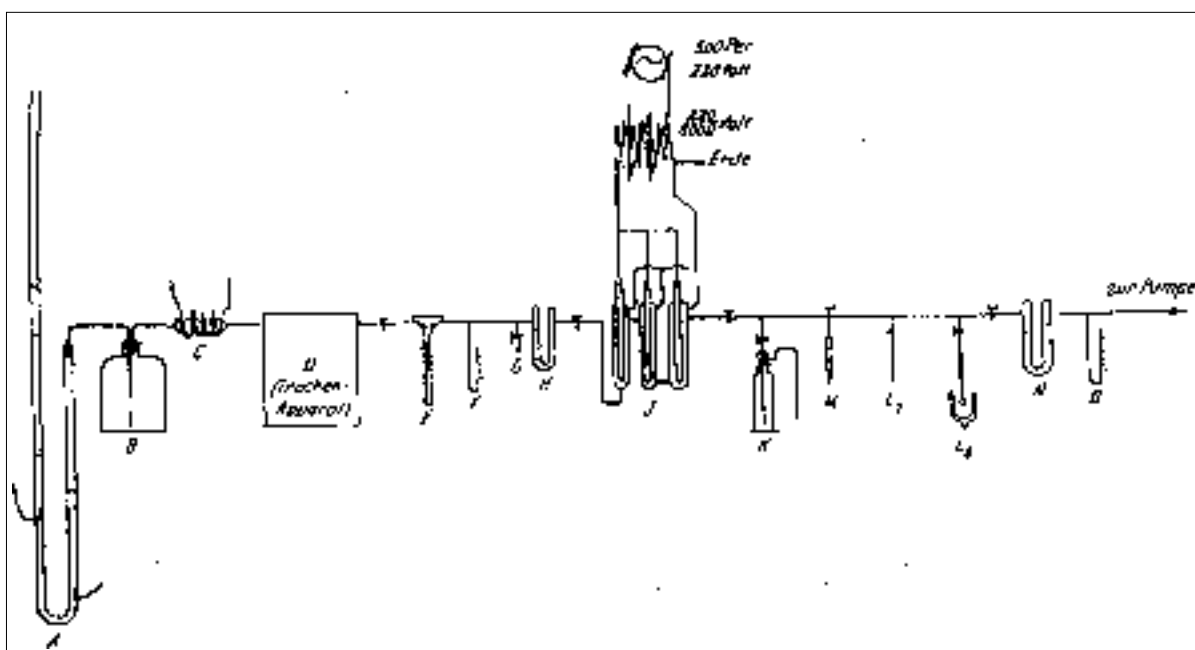


Figure. Apparatus for preparing pure ozone according to H. Riesenfeld and G. M. Schwab, *Ber.*, **1922**, 55, 2088-99; G.-M. Schwab, *Z. Phys. Chem.*, **1924**, 110, 599-625.

for determining physical constants of liquids made it feasible to investigate the behavior of pure ozone using very small amounts of substance thereby minimizing the hazards involved. A detailed description of the procedure used (24, 26) is instructive and illustrates the various precautions required because of ozone's devilish nature.

The diagram of the apparatus, reproduced from the original drawing (24), is shown in the Figure. It begins with electrolysis (A) of water to generate oxygen, which was collected in (B) and then passed through a heated tube (C, 300°C) to destroy any hydrogen or organic compounds present as well as any ozone formed in the elec-

phase, blue-colored system condensed when the gas mixture was passed into capillary tubes (L_1 - L_6) previously sealed at one end and cooled with liquid air. These were followed by U-tube N filled with soda lime to destroy ozone, thereby protecting the pumping system and the manometer (O). The part of the system containing the liquid ozone-oxygen mixture (M-O) could then be isolated, connected to the vacuum pump, and manipulated as desired.

Ladenburg had noted in 1898 (15) that the condensed liquid from cooling ozone-oxygen mixtures with liquid oxygen contained an appreciable amount of a lower boiling component (oxygen), but the observation of a two-phase system in the capillary tubes L_1 - L_6 was

Table. Physical Properties of Ozone

Property	Riesefeld Results (ref.)	Handbook Chemistry & Physics (orig. ref.)
Melting Pt. (°C)	-251 (a, b, c, d)	-194 ± 0.5 (f)
Boiling Pt. (°C)	-112.3 (a, b, d, f)	-111.9 (g)
Critical Temp (°C)	-5 (c,d,f); -10 (a, b)	-12 (g)
Crit. Pressure (atm)	65 (a), 67(c)	54/6 (g)
Crit. Density, (g/ml)	0.537 (a, c, d)	
(cc gas/mol)	89.4	
Liquid Density(-183° C (g/ml))	1.71 (a, d, h)	1.571 (i)
Crit Temp (°C); liquid O ₂ -O ₃ mixture	-158 (b, d)	-180 (j, k)
Heat of Vaporization (cal/mol)	0 K: 3500 (d); -112° C: 2547 (d)	

References: (a) Ref. 17; (b) Ref. 20; (c) Ref. 23; (d) Ref. 24; (e) Ref. 44; (f) Ref. 26; (g) A. C. Jenkins and C. M. Birdsall, "The Vapor Pressures and Critical Constants of Pure Ozone," *J. Chem. Phys.*, **1952**, 20, 1158-1161; h) C. Brown and K. D. Franson, "Manometric Determination of the Density of Liquid Ozone," *J. Chem. Phys.*, **1953**, 21, 917-919; (i) R. I. Brabets and J. M. McDonough, "Density of Liquid Ozone," *J. Chem. Phys.*, **1957**, 27, 880-882; (j) C. K Hersh, A. W. Berger, and J. R. C. Brown, "Physical Properties of Liquid Ozone-oxygen Mixtures: Density, Viscosity, and Surface Tension," *Advances in Chemistry Series*, No. 21, American Chemical Society, Washington, DC, 1959, 22-27; (k) A. C. Jenkins, F. S. DiPaolo, and C. M. Birdsall, "The System Ozone-oxygen," *J. Chem. Phys.*, **1955**, 23, 2049-2054.

unexpected. This was shown in the Riesefeld work to be due to the formation (23) of two immiscible layers with the lower layer consisting of 30% oxygen dissolved in ozone and the upper layer of 30% ozone dissolved in oxygen. The composition varied with temperature; the critical temperature for this two-phase phenomenon was shown to be -158° C. Brown, Hersh, and Berger (19) confirmed these results in 1955 but obtained a value of -180° C for the critical temperature. When a vacuum was applied to the two-phase system cooled in liquid air, the volume decreased and eventually a single phase was observed accompanied by a decrease in pressure to less than 1 mm mercury. The tubes L₁-L₆, each containing a few drops of deep blue liquid, could then be sealed off and used for subsequent measurement. This blue residue, presumed to be pure ozone, was analyzed by collecting a small volume in a bulb cooled in liquid air which was then sealed and transferred to a second apparatus where it was broken under a 2-5% potassium iodide solution buffered with boric acid. The volume of oxygen produced was measured and the aqueous solution titrated with sodium thiosulfate. These measurements indicated that the blue liquid consisted of approximately 95% ozone, the 5% discrepancy being attributed to thermal decomposition of ozone and errors introduced by the manipulations involved.

The Riesefeld group reported the boiling point, liquid density at various pressures, critical pressure, heat of vaporization of liquid ozone, and the melting point of the solid (see below). Their values are listed in the Table together with the values given in recent editions (27) of the *Handbook of Chemistry and Physics*. Most of these were taken from summary articles by Streng (28) and by Hersh (29). An examination of the table shows that, with the exception of the boiling point, the micro techniques of the 1920s left something to be desired so far as accuracy of measurement was concerned.

Beja (25) determined the vapor pressure over the temperature range -108.5 to -169° C in 1923 and Spangenberg (30) extended these measurements to -183° C in 1926. Temperature control in these experiments employed a mercury block cooled by hydrogen gas; the block temperature was measured with a platinum resistance thermometer and taken to be the temperature of the liquid. Spangenberg obtained the following expression (30) for the vapor pressure of ozone as a function of temperature (T/K):

$$\log p \text{ (mm)} = -809.5/T + 1.75 \times \log T - 0.01116 \times T + 5.850$$

Incidental to the work of the Riesenfeld group was the conclusion (23, 24) that no significant amount of a heavier allotrope of oxygen, such as Harries' oxozone (O_4 , MW 64, see Ref. 1) was present in the product from action of silent discharge on oxygen. According to Harries, ozone generated by silent discharge contained about 30% of oxozone. Such a product would have been expected to have a significantly higher boiling point than O_3 and would vary considerably in other properties as well, but no variations in properties were observed as a function of the extent of distillation. Further support for the absence of oxozone derived from the reproducibility of the physical constants obtained by different workers. Briner and Biederman (31) reached the same conclusion ten years later using samples of ozone obtained by silent discharge at various frequencies.

Condensation of ozone-oxygen mixtures from silent discharge, using liquid air or liquid oxygen as coolant, became a standard procedure for obtaining liquid mixtures in later years. Pure ozone was then obtained by pumping on the liquid oxygen cooled ozone-oxygen mixture until a very low pressure was achieved; more careful investigators used trap-to-trap distillation and pumping. In many cases (21, 32) it was assumed, on the basis of vapor pressure measurements alone, that the product was pure ozone without confirming this by any analytical procedure. Magnetic susceptibility (see below) was a very sensitive criterion of purity. The values for a considerable number of properties of ozone were determined and can be found in the standard reference sources mentioned earlier. These values have remained unchanged for several decades. Thermodynamic properties were determined in large part from spectroscopic measurements.

Two properties, the dipole moment and the magnetic susceptibility of ozone, are of special interest. The dipole moment, which was very important in the long debate on the structure of the ozone molecule, was first reported in 1939 by Lewis and Smyth (33), who used conventional methods on the liquid ozone-oxygen mixture obtained from condensation of the product of silent discharge with liquid oxygen. They obtained a value of 0.49 D, ruling out linear and symmetrical triangular structures for ozone. Trambarulo and co-workers (34) obtained a similar value (0.53 ± 0.02 D) using spectroscopic data.

The unusual magnetic properties of dioxygen prompted investigations of this property of ozone as early as 1881. In that year both Becquerel (35) and

Schumeister (36) reported investigations of the mixture of ozone and oxygen gases produced by silent discharge on oxygen. They were unable to obtain reliable numerical values but both reported that ozone had a specific paramagnetism approximately three times that of oxygen! This surprising result lay dormant in the literature for over 45 years until 1927 when Wulf (37) reported results which led him to conclude that "the numerical value of the volume susceptibility of ozone is but a small fraction of that of oxygen" and suggested that ozone might even be diamagnetic. Vaidyanathan (38) reached the same conclusion one year later. These observations led to further investigations on liquid ozone and ozone-oxygen mixtures at low temperatures by Lainé (39) in 1933 and 1934. He concluded that the specific susceptibility of liquid ozone at temperatures in the region of liquid air was approximately $+1.5 \times 10^{-7}$ compared to a value of $+2406 \times 10^{-7}$ for oxygen under similar conditions. The large difference allowed the determination of very small concentrations of oxygen in ozone and permitted Lainé to establish that a sample of liquid ozone kept at liquid air temperature for 10 hours had changed by less than 1/50,000 in oxygen. Lainé's results were accepted by Brown, Hersh, and Berger (27), who determined the magnetic susceptibility of ozone-oxygen mixtures using an Alnico magnet cooled in liquid oxygen or liquid nitrogen.

It should also be noted that a 1953 report (40) that a maximum temperature, -105°C , occurs at about 80 % ozone concentration in the temperature-composition diagram for ozone-oxygen mixtures, could not be reproduced. The incorrect reported maximum was attributed (41) to improper design of the measuring apparatus.

Liquid ozone acquired special interest as a possible replacement, wholly or in part, for the liquid oxygen used in rocket engines since such replacement would increase the amount of energy available per unit weight. This interest made funding available for the spurt of activity in research on liquid ozone during the 1950s and early 1960s. It was also responsible for the appearance of a considerable number of patents on the dubious attractions of a variety of stabilizers for liquid ozone. To the best of our knowledge, no practical application has been made of any of these stabilizers.

Solid Ozone

The first report of pure, solid ozone also came from the Riesenfeld laboratory in 1922. Schwab (24, 26) de-

scribed *very gradual* cooling of liquid ozone by slow immersion in a liquid hydrogen (-253° C) bath and obtained a blue-black crystalline mass. Time-temperature curves on slow warming, measured in two experiments with a thermocouple in the solid, gave plateaus at 22.4 and 21.2 K which were inferred to be due to melting; the average value was 21.8 K (-251° C). The explosion hazard was also present in this and other work with solid ozone despite the extremely low temperatures involved. Both Schwab and Streng and Gross in 1959 (42) encountered violent explosions upon rapid cooling of liquid ozone, thus demonstrating once again the sensitivity of ozone to any drastic change in physical surroundings. Research on solid ozone has been very limited, perhaps because of the extreme hazards involved in preparing and working with this substance.

Probably the most striking result in solid ozone research was reported by Marx and Ibberson (43) in 2001. Condensation of gaseous ozone at 10-20 K gave solid ozone, which was used for X-ray and neutron powder diffraction analysis. The solid had a bent structure with an O-O-O angle of 117.9°, in good agreement with the gas phase structure! Measurement of the unit cell dimensions over the range 5-54 K provided no evidence for a phase transition, which might explain the discrepancy between the currently accepted melting point of -193° C and Schwab's earlier value of -251° C; the latter was probably an artifact of the measuring technique.

This value, mp -251° C, remained unchallenged for over 30 years. Many reports described use of liquid nitrogen (bp -196° C,) to condense *liquid* ozone from ozone-oxygen mixtures. However, during this period, a number of investigators (42, 44, 45) encountered solid material under these conditions. In 1954 Brown, Berger, and Hersh (44) reported a solid in some of their experiments when distilling ozone into a liquid nitrogen cooled U-tube for manometric measurements. The smooth flow of the condensing liquid halted and application of helium pressure (up to 1 atm) had no effect. Slow immersion of liquid ozone into nitrogen at its triple point (-210° C) invariably led to the formation of a solid which was stable indefinitely at the temperature of liquid nitrogen. "Color photographs and visual observation strongly suggested a crystalline material." Warming the liquid nitrogen bath at a rate of 0.06 °C/min by slow addition of liquid oxygen resulted in melting beginning at -193.4° C which was complete at -192.5° C (average value -193° C). It is clear that liquid ozone readily supercools since numerous measurements have been made on liquid ozone at liquid nitrogen temperature (-196°

C). The formation of a supercooled liquid or an amorphous form of solid ozone was also observed by Hanson and Mauersberger upon condensation of ozone at liquid nitrogen temperature; this was converted to a crystalline form upon cooling to about -203° C.

In 1959 Streng and Grosse went on to determine the density of the solid using the known densities of the liquid at various temperatures for calibration. They measured the height of columns of solid ozone at various temperatures and calculated the free space by measuring the amount of nitrogen that could be added. Molar volumes were 27.8 for the solid and 29.75 cm³ for the liquid, giving a value of +7.1% for the volume expansion on melting.

Hanson and Mauersberger (45), who had determined the vapor pressure of liquid ozone at temperatures in the region of liquid argon, used the same technique to determine the vapor pressures of the two solid forms of ozone. The unique feature of their 1986 method was connection of the vapor pressure apparatus to a mass spectrometer to determine the percent of oxygen present in the vapor section. This allowed correction for thermal decomposition of ozone (or any other source of oxygen) during the course of the measurement. They obtained the following linear relationship between pressure and the reciprocal of temperature (T/K) for the crystalline form of ozone:

$$P(\text{torr}) = 10.460 - 1021.6/T$$

For example, the vapor pressure of ozone at -205° C (68 K) is 1×10^{-5} mm, from which the latent heat of sublimation was calculated to be 97.4 cal/g.

Broida et al (46) suggested that ozone is trapped as the solid in the polar caps of Mars.

Summary

The isolation of pure ozone and the investigation of its properties turned out to be a hazardous endeavor requiring great care from the investigator. Over 80 years elapsed between C. F. Schönbein's discovery of ozone in 1840 and the isolation of pure liquid ozone. While it might have been thought that having the pure substance in hand would simplify research, the difficulties involved in obtaining and handling the pure substance were substantial. Only by avoiding impurities, working with small quantities of substance, and minimizing changes in physical state was it possible to handle ozone with a reasonable degree of safety. Interest in the use of ozone

to wholly or partially replace liquid oxygen as a rocket fuel prompted considerable research on liquid ozone and liquid ozone-oxygen mixtures in the period after World War II, but the hazards of liquid ozone appear to have defeated this.

ACKNOWLEDGMENT

Thanks are due to colleagues and librarians for invaluable assistance in the literature searches involved in preparation of this article. These include Professor R. Gleiter (Heidelberg) and librarians Ms. V. Mitchell, Ms. A. Zeidman-Karpinski, and Mr. J. Jablonski (Eugene), Ms. H. Ilovich and Ms. E. Raskin (Haifa). We also thank the Department of Chemistry, University of Oregon, Eugene, for a visiting appointment.

REFERENCES AND NOTES

- For the previous reference in this series see M. B. Rubin, "The History of Ozone. Part III. C. D. Harries and the Introduction of Ozone into Organic Chemistry," *Helv. Chim. Acta*, **2003**, *86*, 930-940.
- M. B. Rubin, "The Law of Inanimate Malice," *Chem. Intell.*, **1995**, 45.
- M. B. Rubin, "The History of Ozone. The Schönbein Period, 1839-1868," *Bull. Hist. Chem.*, **2001**, *26*, 40-56.
- J.-L. Soret, "Recherches sur la densité de l'ozone," *C. R. Séances Acad. Sci., Ser. C*, **1865**, *61*, 941; *Ann. Chim. Phys.*, [4] **1868**, *13*, 257-281.
- C. F. Schönbein, *Archives de l'électricité. Supp. a la Bibliotheque Universelle de Geneve* **1845**, *V*, 11 "Quant a isoler l'ozone, il n'est peut-etre pas possible d'y reussir a l'aide des procedes que nous offre la chimie, vu la grande facilite avec laquelle ce corps se decompose. Si l'ozone devenait liquide ou solide a un degre de froid accessible a nos procedes physiques, on pourrait esperer de l'isoler, en faisant passer une grande quantite d'air tres-ozonise dans des tubes de verre entoures d'un melange frigorifique."
- T. Andrews and P.-G. Tait, "On the Volumetric Relations of Ozone, and the Action of the Electrical Discharge on Oxygen and other Gases," *Philos. Trans. R. Soc. London*, **1860**, *150*, 113-131. See also *Quart. J. Chem. Soc. London*, **1860**, *13*, 344-367; *Ann. Chim. Phys.* [3], **1861**, *62*, 101. For preliminary reports: "Note on the Density of Ozone," *Proc. R. Soc. London*, **1857**, *8*, 498; *Gazz. Chim. Ital.*, **1857**, *319*; *Ann. Chem. Pharm.*, **1857**, *104*, 128.
- P. Hautefille and J. Chappuis, "Sur la liquéfaction de l'ozone," *C. R. Séances Acad. Sci., Ser. C*, **1882**, *94*, 1249-1251.
- P. Hautefille and J. Chappuis, "Sur la liquéfaction de l'ozone et sur la couleur à l'état gazeux," *C. R. Séances Acad. Sci., Ser. C*, **1880**, *91*, 522-525; *Ber. Dtsch. Chem. Ges.*, **1880**, *13*, 2408.
- P. Hautefille and J. Chappuis, "Sur la liquéfaction de l'ozone en présence de l'acide carbonique et sur sa couleur à l'état liquide," *C. R. Séances Acad. Sci., Ser. C*, **1880**, *91*, 815-817.
- J. Chappuis, "Sur le spectre d'absorption de l'ozone," *C. R. Séances Acad. Sci., Ser. C*, **1880**, *91*, 985-986. J. Chappuis, "Étude spectroscopique sur l'ozone," *Ann. sci. de l'école norm. sup.* [2], **1882**, *11*, 137-186.
- K. Olszewski, "Bestimmung des Siedepunktes des Ozons und der Erstarrungstemperatur des Áthylens," *Monatsh. Chem.*, **1887**, *8*, 69-72. Also a summary in *Ber. Dtsch. Chem. Ges.*, **1887**, *20*, 69.
- L. Troost, "Sur la température d'ébullition de l'ozone liquide", *C. R. Séances Acad. Sci., Ser. C*, **1898**, *126*, 1751-1753.
- E. Goldstein, "Ueber Ozonbildung," *Ber. Dtsch. Chem. Ges.*, **1903**, *36*, 3042-3046.
- R. M. Hughes, "Structure of Ozone from the Microwave Spectrum between 9000 and 45,000 Mc," *J. Chem. Phys.*, **1956**, *24*, 131-138.
- Ladenburg, "Ueber das Ozon," *Ber. Dtsch. Chem. Ges.*, **1898**, *31*, 2508-2513.
- E. Ladenburg and E. Lehmann, "Über Versuche mit hochprozentigem Ozon," *Ann. Phys.*, [4], **1906**, *21*, 305-318.
- E. H. Riesenfeld, "Über das Verhalten des Ozons," *Z. Elektrochem.*, **1923**, *29*, 119-121.
- S. Karrer and O. R. Wulf, "Preparation of Pure Ozone and Determination of its Molecular Weight," *J. Am. Chem. Soc.*, **1922**, *44*, 2391-2397.
- C. Brown, C. K. Hersh, and A. W. Berger, "Magnetic Susceptibility of Liquid Ozone-Oxygen Mixtures," *J. Chem. Phys.*, **1955**, *23*, 103-108.
- E. H. Riesenfeld and G. M. Schwab, "Über Ozon," *Naturwissenschaften*, **1922**, *10*, 470-471.
- A. C. Jenkins, *Laboratory Techniques for Handling High-concentration Liquid Ozone*, *Advances in Chemistry Series*, American Chemical Society, Washington, DC, 1959, Vol. 21, 13-21.
- M. Möeller, *Das Ozone. Eine Physikalisch-chemische Einzeldarstellung*, Vieweg u. Sohn, Braunschweig, 1921, 149.
- E. H. Riesenfeld, and G.-M. Schwab, "Die physikalischen Konstanten des Ozons," *Z. Physik*, **1922**, *11*, 12-21.
- E. H. Riesenfeld, and G. M. Schwab, "Über Ozon," *Ber. Dtsch. Chem. Ges.*, **1922**, *55*, 2088-2099.
- E. H. Riesenfeld and M. Beja, "Dampfdruckmessungen an Reinem Ozon," *Z. Anorg. Allg. Chem.*, **1923**, *132*, 179-200.
- G.-M. Schwab, "Über Ozon," *Z. Phys.. Chem. (Leipzig)*, **1924**, *110*, 599-625; from dissertation of Schwab, Berlin, 1923.

27. *Handbook of Chemistry and Physics*, published annually by CRC Press, Boca Raton, FL, London, New York. Until recent editions, the values of physical constants for ozone were collected together on a single page and did not change for many decades of the handbook.
28. A. G. Streng, "Tables of Ozone Properties," *J. Chem. Eng. Data*, **1961**, 6, 431-436.
29. C. K. Hersh, "Production and Properties of Liquid Ozone and Liquid Ozone-oxygen Mixtures, A Review," *Prog. Astronaut Rocketry*, **1960**, 2, 427-444.
30. A. L. Spangenberg, *Z. Phys. Chem. (Leipzig)*, **1926**, 119, 419-438.
31. E. Briner and H. Biedermann, "Sur l'identité des propriétés de l'ozone produit par divers modes d'effluation de l'oxygène: point d'ébullition de l'ozone pur," *Helv. Chim. Acta*, **1933**, 16, 207-213.
32. Ref. 21. Jenkins states that, on a sulfuric acid manometer, dilution of pure ozone by 0.01 mole % of oxygen increases the vapor pressure from 0.1 to 6 mm of mercury.
33. G. L. Lewis and C. P. Smyth, "The Dipole Moments and Structures of Ozone, Silicobromoform and Dichlorogermane," *J. Am. Chem. Soc.*, **1939**, 61, 3063-3066.
34. R. Trambarulo, S. N. Ghosh, C. A. Burrus Jr., and W. Gordy, "The Molecular Structure, Dipole Moment, and g Factor of Ozone from its Microwave Spectrum," *J. Chem. Phys.*, **1953**, 21, 851-855.
35. H. Becquerel, "Recherches sur le magnétisme spécifique de l'ozone," *C. R. Séances Acad. Sci., Ser. C*, **1881**, 92, 348-350.
36. J. Schumeister, "Bestimmung Magnetischer und Diamagnetischer Constanten von Flüssigkeiten und Gasen in Absolutem Masse," *Sitz. Akad. Wiss. Wien II*, **1881**, 83, 45-62.
37. O. R. Wulf, "The Magnetic Behavior of Ozone," *Proc. Natl. Acad. Sci. U.S.A.*, **1927**, 13, 744-748.
38. V. I. Vaidyanathan, "Magnetic Susceptibility of Ozone," *Indian J. Phys.*, **1928**, 3, 151-163.
39. P. Lainé, "Sur les propriétés magnétiques de l'ozone liquide," *C. R. Séances Acad. Sci., Ser. C*, **1933**, 196, 910-13. P. Lainé, "Sur les propriétés magnétiques des mélanges d'ozone et d'oxygène liquides. Susceptibilité magnétique de l'ozone liquide pur," *C. R. Séances Acad. Sci., Ser. C*, **1934**, 198, 918-919.
40. H. J. Schumacher, "The Solubility Diagram and the Temperature-composition Diagram at Atmospheric Pressure of the Liquid System Ozone-oxygen," *J. Chem. Phys.*, **1953**, 21, 1610-1611; H. J. Schumacher, "El sistema ozono-oxígeno y su comportamiento a distintas presiones y temperaturas. IV. El diagrama de ebullicion de la mezcla de ozono y oxígeno a presión atmosférica," *Ann. Assoc. quim. Argentina*, **1953**, 41, 215-229.
41. A. C. Jenkins and C. M. Birdsall, "The Liquid System Ozone-oxygen," *J. Chem. Phys.*, **1954**, 22, 1779.
42. A. G. Streng and A. V. Grosse, "The Density of Solid Ozone," *J. Am. Chem. Soc.*, **1959**, 81, 805-806.
43. R. Marx and R. M. Ibberson, "Powder Diffraction Study on Solid Ozone," *Solid State Sci.*, **2001**, 3, 195-202.
44. C. Brown, A. W. Berger, and C. K. Hersh, "Solid Ozone," *J. Chem. Phys.*, **1954**, 22, 1151-1152.
45. D. Hanson and K. Mauersberger, "The Vapor Pressures of Solid and Liquid Ozone," *J. Chem. Phys.*, **1986**, 85, 4669-4672.
46. H. P. Broida, O. R. Lundell, H. I. Schiff, and R. D. Ketcheson. "Is Ozone Trapped in the Solid Carbon Dioxide Polar Cap of Mars?" *Science*, **1970**, 170, 1402.

ABOUT THE AUTHOR

Mordecai B. Rubin is Emeritus Professor of Chemistry in the Department of Chemistry, Technion-Israel Institute of Technology, Haifa, Israel 32000 (chrubin@tx.technion.ac.il). A major research interest for many years was organic photochemistry. He still teaches a one-semester course in the history of chemistry each year. Retirement is like a permanent sabbatical. As a young man, many years ago, he developed an apparatus for small-scale ozonolysis, which was dubbed the Rubin ozonator.

ACS MEETINGS - 2005

March 13-17, 2005—San Diego, CA

August 28-September 1, 2005—Washington, DC

**The American Chemical Society Division of History of Chemistry
Proudly Announces A New Award Program**

HIST Citations for Chemical Breakthroughs

The American Chemical Society Division of History of Chemistry recently and proudly announced the initiation of a new award program, the HIST Citations for Chemical Breakthroughs. Beginning in 2005, these Citations will recognize breakthrough publications and patents worldwide in the field of chemistry. Plaques, to be placed in the hallways outside the office or laboratory where the breakthroughs were achieved, will be presented annually to the departments and institutions at which these breakthroughs occurred.

Jeffrey Seeman, Chair-Elect of HIST, summarized that “we believe that identifying and celebrating chemical successes are important to the continued prosperity of chemistry worldwide. We envision that our colleagues and friends, seeing these plaques, will feel pride and inspiration in being a contributor to the sciences.” The selection process will involve open solicitation of nominations from the chemical community. An awards committee comprised of eminent scientists and historians of science will provide careful screening of the nominees and selection of each year’s awardees. More details will be available within the next few months.

The HIST Executive Board formed a subcommittee, consisting of Seeman, Roger Egolf, and Mary Virginia Orna. Carmen Giunta subsequently volunteered to join this subcommittee.

HIST recognizes and appreciates that the initial pool of deserving awardees is enormous. In the first few years of this program, only a small percentage of the most deserving recipients can be honored. However, multiple awards will be given each year.

Seeman also commented that “It is critical that HIST partners with other organizations that are themselves committed to preserving, studying and celebrating the history of chemistry.” To that end, HIST is pleased to report that all individuals invited to be a member of the awards committee have accepted: Arnold Thackray, President of the Chemical Heritage Foundation, Judah Ginsberg of the ACS National Historic Landmarks Program, Eugene Garfield, eminent information scientist, Margaret Cavanaugh, Chair of the ACS Committee on Science and National Science Foundation, and the eminent scientists Harry Grey (Caltech) and Amos Smith (University of Pennsylvania). HIST also hopes that many of its members along with ACS Local Sections will be closely involved in the actual award ceremonies. HIST is pleased to have already begun a relationship with Dale Gaddy, Manager of the ACS Office of Local Section Activities.

Citations for Chemical Breakthroughs now joins HIST’s Edelstein Award and its predecessor, the Dexter Award, presented annually since 1956. These latter two awards honor individuals having outstanding achievements in the history of chemistry. Annually, HIST also awards the Outstanding Paper Award, to recognize and encourage outstanding scholarship in the history of chemistry.

HIST intends to enlist ACS Local Sections, HIST Division members, and for international recipients, sister chemical and history organizations to participate in the awards ceremonies. For additional information, contact Dr. Seeman at HIST_CCB@yahoo.com.

BOOK REVIEWS

The Pharmaceutical Industry: A Guide to Historical Records. L. Richmond, J. Stevenson, and A. Turton, Ed., Ashgate, Aldershot, England, 2003; ix + 561 pp, ISBN 0-754-63352-7, \$99.95.

This Guide is one in a series of studies drawn from British business archives. It is based on a survey of various public and private records around the United Kingdom and was funded by The Wellcome Trust. It is obvious that a great deal of painstaking trawling through the identified sources took place in order to assemble such a wealth of detail. The Guide opens with three historical surveys: the first is an excellent review of the early development of the industry during the eighteenth and much of the nineteenth centuries, when it was based in retail pharmacy. The other two surveys—one on industrial developments since 1851, and one an overview of archival sources—are less inclusive.

The first two historical surveys include appropriate bibliographies. However, it is not correct that “in the inter-war period, legislation required that a qualified pharmacist should be in charge of the manufacturing and other departments in a business.” Other professional qualifications were acceptable and indeed were more usual. Today, a high proportion of Qualified Persons are corporate members of the Royal Society of Chemistry. The surveys are followed by a useful chronology of pharmaceutical legislation (though it was the 1941 Pharmacy & Medicines Act that relaxed the regulations on the sale of agricultural and horticultural poisons, not the 1933 Pharmacy & Poisons Act).

There follow a select bibliography, a user’s guide, and a glossary, leading into the main section of the book. In the glossary, the definition given for “patent medicine” has not applied for some time. Going back, say, some 70 years, medicines not declaring their compositions on the labels were subjected to a special excise tax, and a paper tax label had to be applied across the closure to show payment of this. Needless to say, most companies eventually decided to reveal at least the active ingredients in order to avoid liability to this tax and redesigned their labels accordingly. Today, of course, this labelling declaration is mandatory. Again, there is an implication under “surgeon” that medical practitioners in the UK are required to hold an M.D. In fact in the UK this is a post-qualification degree, based on research of appropriate standard, and is achieved by a small proportion of practitioners. The way to professional advancement is instead by the examinations of the relevant Royal Colleges that set and maintain high standards of professional achievement.

The main body of the Guide deals with the records actually found for pharmaceutical businesses, almost all in England. The criterion for selection appears to be merely the existence of historical records: businesses with just one pharmacy and no apparent other activity are intermingled alphabetically with internationally known companies. The rationale of mixing businesses of such diverse size and range of activities is not stated. Presumably detailed sub-classifications would be difficult because there is such an enormous variation and overlap in the volumes of manufacturing or wholesal-

ing activity. On the other hand, the listing of minor collections of records in Appendix 1 could be more logical. Generally it is on a county basis, but some archives, particularly in Lancashire and Yorkshire, are listed by town or city, making it less convenient to determine where a particular record might be located.

The biggest weakness in the present edition is in the poor quality and paucity of information given for multi-national companies operating in the UK, particularly those whose headquarters are not in the UK. A number of archival references are really only secondary sources, such as general review articles by technical journalists. These give a flavor of the company and its background, but too often the underlying interviews were obviously with local junior staff who might not have been aware of the full background of the company and who would not have had access to actual historical records. So the story that comes across may instead be based on what is thought to be the traditional oral history of the company and in some cases is quite inaccurate or indeed misleading—a very close parallel with genealogical research!

Mergers, acquisitions, and disposals within this industry—and indeed in other industries—seem to be proceeding apace these days, even though it is questionable whether they do in fact yield an overall benefit. So any status report is necessarily out of date as soon as the ms. goes to the printer. It would have been a Herculean task to update the text repeatedly even to this stage. Thus the account of Glaxo in the main text finishes with the merger to form GlaxoWellcome in 1995, though one of the historical surveys does refer to the subsequent formation of GlaxoSmithKline early in 2000.

One of the biggest industry mergers of all time was the formation of Drug Inc in the USA in 1928, bringing together the interests of United Drug and Sterling Drug. The Guide does not mention this in the histories of any of the companies affected, though it does record that Jesse Boot sold his company (Boots Pure Drug Co. Ltd.) to United Drug in 1920. Among other companies operating in the UK at that time that were also controlled by Drug Inc were: Bristol-Myers (then part of United Drug) and Bayer Products Ltd., Chas. H. Phillips Chemical Co. Ltd., Proprietary Agencies Ltd., and Scott & Turner Ltd. (all part of Sterling Drug). Commercially, Drug Inc. was highly successful, despite the Depression, but in 1933 it was broken up on a voluntary basis and—as recorded in the Guide—the Boots shares were bought back and Boots was again a freestanding company.

There are some notable absentees. Roche Products (part of Hoffmann-La Roche, referred to *en passant* in one of the surveys) are not mentioned and a review of their archives (were they available) would surely have shown their acquisition of Nicholas Laboratories. The latter were best known for their marketing of Aspro, developed by them in Australia to meet World War I needs; it was the leading branded aspirin over-the-counter preparation in the UK for many years but was finally discontinued in 1997. Again, Amersham are not listed; their range of diagnostic and treatment products was expanded into high volume usage areas by their merger with Nycomed of Norway in 1997. In fact a Compendium of Data Sheets published by the Association of the British Pharmaceutical Industry around the time that this Guide was being prepared lists 133 companies, plus eight that are cross-referenced to associates or principals. However only 40 appear in the Guide, suggesting that appropriate records were not flagged for the balance. Again, some well-known companies such as E. Merck (Germany) and Merck, Sharp and Dohme (USA) appear only by passing mention in one of the surveys.

Over the past four years alone, the major pharmaceutical companies have reported almost 1500 working relationships with small specialised research concerns—joint research programs, partnerships, and collaborative consortia. There do not appear to be any references to this kind of arrangement, perhaps because it has developed only during the last decade or so; but more likely because the specialist companies are not likely to appear in any archives other than their own, and usually they do not have direct sales.

The final sections list the various geographical archives (“minor collections”) and the various public record collections. There are also full indexes by name, geographical location, subjects, and archives.

There are a number of misprints, some due to the evident unfamiliarity of the editors or the proofreaders with trade and brand names in the pharmaceutical industry. “Procter” (in Procter & Gamble) is misspelled, but this frequently happens; “Sterling” appears also as “Stirling” and both forms are indexed; Paludrine is also misspelled on one occasion, as is “Westminster” in the name of the eponymous university in the Foreword. There are also some incorrect attributions of products, particularly where they are assigned to contract manufacturers and packers.

The Guide has its limitations. For example, the current pace of mergers and acquisitions is such that companies mentioned in it may now be operating under quite different names, eg, there is no mention of Novartis, formed by the merger of Ciba-Geigy and Sandoz in 1996 (and they themselves are mentioned only in passing in one of the surveys). Some of the secondary references are unreliable. So any data culled from the Guide should

be carefully crosschecked with their primary sources. Nevertheless, it is a useful starting point for information on the British pharmaceutical industry and so is a suitable addition to the specialist reference library. *John R. Gwilt, Northampton NN7 2NT, England*

The Last Sorcerers. The Path From Alchemy to the Periodic Table. Richard Morris, Joseph Henry Press, Washington, DC, 2003, xi + 282 pp., ISBN 0-309-08905-0, \$24.95.

This is history of science as a pearl necklace, with individual biographies being strung together. The hidden assumption is that brilliance can be transferred from life to writing. Somehow, magically, portrayal of remarkable people becomes infused with their originality. We all know how mistaken this can be.

Let me submit as an example the seven pages Morris devotes to Joseph Priestley, who comes across as the epitome of the self-made man. His story reads like an outline for a television episode, very American, even very simplistic. Simplistic? Morris did away with all the elements in Priestley's life that did not jibe with his caricatural view of Priestley as arch-individualist, radical thinker and, yes, something of a crazy genius. This is a travesty of the historical truth. Priestley was not such a cardboard cutout, far from it. What about, for instance, the Lunar Society of which he was a member, jointly with Erasmus Darwin, Josiah Wedgwood, Mathew Boulton, James Keir, and James Watt? Surely, their emulation had something to do with their numerous achievements, such as Priestley's devising of soda water, and of the rubber eraser, Keir's arranging the mass production of soap, and their collective campaign against slavery. There was fascinating group dynamics. Morris does not offer a single word on this.

Chapter 7 exemplifies the author's flippancy. Entitled "The Atom," it consists exclusively of a capsule biography of John Dalton. Its major tenet, viz., "When Dalton propounded his theory, chemistry was not yet a quantitative science" (p 130), makes light of one of Lavoisier's major inputs. We are told of Dalton's involvement as a Quaker in teaching; of his meeting John Gough; of his becoming a run-of-the-mill natural historian; of his being appointed to New College, Manchester; of his reading a paper on color blindness; of Dalton's experiments in pneumatic chemistry; of his cryptic announcement of atomic theory five years prior to formal publication; and of the public recognition which came to him in later years. Did atomic theory come to Dalton by divine visitation? There is not a word here on atomism during the seventeenth and eighteenth centuries; there is no mention of the problems Dalton's atomic theory strove to solve, nor any discussion whatsoever of the epistemic status of theory versus the empirical evidence at the beginning of the nineteenth century. The fascinating 1803-1808 lag time, which anticipates Darwin's own trepidation in coming out with the theory of evolution, is only mentioned in passing.

I can just hear the retort, "You should not take this book so seriously; after all it is only a popularization. What you are asked for is to evaluate its quality as light reading. Should it not, for instance, be recommended to students as additional reading?" I contend that students find such books boring and devoid of interest. How can they identify with any of the loonies in such a gal-

lery—Joseph Priestley, who preached a strange religion; John Dalton who never knew how to consort with females; Berzelius “living in a room that was also a store-room for potatoes” (p 145); Cannizzaro who “heard that rebellion had again broken out in Sicily. He traveled there to participate but ... he arrived too late. The ‘red shirts’ led by Guiseppe (sic) Garibaldi had already freed Sicily. It was at about this time that Cannizzaro received an invitation to attend the conference at Karlsruhe. Because there was no revolution to become involved in, he accepted at once.” (p 152). “(Mendeleev) looked more like a Siberian shaman than a distinguished chemist.” (p 158). “Einstein ... expressed the opinion that if such a crazy theory (Bohr’s) proved to be correct, then physics would be at an end; it would no longer be possible to do physics.” (p 187).

This is not the way to treat students. They need good, solid fare and there are two ways to go about it. One is to encourage them to research issues in science history and write short personal essays on them; an example would be “A Short History of the Chemical Stockroom.” The other is for the instructor to serve as a guide and show the class, with all the needed depth, science in the making. It can be made as gripping as the narrative of a difficult, technical, and risky climb. No, to throw formulaic writing at students, replete with stereotypes, is not the right approach. How can it be? To wallow in conventional wisdom is totally counterproductive, since scientific thinking—any thinking for that matter—and any life worth living go against the grain—not along the smooth, easy, and well-traveled route.

A major criticism I will level against Morris’s book is its all-too-obvious ignorance of the status chemical science has now reached. Morris has not gone to the effort of finding out what chemists have been up to during the last half century. His perception of chemistry is hopelessly and totally out-of-date. He sees chemistry as exclusively analytical, with the mission of defining and isolating the elements from which matter is built. Not only is such a perception totally archaic, devoid of the major steps chemical science has taken since the 1950s; worse, it is a bore: how can it measure up, coming as it does after Primo Levi’s *The Periodic System*; or, to mention a more recent title, also vastly superior to the book under review, Oliver Sacks’s *Uncle Tungsten*, with the combined charms of the autobiography and of the author’s strong personality?

I have to inveigh against the title. True, it is consonant with those of the previous Morris books; however,

this time it is too much, too commercial, too demagogic. For a professional chemist in this day and age, being lumped together—even with honorable intentions and somewhat tongue-in-cheek—with witches and with the sorcerer’s apprentice does not fly. Such stereotypes only feed public chemophobia.

One of the distinctive marks of American culture is its anti-elitism. There is a widespread allergy to unusual words, smacking of a classical European education. As Lawrence Levine writes in his book, *Highbrow/Lowbrow. The Emergence of Cultural Hierarchy in America*, Harvard University Press, Cambridge, MA, 1990:

If there is a tragedy in this development, it is not only that millions of Americans were now separated from exposure to such creators as Shakespeare, Beethoven, and Verdi, whom they had enjoyed in various formats for much of the nineteenth century, but also that the rigid cultural categories, once they were in place, made it so difficult for so long for so many to understand the value and importance of the popular art forms that were all around them. Too many of those who considered themselves educated and cultured lost for a significant period—and many have still not regained—their ability to discriminate independently, to sort things out for themselves and understand that simply because a form of expressive culture was widely accessible and highly popular it was not therefore necessarily devoid of any redeeming value or artistic merit.

Such perceptive comments bear on current popular presentations of science to the general public, which are typically productions by for-profit-organizations, disseminated predominantly by the printed word and by television. They play to the perceived tastes of the readers or of the viewers. They cater to selfish concerns for one’s well-being, material comfort, and health. They turn science into a springboard for utopias, space operas. They regurgitate stereotyped accounts of human science and history. Popular presentations of this later, twentieth-century type, while drawing on the same distaste for intellectual-sounding language as their earlier counterparts, do not offer education to the public, only hedonistic time-killers.

As for books, “science” sections of bookshops in English language countries abound in short-lived titles covering not only an easy read, but also one totally unchallenging. The keyword here is the adverb “un-thinkingly.” The readership of such books, which sometimes turn into bestsellers, enjoys them, to some extent,

because they sell an illusion of effortless increased knowledge. Thinking has become a dirty word. It is a solitary vice in the Orwellian, Newspeak world in which these nonbooks are written.

This has given us popular science writing at its formulaic worst, of personality-mongering and of scene-setting. Those are legacies from Henry Luce's instructions to his stable of writers for Time magazine. Why take issue with such stereotypes? Because, no more than

appreciation of a painting by Vincent van Gogh is informed by the cutting-of-his-ear anecdote, can the throbbing pulse of science be perceived from such narratives. They dull the understanding. They are derivative and secondhand. They lack the familiarity that breeds admiration. They are ignorant, in the most crass sense. My main problem with such fast foods as *The Last Sorcerers* is that they kill the taste for gourmet fare. *Pierre Laszlo, P.O. Box 665, Pinehurst, NC 28370.*

Ernest Rutherford and the Explosion of Atoms. J. L. Heilbron, Oxford University Press, Oxford, 2003, 142 pp, ISBN 0-19-512378-6, \$27.50.

At the beginning of the 19th century, John Dalton proposed that the world was composed of atoms with specific weights. These atoms, he argued, would explain observations that elements reacted in specific weight ratios. Even though there was no direct evidence that such discrete particles actually existed, his theory was utilized throughout the 1800s. Using atoms as models, scientists developed theories of organic chemistry, stereochemistry, crystallography, ionic and covalent bonding, and electrochemistry. The few who maintained that atoms did not exist admitted that they nevertheless were useful models, and the scientific community generally accepted the fact that chemistry behaved as if atoms existed. But since no one had ever seen an atom, some scientists could still gainsay their existence, even into the twentieth century. Ernst Mach denied them to his death in 1916.

Ernest Rutherford entered the scientific scene just as radioactivity was discovered in 1896 by Henri Becquerel of Paris. Born in 1871, Rutherford was raised on a flax farm in New Zealand. After his education in New Zealand, Rutherford arrived at Cambridge University in 1895. His first research involved hertzian (radio) waves, but he then moved on to the study of ura-

nium rays with J. J. Thomson. In 1898 Rutherford took a post at McGill University, Montréal, Canada, while Marie and Pierre Curie in Paris were discovering polonium (1898) and radium (1899). This new phenomenon of radioactivity mystified the best minds, but Rutherford's brilliant mind and fertile imagination allowed him to view atoms not only as useful, but also as necessary, models to offer coherent explanations.

Ernest Rutherford did not doubt the existence of atoms for a moment. He was the first to recognize natural transmutation of elements; he saw that the atom had a structure; he correctly proposed a positive nucleus concentrated at the core of the atom; he induced artificial transmutation of elements; he proposed a neutral particle, later discovered; and his model allowed others to develop the quantum description of the atom and the modern arrangement of the periodic table. Scientists who would later become famous in their own right flocked to his laboratory for training and collaboration, such as Niels Bohr (who first described the quantized atom), Otto Hahn (who discovered atomic fission), Frederick Soddy (who invented the term "isotope"), Henry Moseley (who discovered atomic numbers from his X-ray research), Georg von Hevesy (who discovered hafnium), James Chadwick (who discovered the neutron), and Hans Geiger (famed for his eponymous counting device). Rutherford was a giant in his field and was mourned at his premature death at the age of 66

Ernest Rutherford and the Explosion of Atoms by J. L. Heilbron is a delightful little book that blends Rutherford's research with the moving backdrop of the scientific community. Rutherford was a pioneer not only because of his brilliance; the British method of modeling was perfect for the advance of nuclear chemistry at this particular moment in history. The British were fond of explicit descriptive models to explain nature. Lord Kelvin said he could not reason "without making a visualizable picture" of the phenomenon he wanted to describe. J. J. Thomson of the Cavendish Laboratory at Cambridge was using the idea of charged corpuscles to explain cathode rays, and he proposed the atom was a dynamic, moving mixture of positive and negative charges. Scientists on the continent, by contrast, were not impressed by this "picture making." The Curies, for example, considered the British method as "childish, arbitrary, and English." The German chemist Wilhelm Ostwald, who did not believe in atoms, thundered, "Thou shalt not take unto thee any graven image or any likeness of anything." The Curies thought Rutherford's premature model making ran the risk of leading to nonsense (which it actually did sometimes, such as Rutherford's 1920 proposed structure of the nuclei as a conglomeration of alpha particles). Moseley, unaware that the French might "have a different way of doing things," was promptly educated when visited by Urbain from the Sorbonne in Paris, who was attempting to confirm the existence of a new element "celtium" in his rare earth mixture by Moseley's novel X-ray technique. After Urbain's visit Moseley confided to Rutherford that, whereas the British try to find models or analogies, the French "are quite content with laws." As Heilbron explains, "Rutherford knew this fact very well. The English method had helped him to outrun the Curies and Becquerel."

Heilbron traces Rutherford's research as he moved from Cambridge University as a student, then to McGill University, to the University of Manchester, and finally back to Cambridge. Under Thomson, Rutherford showed that ionizing radiation from uranium consisted of two main types, which he called alpha and beta "for simplicity." At McGill Rutherford found that thorium produced a gaseous radioactive product, which he called "emanation" (one of the isotopes of radon). He came to understand radioactive decay and developed the concept of "half-life;" with Soddy he developed the "transformation theory," which showed radioactivity was a nuclear property; and he showed alpha particles were positively charged. At Manchester Rutherford contin-

ued his study of alpha particles by showing they were helium nuclei and by conducting his classical experiments with the recoil of alpha particles on gold foil that showed atoms were mostly empty space and possessed a nucleus. At Cambridge, Rutherford studied the artificial transmutation of the elements by bombardment with energetic alpha particles; and as his fame grew he became heavily involved in the relationship between science and society. Heilbron completes Rutherford's contribution to society by devoting an entire chapter to World War I with its enormous impact on the nature of research and the direction of future investigations. Before the War, research was considered an individual activity, or perhaps a research effort by a small group under the command of one professor. After the War, research projects were mobilized, sometimes on a national scale. The relations between universities, technology, industry, and government intensified. Rutherford's role in this evolution of research was enormous, and he became the dominant force in British physics and a spokesman for British scientists.

Even though the "power of British pictorial physics and his own vivid imagination" allowed Rutherford to advance the watershed theories of the atom, his own weakness in mathematics prevented his moving beyond the basic models. Bohr, now in Copenhagen, was using Max Planck's recent ideas to quantize the atom. Bohr's sophisticated model showed Rutherford's model was indeed "childish" by comparison. However, the original concepts paved the way for Bohr's atom, exemplifying that "one quality of a successful physical theory is that it points the way to its replacement."

Heilbron's book is a delightful, readable book, enjoyable not only for scientists who may already be knowledgeable about Rutherford's science and life, but also for the layman. The book appeals to a wide audience because it works on several different levels. Thus, the author presents his provocative insight of British vs. Continental scientific philosophies (appealing to the scientist already familiar with scientific evolution in the early twentieth century), while he traces scientific events (useful to teachers and students), as he delivers an absorbing story of personalities (capturing the imagination of the nonscientist). The book seizes the attention of high school and college students because of its inclusion of episodes between Rutherford and Madame Curie, a name known to everybody. An aid to the teacher and student is the frequent inclusion of "boxes," which explain scientific experiments and theories for those

who want more detail. These short essays include, for example, a brief description of J. J. Thomson's original experiments leading to his ideas of the electron; a description of Rutherford's first experiments leading to his proposed decay chains or radioactive elements; Rutherford's original "childish" models of the atom; and a description of the principle of the cyclotron. The plentiful and descriptive figures include not only photographs of people, places, buildings, and events, but also reproductions of Rutherford's sketches of equipment and his handwritten theories and ideas. Since this book was written as a "portrait" (being one of the "Oxford Portraits in Science"), Heilbron intentionally avoids involved mathematical descriptions (such as treatment of radioactive half-life) and cuts short stories of various personalities. These omissions, however, do not detract from the book, since they inspire one to learn more about this unusual scientist.

If one reads Rutherford's original publications, one is struck by the uncanny ability with which he methodi-

cally performed an experiment, concluded precisely what could be learned from the experiment (and no more), and realized the implications of the experiment so that he could design the next perfect experiment. This is why he advanced so rapidly: a combination of common sense, vivid imagination, and scientific discipline—and how he rose from his lowly roots in rural New Zealand to become a Nobel Laureate, the world's leader in the investigation of radioactivity

Rutherford's death was announced to a somber crowd at an international meeting in Bologna, Italy, in 1937. He was buried in Westminster Abbey, near the remains of Isaac Newton, Lord Kelvin, and Charles Darwin. In the modern periodic table, directly below hafnium—which had been predicted and discovered in Bohr's laboratory in Copenhagen—lies element 104, rutherfordium. *James L. Marshall and Virginia L. Marshall, Department of Chemistry, University of North Texas, Denton TX 76203-5070.*

The Life and Work of J. W. L. Thudichum. T. L. Sourkes, Osler Library, McGill University, Montreal, 2003; x + 95 pp, \$25.

This slim volume is not a cohesive nor comprehensive biography of the nineteenth-century medical chemist J. W. L. Thudichum, best known for his work on the chemistry of the brain. Rather, it is more a collection of brief essays on different aspects of Thudichum's life and work, as well as on individuals who influenced him (such as Justus Liebig and John Simon). The book does provide some useful biographical information about Thudichum, but fails to convey a satisfying portrait of the man or to place his contributions in adequate historical perspective. Those who are interested in Thudichum would be better served by consulting David Drabkin's dated but still valuable book, *Thudichum, Chemist of the Brain* (University of Pennsylvania Press, Philadelphia, 1958).

The volume reflects its origins. It originated as an essay prepared as the basis for an exhibit about Thudichum at the Osler Library on the centennial of his death in 2001. No doubt it served this purpose admirably. It was expanded into its present form, which, the author explains, "serves both as an exhibition catalogue and as a fresh biography of an important pioneer in biomedical research." While it succeeds in the former purpose, it is wanting, as noted above, in the latter purpose.

The illustrations, bibliography, and appendices add to the value of the work. This book should be on the shelves of libraries with collections in chemical and medical history, as it has some reference value. Few chemists or historians, however, other than those with a specific interest in Thudichum, are likely to find the book of much interest. *John Parascandola, Historical Consultant, 2617 Holman Avenue, Silver Spring, MD 20910.*

From Elements to Atoms: A History of Chemical Composition. Robert Siegfried, American Philosophical Society, Philadelphia, PA, 2002 (Transactions of the American Philosophical Society, 94, pt. 4), x + 278 pp, ISBN 0-87169-924-9, \$24.

Chemical composition is such a fundamental concept in chemical thought that chemists probably don't think about it very much. At least not explicitly, though it's certainly implicit in much of what they do. The ideas of element, atom, compound, and definite composition fit together so seamlessly that it's difficult to imagine chemistry without them. But, of course, the nature of matter and its transformations were studied for centuries, either without these ideas at all or with versions of them that might be hard to recognize today.

Historians have apparently not thought much about composition either. The Introduction to Robert Siegfried's *From Elements to Atoms* opens with the sentence, "In spite of the fact that composition is the singular organizational basis of modern chemistry, its history before Dalton's atomic theory has never been written." Although Ida Freund took a historical approach in her 1904 classic, *The Study of Chemical Composition: An Account of its Method and Historical Development*, her goal was to write a chemistry book, not a history of composition.

As his subtitle indicates, Siegfried has written such a history. It traces the evolution of ideas about chemical composition from the centuries-long tradition of the metaphysical elements to the concept of simple material bodies, which are defined operationally. That is, it's the history of composition from the 17th-century interpretation of Aristotle's four elements to John Dalton's 19th-century atoms.

This book grew out of the course in the history of chemistry that Siegfried taught at the University of Wisconsin in the 1980s. By way of biographical prologue, he briefly outlines his journey from graduate student in the History of Science Department at Wisconsin in the late 1940s to faculty member in that same department by 1963. Luckily, for us—and apparently for him as well—he completed his Ph.D. degree in both the History of Science and Chemistry departments, and he seems to have kept one foot in each camp ever since. Thus, the author seems uniquely qualified to write this book.

In the Preface (pp. v-ix) and Introduction (pp. 1-23), Siegfried lays out the context for the book's four-

teen chapters. As he tells us what material he's going to cover, how he's going to cover it and why, he candidly provides an overview of his own attitudes and biases about both chemistry and history. With his dual background, Siegfried has something significant to say about both.

He reminds us that there's something "magical" about chemical change. "Bodies disappear and new bodies with different qualities appear in their stead. . . . A piece of metal can be added to a clear, colorless liquid, the metal disappears, and a blue color appears. Based on direct experience alone there is no explanation available" (pp. 1-2).

Today we have elaborate theories to help us explain and understand the chemical changes we see, but how these connections between observation and understanding developed is not at all obvious. There have been attempts to explain and understand change (or the lack of it) since at least the time of Thales, but "chemical change is so magical in its character that these attempts remained in metaphysical rather than in experimental language and concepts well into modern times. Finally in the eighteenth century we see the slow and largely undeliberate transformation of implicit operational concepts of composition into explicit definitions and statements of principle" (p. 2).

Before beginning the story of that transformation, however, Siegfried outlines his own "historical perspective" (pp. 15-18). Of the two obligations of historians—"to do the past no injustice" and "to write intelligibly for [their] readers" (p. 16)—contemporary historians have done better with the former than with the latter, according to Siegfried. While historians have spent a great deal of time with the topics they write about, many of their readers haven't, so historians must convey their own understanding to their readers in terms that make that understanding available to the intended audience.

Siegfried has chosen to tell his story through the prism of modern chemical concepts. This may distress some readers, but it makes sense pedagogically, not only for his audience of undergraduate chemistry students, but also for professional chemists interested in the history of their craft and science. Here's his rationale. Just as scientific laws represent a reference against which "real" phenomena can be compared, modern concepts of chemistry also provide a reference for comparing past ideas of composition, many of which are now explicit and can be found implicitly in the thought

and work of earlier chemical scientists. Indeed, Siegfried points out that by the mid 17th century, such practitioners were caught between “their operational familiarity with real, material bodies” and “some of the conceptual consequences of the metaphysical tradition they had inherited” (p. 3) not only from Aristotle’s four elements, but also from the 16th-century *tria prima* (mercury, sulfur, and salt) of Paracelsus. Thus, Siegfried’s story details how the metaphysical tradition eventually disappeared altogether and how ideas about chemical composition emerged gradually until Dalton’s “atomic theory suddenly gave clarity to many discoveries and concepts that had accumulated in the previous century without having yet acquired coherence and unity” (p. 15).

Siegfried says that he chose this perspective of modern chemistry not to judge earlier ideas, but rather to try to understand them and to find more familiar modern ideas implicitly embedded in them. The author is not arguing for a Whiggish interpretation of history, but is instead pointing out “that a certain amount of such interpretation is unavoidable” (p. 17). In fact, he cautions against both Whiggish history and its opposite extreme, the idea that one is writing history “as it really happened.” Before finishing the Introduction, I felt comfortable with an author who had obviously spent time not only in studying his subject, but also in thinking about how to present it to a particular audience. These opening pages convinced me that I was in the company of a trustworthy storyteller, and I was ready to be guided through the history of chemical composition as it developed between the constraints of what scientists knew at any particular time and of “what they knew for sure that wasn’t so” (p. 22).

The book’s tour of chemical composition covers a great deal of familiar and not-so-familiar territory, but the author’s particular point of view frequently offers the opportunity to see even familiar material from a new perspective. The first nine chapters offer a detailed overview of the state of chemistry and chemical thought during the 150 years preceding Lavoisier. Siegfried does an excellent job in describing the 17th-century textbook tradition within the context of Paracelsan iatrochemistry and its later modifications. He also includes the history of the concept of a neutral salt, which, he argues, made possible the compositional nomenclature of the latter 18th century and which also represented “the most secure, the most explicitly empirical of all chemical knowledge” (p. 99) by 1750.

Chapters 5 (“An Historiographic Digression: Phlogiston”) and 6 (“How Air Returned to Chemistry”) interrupt the flow of the book’s narrative. Although they seemed out of place as I read them, these chapters were interesting in and of themselves, and Siegfried brings both topics back into the main narrative in subsequent chapters. He argues that phlogiston was not a problem for 17th- and 18th-century chemists even though modern historians often present it as such. Phlogiston and combustion did not become problematic “until Lavoisier challenged the traditional view that combustion and calcinations were decomposition processes” (p. 102). Regardless of the validity of his argument—which I found persuasive—I will certainly approach discussions of phlogiston in the future differently as a result of having read this book.

In discussing the consolidation of 17th-century chemistry in the following century, Siegfried focuses on G.-F. Rouelle, whose chemical thought brought together the chemistry of Boerhaave’s chemistry and the tradition of the French chymists discussed earlier in the book, as well as the concept of phlogiston. Both directly through his lectures and indirectly through the writings of his followers, Rouelle prepared the way for a resurgence of chemical interest in gases and “more than anyone else in mid-eighteenth century defined the chemistry that Lavoisier inherited and eventually replaced” (p. 133). After a brief overview of the relevant work of Joseph Black, Henry Cavendish, and Joseph Priestley, the last of whom finally elevated the concept of phlogiston “to a veritable chemical theory” (p. 161), the stage was finally set for Lavoisier.

In discussing the accomplishment of Lavoisier and the chemical revolution (Chapters 10-12), Siegfried most clearly presents familiar material from a fresh perspective. The chemical revolution is usually viewed in terms of the overthrow of phlogiston, but Siegfried argues that “little attention has been given to more fundamental consequences deriving from the operational concept of simple body” (p. 190), which was crucial to Lavoisier’s *Traité élémentaire de chimie*. While his three guiding principles—the caloric model of gases, the role of oxygen in the release of caloric during combustion, and the role of oxygen as the principle of acidity—“were all quickly abandoned by nineteenth century chemists . . . [t]he concept of ‘simple body’ as the operational unit of composition became widely accepted” (p. 192). In fact, Siegfried cites the simple body as “the final step in the move toward the materialization of chemical composi-

tion that we have traced from the early seventeenth century” (p. 216).

Simple bodies, however, proved problematic as their number increased substantially in the years following Lavoisier. According to Siegfried, many chemists began to search for new order in the increasingly complex world of chemistry that evolved with the assimilation of the new chemistry of Lavoisier. The book’s final chapter presents Dalton’s atomic theory as the source of that new order despite its mixed reception by his contemporaries. The idea of relative atomic weights was not only of great practical value to chemists, but it also fit with the long-term movement toward a mathematical chemistry. At the same time, many chemists “either rejected the reality of atoms outright, or expressed great doubts that the weights being used bore any knowable relationship to the atoms themselves” (p. 258).

The fate of atoms in the 19th century, however, is not part of Siegfried’s story. “Dalton’s atomic theory must be seen as the climax of the history of chemical composition and terminates this story” (p. 262). Indeed, after only one more paragraph, the book ends, perhaps a little too abruptly. My first reaction upon finishing the book was that the book’s opening sentence—the “history [of composition] before Dalton’s atomic theory has never been written” (p. 1)—was no longer true. From *Elements to Atoms* presents just that story in a lucid and thought-provoking way for a reader with some knowledge of modern chemistry.

My own enjoyment in reading this book was punctured by very few distractions. Its physical appearance

is perhaps a minor one. It’s an oversized paperback (6 1/2” x 10”), and its front cover has blue lettering on a mottled tan background, which reminded me of a generic burlap Windows wallpaper. Once the book is open, however (and the cover is no longer visible), it’s a pleasure to hold and read. The typeface is easy on the eyes, and the binding allows the book to remain conveniently open by itself.

I found only a few typos. The sentence that continues from page 28 to the next page is clearly missing a few words, and “corporeal” is misspelled on page 34. Probably the greatest distraction was the number of times that Siegfried states, restates, and rephrases his goals and aims, as well as the book’s themes, first in the Preface (pp. v, vi, ix), then in the Introduction (pp. 3, 12, 14-15, 15), and finally in Chapter 4 (p. 74). I could only surmise that he wanted to be sure that he was being completely explicit himself in telling the story of how implicit ideas about chemical composition gradually became explicit. But even this is a small distraction to the overall success of the book, which also, by the way, has an excellent bibliography of both primary and secondary sources.

I found it a fascinating book. Some of the material was familiar—though it can be quite pleasurable to revisit familiar places—but I also learned much that I didn’t know, and Siegfried offered me a good deal to think about. From *Elements to Atoms* is a book that I will definitely keep on my bookshelf for reference and no doubt for re-reading as well. *Richard E. Rice, P.O. Box 1210, Florence, MT 59833-1210.*

The Ingredients. A Guided Tour of the Elements. Philip Ball, Oxford University Press, New York, 2002. xii + 228 pp, Cloth, ISBN 0-19-284100-9.

This book is a double delight. The reader, chemist or not, will be skillfully informed in readily comprehended language, with uncommon facts, connections, and insights, about the chemical elements. And this will be done with elegantly, charmingly constructed sentences and paragraphs. In trying to convey to potential

readers the pleasure to be found here, there is a strong urge to quote extensively. For the moment, though, two examples: (1) “...the story of the elements is not simply a tale of a hundred or so different types of atom, each with its unique properties and idiosyncracies. It is a story about our cultural interactions with the nature and composition of nature.” (2) “But only with the development of new ultra-sensitive techniques of chemical analysis have we become alerted to the complexity with which [the elements] are blended in the

world, seasoning the oceans and the air with exquisite delicacy.” Ball has a way of making a rather startling statement—“The [oxygen-rich] chemical composition of the air is not a precondition for life but the result of it.”—and then supporting it with quiet exposition of the logic for it.

Besides a Preface, a page of Contents, a List of Figures, five pages of Notes, a page headed Further reading, and 13 pages of Index (which cites 80 modern elements), the book consists of seven chapters, ranging in length from 23 pages to 35 pages and whose titles strongly suggest their content:

- 1 Aristotle’s Quartet: The Elements of Antiquity
- 2 Revolution: How Oxygen Changed the World
- 3 Gold: The Glorious and Accursed Element
- 4 The Eightfold Path: Organizing the Elements
- 5 The Atom Factories: Making New Elements
- 6 The Chemical Brothers: Why Isotopes are Useful
- 7 For All Practical Purposes: Technologies of the Elements

Every freshman chemistry text now in use likely includes reference to the four elements – earth, air, fire, and water – of the ancients, but how many, if any, lead to any understanding of why that list dominated thinking about elements from the 7th century BC into the 17th century AD? Chapter 1, which considers the social context (impact) of the elements and emphasizes processes of the mind in confronting the issue of elements as well as the reasonableness and evolution of the philosophy of element identification, does foster such understanding. It treats the puzzle of why several metals, known thousands of years BC in “impressively pure state,” were not regarded as elements by Greek philosophers, whose viewpoints and influence extended into the 17th century AD, when experimentation finally began to power and guide the inquiry into elements. “In short, there is nothing obvious about the elements. [They] cannot be deduced by casual inspection of the world....[Aristotle’s quartet] are not the elements of chemistry, but they say something resonant about how we interact with the world and about the effect that matter has on us.”

In Chapter 2 Ball illuminates the significant role of physical experiments in the identification of an element and of the difficulty of scientists to accept the implication of their own data, to relinquish old, familiar ways of thinking. He cites and effectively uses the recent play *Oxygen*, by Roald Hoffman and Carl Djerassi. After an

elegant account of the interlacing work of Lavoisier, Priestly, Scheele, and others, and their distinguishing views about what their experiments demonstrated, Ball states forthrightly, “It was Lavoisier who made oxygen an element.” What a difference from writing, “It was Lavoisier who discovered oxygen”!

Chapter 3 opens with detailed accounts of two ancient legends—King Midas and Polymnestor—about the lure of gold and its tragic consequences. Then come a few other stories, more sketchily told, of long-ago happenings focused on gold and on to James Bond and Goldfinger. “And the crowning irony is that gold is that most useless of metals, prized like a fashion model for its ability to look beautiful and do nothing....It is gold’s very uselessness, its inert and detached nature, that makes it so precious.” Gold is contrasted with other, more useful metals, and the chemical basis for placer deposits and panning is described. Description of the color generation by nanometer-sized gold particles leads to a readily comprehended explanation of colloidal properties that would do a chemistry text proud and to the fascinating story of how two gold Nobel Prize medallions belonging to German physicists were, with the intervention of Niels Bohr and his colleague, Gyorgy de Hevesy, kept safe from confiscation during World War II. Finally the chemical inertness of gold is accounted for by an unimposing description of bonding and antibonding,

Chapter 4 tells of the long evolution of the concept of atoms and of atomic structure. Names of famous chemists from the 18th century AD onward are numerous. The Periodic Table, first by groping inquiry, on to current electronic explanations, is the primary focus of the chapter. The chapter concludes with: “So that is why an element’s location in the Periodic Table—its row and column—tells us a lot about its chemical behavior...The table is the best crib sheet a young aspiring chemist, sweating through a summertime exam, could wish for.”

Chapter 5 begins with an account of the discovery of radioactivity and the growing appreciation of its implications for atomic structure. Discussion of atomic fission; the bomb; the discernment of the process for the sun’s heat; cyclotronic generation of unnatural elements; and the description of barely over a century of amazing developments is replete with human terms, with names and points of view. Even the contemporary controversy over naming some of the manufactured elements is included.

“Chemical Brothers” is an inspired way of referring to isotopes (Chapter 6). The chapter begins with radioisotopes in fascinating, debate-settling applications to dating questions that involve people’s long-held beliefs. Similar uses of stable isotopes ($^{16}\text{O}/^{18}\text{O}$, for example) and medical applications conclude the chapter.

The final chapter emphasizes iron in history, treating it almost as an icon. Ball moves easily from glass making into semiconductors with lucid, yet not technically overpowering, details of the semiconducting phenomenon, doping, and transistors. The platinum group metals and their roles in catalytic converters and cold fusion are highlighted. In discussion of the rare earths, Ball uses a readily-comprehended description of the experimental evidence: “...their presence was revealed by inspecting the ‘bar code’ of elemental emission lines in the glow produced when the material was heated.” He tells of their use as phosphors for TVs. He concludes that “No cook could ever match the natural genius that brews such riches from simple ingredients.”

This book may be annoying to those who prefer the presentation of chemistry to be cut and dried. But to those who enjoy the revelation and excitement of the human element in the development of chemistry, *The Ingredients* is a treasure box ready to be opened. A trendy project in some cities and universities encourages all residents to read the same book during a set period of time, with the hope that fruitful discussions and informed learning will result. I believe that this book would be a superb selection for such a project. Scientific illiteracy would most likely be diminished while appreciation of literature and perspective would be enhanced.

(This book is a companion volume to Ball’s earlier book about molecules, *Stories of the Invisible*, Oxford University Press, Oxford, 2001.) *James G. Traynham, Department of Chemistry, Louisiana State University, 122 Highland Trace Drive, Baton Rouge, LA 70810-5061.*

Ladies in the Laboratory II. West European Women in Science, 1800-1900. Mary R. S. Creese, The Scarecrow Press, Inc., Lanham, MD and Oxford, 2004, 290 pp.

This hardcover updated version of the earlier (1998) edition contains all of the entries found in the

earlier edition. The author has here included an Appendix to supplement the information in the 1998 softcover book. For an idea of the coverage and value of this survey, the reader is directed to the earlier review: *Bull. Hist. Chem.*, **2000**, 25, 132-133. *Paul R. Jones, University of Michigan, Ann Arbor, MI 48109-1055.*

HIST ELECTION 2004 - CALL FOR NOMINATIONS

The following offices are up for election this fall:

Chair-Elect
Secretary/Treasurer
Councilor (2 seats)
Alternate Councilor (1)

Please send nominations, with contact information, to Vera V. Mainz, the Sec/Treas.

Vera V. Mainz
142B RAL, Box 34 Noyes Lab
600 S. Mathews Ave.
Urbana, IL 61801

Phone: 217-244-0564; Email: mainz@uiuc.edu

CALL FOR NOMINATIONS FOR THE EDELSTEIN AWARD FOR 2005

The Division of the History of Chemistry (HIST) of the American Chemical Society (ACS) solicits nominations for the 2005 Sidney M. Edelstein Award for Outstanding Achievements in the History of Chemistry. This award honors the memory of the late Sidney M. Edelstein, who in 1956 established the Dexter Award for Outstanding Achievements in the History of Chemistry. The Dexter Award ended in 2001; from 2002 the Edelstein Award has continued this tradition.

The Edelstein Award is sponsored by Ruth Edelstein Barish and Family, and is administered by HIST. In recognition of receiving the Edelstein Award, the winner is presented with an engraved plaque and the sum of \$3500, usually at a symposium honoring the recipient at the Fall National Meeting of the ACS, which in 2005 will be held in Washington D.C., from August 28 to September 1. The award is international in scope, and nominations are welcome from anywhere in the world. Previous winners of the Dexter and Edelstein Awards have included chemists and historians from the U.S., Canada, Germany, France, the Netherlands, Hungary, and the United Kingdom. Details may be found on the HIST web site, <http://www.scs.uiuc.edu/~mainzv/HIST/>

Each nomination should consist of:

- a complete curriculum vitae for the nominee, including biographical data, education, publications, presentations, awards, honors, and other services to the profession;
- a letter of nomination, which summarizes the nominee's achievements in the field of history of chemistry, and cites his or her contributions that merit a major award; and
- at least two seconding letters.

Copies of no more than three publications may also be included.

All nominations should be sent in triplicate to Professor Alan Rocke, Chair, Edelstein Award Committee for 2005, History Department, Case Western Reserve University, Cleveland, OH 44106 U.S.A. (email: alan.rocke@case.edu), for arrival no later than December 31, 2004.

BULLETIN FOR THE HISTORY OF CHEMISTRY

William B. Jensen, Founding Editor

EDITOR

Paul R. Jones
Department of Chemistry
University of Michigan
930 N. University Avenue
Ann Arbor, MI 48109-1055
prjones@umich.edu

ASSOCIATE EDITORS

Dr. Carmen J. Giunta
Department of Chemistry
Le Moyne College
Syracuse, NY 13214
giunta@mail.lemoyne.edu

Dr. Mary Ellen Bowden
Chemical Heritage Foundation
315 Chestnut Street
Philadelphia, PA 19106-2702
mebowden@chemheritage.org

Dr. Leo B. Slater
Stetten Memorial Fellow
Bldg. 31, rm 5B38, MSC 2092
National Institutes of Health
Bethesda, MD 20892-2092

HIST OFFICERS, 2004

Dr. David E. Lewis, Chair
Dept. of Chemistry
University of Wisconsin-Eau Claire
Eau-Claire, WI 54702-4404
lewisd@uwec.edu

Vera V. Mainz, Sec/Treas
School of Chemical Sciences
Un. Illinois
Urbana, IL 61801
mainzv@aries.scs.uiuc.edu

Roger A. Egolf, Program Chair
Dept. of Chemistry
Penn. State Univ.
Fogelsville, PA 18051
rae4@psu.edu

Ben B. Chastain, Councilor
538 Hampton Drive
Birmingham, AL 35209
bbchasta@samford.edu

Mary Virginia Orna, Councilor
16 Hemlock Place
New Rochelle, NY 10805
mvorna@mvorna.cnr.edu

Carmen Giunta, Alternate Councilor
Le Moyne College
1419 Salt Springs Rd.
Syracuse, NY 13214-1399
(315) 445-4128 fax 445-4540
giunta@lemoyne.edu

The BULLETIN FOR THE HISTORY OF CHEMISTRY (ISSN 1053-4385) is published biannually (February & September) by the History of Chemistry Division of the American Chemical Society. All matters relating to manuscripts, book reviews, and letters should be sent to Dr. Paul R. Jones, Editor. Subscription changes, changes of address, and claims for missing issues, as well as new memberships, are handled by the Sec./Treas.

BULLETIN FOR THE HISTORY OF CHEMISTRY

Subscription and Membership Application

___ ACS Member at \$15/year (includes HIST Division membership)

___ Associates: \$20/year

___ Associates outside North America: \$25/year

___ Annual Library Subscription: \$36/domestic; \$40/foreign

Begin subscription with the year 20 __

Name _____

Address _____

Signature _____

Return to Dr. Vera V. Mainz, HIST Secretary/Treasurer, School of Chemical Sciences,
University of Illinois, Urbana, IL 61801. Checks should be made payable to the Division of the
History of Chemistry, American Chemical Society.

BULLETIN FOR THE HISTORY OF CHEMISTRY

Dr. Paul R. Jones, Editor

University of Michigan

Department of Chemistry

930 N. University Avenue

Ann Arbor, MI 48109-1055

Non-Profit Org.
U.S. Postage
PAID
Ann Arbor, MI
Permit No. 144