

1 **Chapter 14**  
2 ***Chymia* and HIST**

3 During the 1920s members of HIST that wanted to publish articles of interest to  
4 HIST members often chose *Industrial and Engineering Chemistry*. Later, many  
5 articles were published in *The Journal of Chemical Education*. In the 1940s, *J.*  
6 *Chem. Ed.* decided to no longer publish articles that were not directly related to  
7 pedagogy. The Division of the History of Chemistry decided to found a journal that  
8 would be both available and accessible to all historians of chemistry in the world.  
9 The original Editorial Board consisted of:

10 Tenney L. Davis, Editor in Chief MIT

11 Claude K. Deischer PENN

12 Rudolph Hirsch PENN

13 Herbert S. Klickstein CAL

14 Henry M. Leicester College of Physicians, SF

15 Eva V. Armstrong PENN

16  
17 The initial title page:  
18

# Chymia

ANNUAL STUDIES IN  
THE HISTORY OF CHEMISTRY

TENNEY L. DAVIS

EDITOR-IN-CHIEF



· VOLUME I ·

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- 19  
20 The Editorial Board chose a distinguished group of historians of Chemistry from  
21 many countries:

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CLARA DE MILT, *U. S. A.*  
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CONWAY ZIRKLE, *U. S. A.*

22  
23 One benefit that proceeded directly from this gesture was a large number of articles  
24 from the Advisory Board. The initial Table of Contents appears below. The late  
25 1940s was a time of transition for HIST. Edgar Fahs Smith had died in the 1920s.  
26 And Charles A. Browne died in 1947. Eva Armstrong recalled the fond wish of  
27 Edgar Fahs Smith to found a journal like *Chymia*, and was proud that the Edgar  
28 Fahs Smith Collection was a sponsor. Claude Deischer (1903-1992) provided a  
29 nice eulogy and memorial for Browne. Tenney Davis (1890-1949) was active to  
30 the end and edited Volume 2 as well. (Henry Leicester wrote a great biography of  
31 Davis.) The most famous historian of Chemistry in this time frame was J.R.  
32 Partington (1886-1965). Clara de Milt (1891-1953) was one of the most famous  
33 active teachers of the history of Chemistry at Tulane University, where she was  
34 Chair of the Department.

35  
36

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v

37  
38 Partington wrote the monumental four volume History of Chemistry. He received  
39 the Dexter Award from HIST in 1961. In his article he discussed the evolution of  
40 our understanding of the concept of “substance.” Throughout most of the last three  
41 millennia, humans could observe matter only with unaided eyes. Philosophers  
42 speculated that there existed a unique “primary matter” and that all substances  
43 were derived from this. Two forms of the *materia prima* were proposed: 1) a  
44 continuous fluid, and 2) a discrete “particle.”

45

46 Eventually chemists carried out deliberate experiments to explore the speculations.  
47 Macroscopic observation often obscured the microscopic details of the chemical  
48 process. For example, inserting a rod of iron into a solution of blue vitriol  
49 produced a “copper rod.” This was interpreted as transmutation from iron to  
50 copper. Van Helmont carried out a full set of reactions that revealed that blue  
51 vitriol was copper sulfate. He was also able to discern that “green vitriol” was iron  
52 sulfate.

53  
54 Aquinas, following Aristotle, believed that particular substances were holistic, and  
55 that all previous states of the material were erased by the new substance. If this  
56 were true, there could be no actual philosophical chemistry. Robert Boyle stressed  
57 the need for both analysis and synthesis.

58  
59 In the 18<sup>th</sup> century, chemists were able to carry out thousands of chemical  
60 reactions. They discovered that, within the limits of experimental error, the total  
61 mass of a closed chemical system remains the same during the reaction. Richter  
62 generalized this insight into the correct theory of stoichiometry.

63  
64 The fact of constant and proportional composition could be rationalized by  
65 assuming that each element was composed of unique chemical atoms, and that they  
66 could combine in integral units. In the 19<sup>th</sup> century John Dalton both envisioned  
67 this stance and encouraged its adoption by good arguments and careful  
68 experiments. Dalton’s theory, by itself, was not sufficient to construct a full theory  
69 of atoms and atomic substances. But it was a sound foundation that needed  
70 correction and articulation. The most important additional concept that was needed  
71 was a way to “count atoms.” Avogadro envisioned gases as dynamic assemblies of  
72 particles. If the ideal gas law was correct, the number of particles needed to  
73 produce a particular pressure at a particular volume and temperature could be  
74 calculated. The mass density of the gas could be measured, and hence the particle  
75 mass of the gas particles could be calculated.

76  
77 Early hopes that all atoms were multiples of hydrogen (Prout’s Hypothesis) was  
78 conclusively disproved. Even the bold assertion that all chemical atoms of the  
79 same element had the same mass turned out to be false. Physical reality is usually  
80 more complicated and more interesting than ideal speculations. But the overall  
81 paradigm envisioned by Dalton has proved to be robust. (Boerhaave actually  
82 demonstrated that pure mercury is composed of multiple different atomic weights.)

83 In the 20<sup>th</sup> century, our concept of chemical atoms has been extended to include  
84 both decomposition and synthesis of atoms. The electronic properties of atoms are  
85 far more complicated than envisioned in the 19<sup>th</sup> century. And the properties of  
86 crystalline solids impose geometric constraints on ideal structures. Real chemistry  
87 is so much more interesting than the pale version taught in school. Partington  
88 preferred reality!

89

## 90 **Volume 2 (1949)**

91

92 While Tenney Davis is still listed as the Editor-in-Chief, His Memorium  
93 immediately follows:

### IN MEMORIAM

TENNEY L. DAVIS, 1890-1949

Tenney L. Davis, distinguished as an organic chemist, was a master in the field of the history of chemistry. His passing is a great loss, not only to *Chymia*, but to the world of science and culture in general. To his broad vision and careful scholarship *Chymia* owes much. He unselfishly gave of his time and energy in launching the first volume and in developing *Chymia* as an international publication. His memory will ever be an inspiration to those who carry on. Tenney L. Davis won the respect, admiration, and affection of his colleagues on the Editorial Board, and in this spirit the present issue is dedicated to his memory.

94

95

96 The fully international character of *Chymia* was retained in Volume II. There were  
97 even articles published in French and German. Tenney Davis published his last  
98 article in this issue: "Pulvis Fulminans." Davis was an explosives expert and was  
99 Director of Scientific Research and Development at National Fireworks, Inc. He  
100 traces the origin of fulminating gold to the 17<sup>th</sup> century and authors including  
101 Rudolf Glauber, "Basil Valentine," and Jean Beguin (Beguinias). The recipe is:

102

103

Prepare "aqua regia" by dissolving sal ammoniac in nitric acid.

104

Add gold.

105

Add solution of potassium carbonate.

106

Collect precipitate and wash.

107

Carefully dry in air out of the light.

108

109 Cornelis Drebbel (1572-1633) manufactured this mixture and sold it to the English  
110 government.

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112  
 113 The explosive designated “pulvis fulminans” (Exploding powder) is a mixture of  
 114 potassium hydrogen tartrate, potassium nitrate and flowers of sulfur. It can be  
 115 detonated by placing on a hot iron plate. The sulfur melts and then the sublimate  
 116 catches fire. Then the residue explodes and vaporizes. It was very popular in the  
 117 17<sup>th</sup> century and many users were cited. Antoine Baume (1728-1804) carried out  
 118 detailed analyses of the entire process and discovered the importance of potassium  
 119 polysulfide that is produced during the reaction. Another common mixture used in  
 120 this period was called “liver of sulfur.” It is a mixture of potassium (sulfide,  
 121 polysulfide and thiosulfate). When the “fulminans” is created by mixing saltpeter  
 122 with liver of sulfur and heated in an iron spoon, the “retort” is quick and loud. The  
 123 trinity of Geoffroy, Baume and Macquer were celebrated by Davis.

124 **Volume 3 (1950)**

125

126 Henry Leicester is now the Editor-in-Chief and John Read (1884-1963) has now  
127 joined the Editorial Board.

128

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v

129

130



131 George Sarton (1884-1956) of Harvard chose to publish his Carmalt Lecture at  
132 Yale in *Chymia!* Sarton is generally viewed as the “father” of American history of  
133 science. This demonstrates that *Chymia* was viewed positively by the entire  
134 history of science community.

135  
136 Sarton identified the 17<sup>th</sup> century as a remarkable flowering of both science and  
137 scholarship. He listed around 100 key figures. For this lecture he chose to focus on  
138 Robert Boyle (1627-1691) and Pierre Bayle (1647-1706). Sarton admired Boyle as  
139 much for his publication of his scientific results as for his laboratory prowess.  
140 Sarton was a fierce critic of alchemy, but he fell for the inventions of Carl Jung.  
141 Sarton placed Boyle in historical context and appreciated his *Sceptical Chymist*  
142 (1661). Boyle had studied ordinary air, and concluded that it was “not simple!” (It  
143 would be many years before other chemists acknowledged the chemical activity of  
144 air.) Boyle was also humble about his level of understanding and the need to  
145 acknowledge the provisional nature of his results. While he knew he had not  
146 arrived at a clear and convincing notion of a chemical element, he was confident  
147 that time and talent would succeed.

148  
149 Pierre Bayle was a French Protestant. Pierre finished his education in Geneva  
150 under the teaching of the Cartesian Jean Chouet (1642-1731). Eventually Pierre  
151 was called to teach in the new school in Rotterdam. He was well-read, in both  
152 Catholic and Protestant writings and also thinkers like Erasmus of Rotterdam!  
153 Like Comenius, he promoted an irenic approach to religious controversy. When  
154 Roman Catholic authors published a stirring defense of the Revocation of the Edict  
155 of Nantes and the glories of France, Bayle produced a real historical treatment of  
156 French intolerance. He explained that human society is not viable when violence  
157 is used to force people to either die or become hypocrites.

158  
159 Bayle is most famous for his role in promoting the “Republic of Letters.” He  
160 founded a journal dedicated to irenic discussion of real issues by men of good will  
161 and great sagacity. He also wrote an irenic and scholarly “Dictionnaire” after he  
162 was purged from his professorship by Calvinist bigots. (Yes, bigotry is an equal-  
163 opportunity sin.) Sarton included a montage of some of his most famous books.

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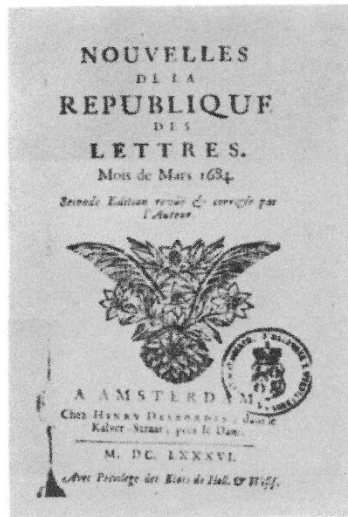


Fig. 8

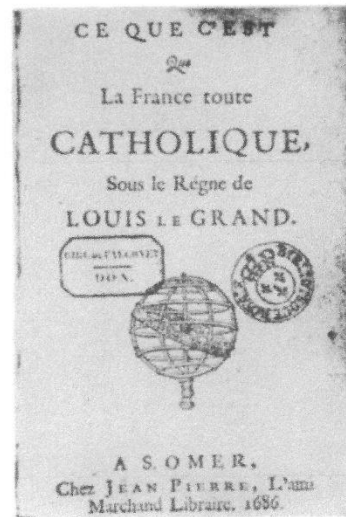


Fig. 9

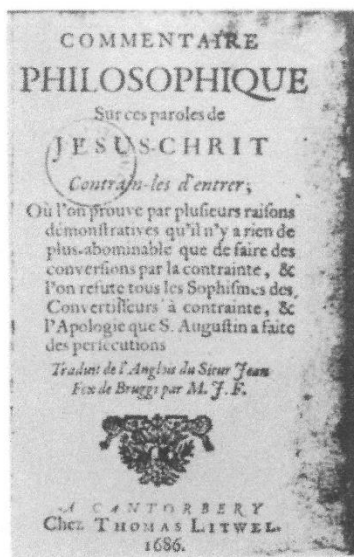


Fig. 10

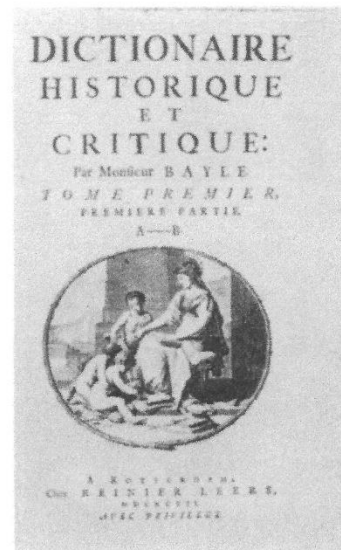


Fig. 11

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176

Sarton provided a masterful comparison of his two subjects. It begins with the dictum: “Doubting is the beginning of historiography as it is the beginning of science.” Descartes is the fountain of this stream. Sarton hoped for a figure that was both a great scientist and a great man of letters. Remarkably, Isaac Newton was hiding right under his nose! One of my favorite books by Newton is the *Irenicum*.

177 **Volume 4 (1953)**

178

179 Volume 4 appeared three years after Volume 3. Fortunately, philanthropic gifts  
180 enabled the return to publication of *Chymia*.

#### ACKNOWLEDGMENT

Publication of Volume 4 was in part made possible by the generosity of Mr. Pierre S. du Pont and Mr. Chester G. Fisher. The Editorial Board also wishes to express its thanks to the University of Pennsylvania for continuing its subsidization of CHYMIA.

181

182 Volume 4 also included a name index for Volumes 1-4.

183

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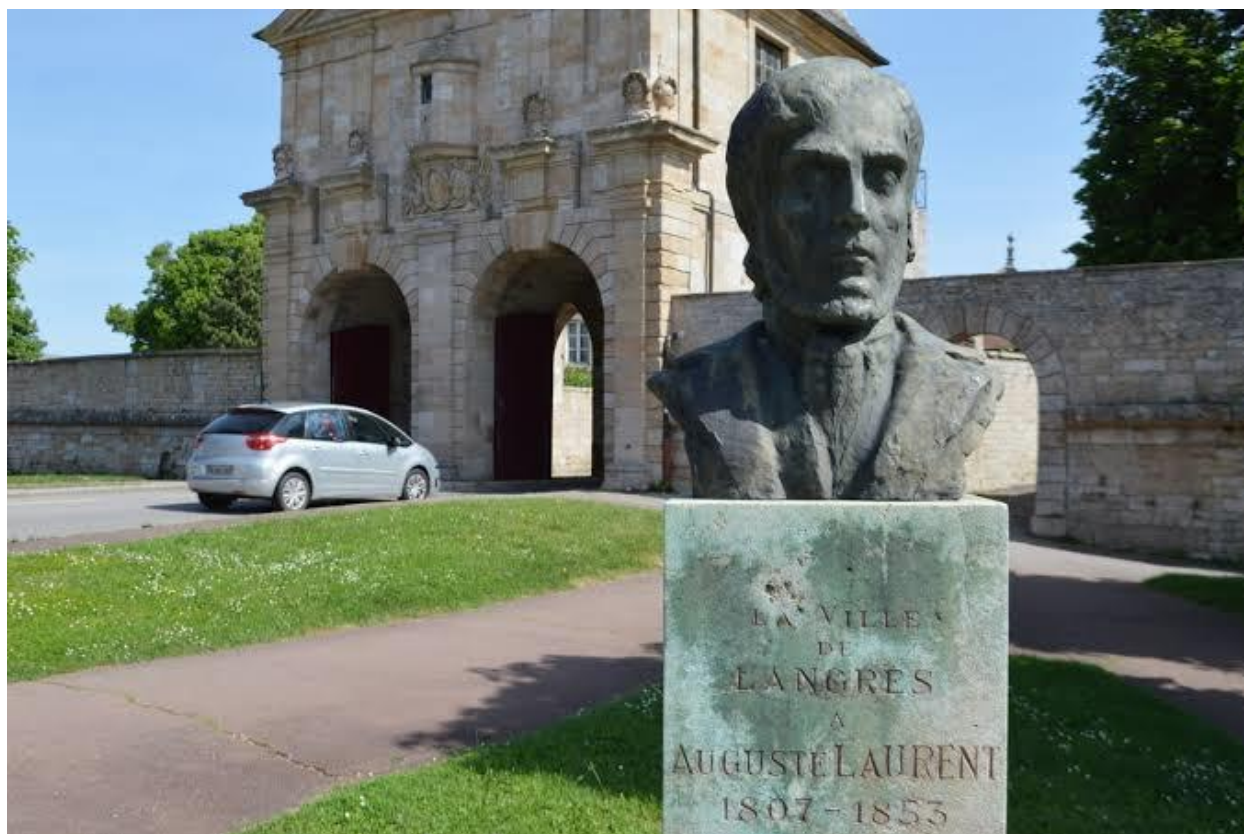
185

186 The last contribution by Clara de Milt is found in Volume 4: “August Laurent,  
187 Founder of Modern Organic Chemistry.” (She died in 1953. A nice biography is  
188 found in Miles, *American Chemists and Chemical Engineers* (1976).)

189

190 1953 was the centenary of the death of August Laurent (1807-1853).

191



192

193

194 After his death, his friends organized his work and produced the now classic work:  
195 *Methode de Chimie* (1854). In his own country, Laurent was marginalized by  
196 famous chemists such as Wurtz and even his collaborator Gerhardt. De Milt  
197 wished to provide the credit that Laurent deserves. She pursued all the historical  
198 material she could in 1953 and constructed a narrative that gave appropriate credit  
199 to Laurent.

200

201 Although Laurent was a “child of the provinces,” he eventually was able to  
202 matriculate at the Ecole des Mines in Paris. He learned crystallography and hence  
203 geometry. After graduation in 1830 he went to work with Dumas at the “Central  
204 School of Arts and Manufactures.” Not only did Laurent learn the superb  
205 laboratory techniques of Dumas, he devoured all the known speculations about the

206 reality of atoms and molecules. By 1846 Laurent was able to publish the  
207 foundational paper: “Recherches sur les combinaisons azotees,” *Ann. Chim. Phys.*,  
208 **18**, 296 (1846). Laurent admired Dumas and commented in the *Method*:  
209

Dumas was the first to point out the remarkable relations which associated alcohol and ether with the other vinic combinations. He colligated these relations into a theory, by saying that *the vinic combinations* CONTAIN *a hydrated acid plus etherine*. In the ethyl theory, it is said that *the vinic combinations* CONTAIN *an anhydrous acid plus oxide of ethyl*. If for the expression *contain*, we substitute *may be represented by*, the two theories will express exactly the same thing.<sup>27</sup>

210  
211  
212 Rather than erecting a wall between inorganic and organic chemistry, Laurent  
213 applied the structural knowledge of crystals formed from atoms to molecules  
214 formed from atoms. In order to bring “order out of chaos,” Laurent envisioned the  
215 concept of a hydrocarbon “core” for organic molecules. This entity could be  
216 ornamented in many different ways. He constructed a *programme* for molecules  
217 that included four classes of distinction: 1) recipe for synthesis, 2) physical  
218 properties, 3) demonstrated “derivatives,” and 4) published chemical reactions.  
219

220 Three of his early core molecules were naphthalene, benzene and ethylene. One  
221 class of derivatives was created by chlorination. 1,3,5 trichlorobenzene was one  
222 derivative. Laurent needed to defend his conclusions against later statements by  
223 others:

In considering the results (of the nitration of anthracene) one arrives at the following conclusions of which the first belongs to M. Dumas. 1) Whenever chlorine, bromine, nitric acid, or oxygen exerts a dehydrogenating action on a hydrocarbon, each equivalent of hydrogen lost is replaced by one equivalent of chlorine, bromine, or oxygen. 2) There is formed at the same time an acid, hydrochloric, hydrobromic, nitrous acid, or water, which sometimes is given off, sometimes remains combined with the new radical which is formed.<sup>47</sup>

224  
225  
226 The great Berzelius was fixated on one class of reactions, largely inspired by  
227 inorganic chemistry. Laurent was exploring “substitution” reactions. In 1837  
228 Laurent defended his doctoral thesis before Dumas, DuLong, Beudant and  
229 Despretz. He appealed to clearly geometric arguments for the observed reactions  
230 of his hydrocarbons.  
231

232 Laurent was attacked by Liebig for stealing the limelight in the progress in  
233 understanding both molecular structure and chemical reactions. Liebig appealed to  
234 his friend Wohler to help in solving some of the experimental problems and to  
235 draw attention away from his own work that was in opposition to Berzelius.

236 De Milt was very sensitive to the human side of science. Another great French  
237 chemist, Victor Regnault, confirmed many of the ideas of Laurent. De Milt  
238 anticipated the dicta of Thomas Kuhn: Humans are unwilling to abandon bad ideas  
239 and must take them to the grave.

240  
241 In 1838 Laurent was appointed Professor of Chemistry at the University of  
242 Bordeaux. He formed an active collaboration with Gerhardt. At his own expense  
243 he continued his research on coal tar distillates. He also investigated the organic  
244 acids derived from fats. In 1844 he published an extensive discussion of his full  
245 theory of chemical nomenclature: "Classification chimique," *Compt. Rend.*, **19**,  
246 1089 (1844). This approach was adopted by Gmelin and was the one chosen by  
247 Beilstein for his monumental "Handbuch."

248  
249 Laurent returned to Paris to be closer to the "action." He had no real position and  
250 was assisted by his friends. One of the most felicitous events in the history of  
251 chemistry is the friendship between Pasteur and Laurent. Laurent suggested the  
252 topic of Pasteur's thesis on the optically active tartrates.

253  
254 By 1850 many European chemists had become convinced of the value of Laurent's  
255 system. He was elected a foreign member of the London Chemical Society.  
256 Unfortunately, events in Paris proved to be a great disappointment. Laurent was a  
257 serious candidate for the chemistry chair at the College de France. Dumas was  
258 able to prevent this, and Laurent never recovered. While Dumas' greatest student,  
259 Wurtz, quietly adopted Laurent's system, Dumas continued to damage Laurent's  
260 reputation until he too died.

261  
262 Upon publication of Laurent's masterpiece *Methodes de Chymie*, Jean-Baptiste  
263 Biot, one of the most beloved members of the Academie, read his Introduction:

This work, abounding with new ideas, oftentimes fruitful in their results to the author himself, presents us with the intimate convictions of a man who has enriched science by numerous and unlooked for discoveries. It is a summary of the thoughts of his whole life; and so great an interest did he attach to the bestowal of this heritage, that he laboured to effect its completion until within the very grasp of death. That his work deserves to be received with serious attention, exempt from any preconceived notions, is sufficiently evident from the above considerations. But to read it with advantage, to appreciate it with justice, we must place before our eyes the object which Laurent proposed to himself by its composition.

He wished, he hoped, to place in the hands of chemists a grouping of symbolical analogies, deduced from experiment, which should guide them with the strongest probability if not certainty, in the interpretations to which they are continually obliged to have recourse.<sup>123</sup>

265

266

267 De Milt recommended that every serious organic chemist should read the *Methodes*.  
268 While modern organic chemistry texts tend to ignore it, no serious researcher  
269 should do this. She concluded her article with a quotation from Laurent's  
270 biographer, Jerome Nickles:  
271

If ever a man elevated himself by the force of genius and perseverance, such preëminently was Laurent, to whom everything was denied, and who made his chef-d'oeuvre out of nothing. Laurent was one of those men who must die before they can be fully appreciated; I well know that he will receive his due only when impartial history shall be substituted for self-love and party spirit. It will then be acknowledged that during the short space of time in which he appeared above the scientific horizon, the ideas that he brought forward were successively confirmed, after the announcement of

---

his fundamental principle which he thus expresses: —that Form or arrangement has often more influence on properties than matter itself—a principle which served as the guiding thread in his researches, even to the theories of substitution, of hemimorphism, of isomeromorphism, and of crystalline types, these in fact being corollaries [*sic*] from this principle.<sup>131</sup>

272

273

## 274 **Volume 5 (1959)**

275

276 Once again there is a substantial hiatus in the publication of *Chymia*. There is also  
277 a reformed Editorial Board:

### EDITORIAL BOARD

HENRY M. LEICESTER, *Editor-in-Chief, College of Physicians & Surgeons, San Francisco, California*

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SIDNEY M. EDELSTEIN, *New York City, New York*

MURRAY G. MURPHEY, *University of Pennsylvania*

CONWAY ZIRKLE, *University of Pennsylvania*

278

279 One of the most significant new members is Sidney Edelstein, who was the  
280 Secretary/Treasurer of HIST. He contributed a major article on the Chemical  
281 Revolution in America (see below). This paper had been given orally to the  
282 Division of the History of Chemistry on September 12, 1957 at the New York ACS  
283 Meeting. HIST now had an outlet for great work.

284

285

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287  
 288 There are times when a full story can be told by consulting the full run of a  
 289 particular journal. (The HIST History of the founding of the ACS is found in the  
 290 journal *The American Chemist* (1870-77)). The story of the controversies in  
 291 America initiated by the immigration of Joseph Priestley to America can be found  
 292 in the *Medical Repository* edited by Samuel Latham Mitchill (1764-1831) of  
 293 Columbia College. Two other participants in this story are James Woodhouse  
 294 (1770-1809) from the University of Pennsylvania and John Maclean (1771-1814)



295 from the College of New Jersey at Princeton. Forty-three articles were published  
296 in response to Priestley's "Considerations on the Doctrine of Phlogiston and the  
297 Decomposition of Water" (1796). In the first issue of the *Medical Repository*  
298 (1798) we read:

The worthy and indefatigable author of the pamphlet before us, since his arrival in America, continues his chemical labours, and appears as zealous as ever to promote the progress of science. It must give pleasure to every philosophical mind to find the United States becoming the theatre of such interesting discussion as now occupies some of the leading chemists of the day; for this essay, which is addressed to Messrs. Berthollet, De la Place, Monge, Morveau, Fourcroy, and Hassenfratz, the surviving answerers of Mr. Kirwan, has been answered, as we shall more particularly observe in its proper place, by the ci-devant Minister of the French Republic to the United States, ADET, just before his departure from Philadelphia to France, in May last. We hope that publications upon such subjects, by men of so much ability, will not only prove on which side of the argument the truth lies, but will be a means of diffusing a taste for this kind of philosophical research among the people of the western world.

Although the Lavoisierian theory had made proselytes of the greater part of the philosophers in Europe and America, and though Dr. Priestley had observed his friends and acquaintance deserting the standard of phlogiston, not merely one by one, but frequently going over to the other side in whole troupes, he has never yet found himself disposed to change sides and engage in this revolutionary scheme. Firm in his original persuasion, that the doctrine of STAHL is preferable upon the whole, he adheres to it upon principle; professing, at the same time, with perfect candour his willingness and readiness to adopt the sentiments of his opponents whenever they shall convince him he is wrong.

299

300

301 The battle was joined, but Priestley remained both adamant about his views and  
302 eager to debate "the truth." Many gases were now known, including the oxygen  
303 discovered by Priestley and celebrated by Lavoisier. But the same experiments  
304 were interpreted differently by the two "giants." Priestley believed that  
305 "inflammable air" was "produced" by phlogiston! He also believed that the  
306 "smell" produced by burning iron under a bell jar with a "burning lens" was due to  
307 phlogiston. Since a metal calx can be "reduced" to the pure metal by either  
308 "inflammable air" or charcoal, Priestley believed that charcoal "contained"  
309 phlogiston.

310

311 One of the most egregious assertions of the "phlogistonists" was the belief that the  
312 detonation of hydrogen and oxygen in a sealed tube produced "nitrous acid." He  
313 claimed that atmospheric nitrogen was "phlogisticated air" and hence could be  
314 produced by taking phlogiston from the hydrogen.

315

316 The French Ambassador to the United States, Piere Adet (1763-1834), had worked  
317 with Lavoisier. In 1796 he was elected to the American Philosophical Society in  
318 Philadelphia. He composed a detailed reply to the pamphlet of Priestley. Mitchill

319 reviewed this article in his *Medical Repository*. Adet reminded the reader that pure  
320 metals were elements (simple substances) and that metal calces were compounds  
321 with oxygen. He reminded Priestley that Boerhaave had produced mercury oxide  
322 by distillation in the presence of oxygen and recovered the pure mercury by dry  
323 distillation of the red HgO. Adet also discusses the production of black iron oxide  
324 produced by flowing steam through a red-hot gun barrel. He recognizes that there  
325 can be more than one form of iron oxide, a great deduction for 1797.

326  
327 John Maclean also composed a refutation of Priestley's pamphlet that was given as  
328 two lectures at Princeton and reviewed in the *Repository*. Priestley was well-  
329 acquainted with the full iatrochemical pharmacopeia. He tried to explain the  
330 properties of the powerful mercury containing emetic, turbith mineral, in terms of  
331 phlogiston. Maclean refuted his assertions in the laboratory where he recovered  
332 the mercury contained in turbith merely by heating in a sealed distillation  
333 apparatus. Philosophical or theological arguments are of no use when compared to  
334 actual laboratory results.

335  
336 Mitchill attempted to harmonize the two contradictory systems.

337

On reviewing the state of philosophical controversy, as carried on both  
in Europe and America, between the phlogistians and their opponents, it  
has of late appeared to me, that much of the difficulty which attends the  
subject, arises, as in abundance of other cases, from the want of a precise  
language and of a right understanding of each other's meaning. This was  
so evident to me, in the present case, that I informed my audience of it in  
one of my public lectures in Columbia College; and added my belief, that  
due attention to terms, their application and use, would have great influ-  
ence in bringing the dispute to a termination.

338

339 While Priestley appreciated the attempt at "goodwill," he understood that two  
340 "contradictory" systems cannot be reconciled by polite obfuscation.

341

I thank you for your ingenious, and well intended, attempt to promote  
a peace between the present belligerent powers in chemistry; but I much  
fear your labour will be in vain. In my opinion there can be no compro-  
mise of the two systems. Metals are either necessarily simple or necessarily  
compound; and water is either resolvable into two kinds of air, or it is not.

342

343

344 As the controversy continued, Priestley realized that "phlogiston" was entirely  
345 "fictive:" (it could not be isolated in its pure form). He was content to think like  
346 Aquinas and to invent fictive properties such as inflammability or fluidity. Since  
347 the oxygen theory of Lavoisier was also corrupt, Priestley could attack both

348 experimental and theoretical errors. A new theoretical system was needed to escape  
349 from the hell of phlogiston.

350

351 One of the thorniest issues was water itself. Priestley viewed it as a simple  
352 substance. He refused to believe that water was a compound of oxygen and  
353 hydrogen. Even worse, he misidentified to products of the “water-gas” reaction:

354



356

357 He thought that the “inflammable air” came from the carbon, and ignored the carbon  
358 monoxide. Eventually Priestley did realize that carbon monoxide, a highly  
359 combustible gas, was different from inflammable air.

360

361 Edelstein concludes with the Eloge printed in the seventh volume of the *Repository*:

362

On the morning of Monday, February 6, 1804, this venerable man paid the debt of nature, and was buried on the Thursday following, at Northumberland, in Pennsylvania, where he had lived chiefly since his arrival from Britain.

Of the most important and fashionable study of Pneumatic Chemistry, he may fairly be said to be the father. His discoveries of the various gases, which his writings first announced to the world, exceed not merely in number, but in importance, even those of the illustrious Scheele, of Sweden, and the French Lavoisier.

He has contributed to make the present generation of readers think and investigate beyond any writer of his day. His life is closed. He has lived and died an example of the sublime simplicity of character, which has never been attendant but on the first-rate abilities, uniformly exerted for the benefit of mankind.

363

364 Perhaps Priestley died a decade too soon. Perhaps if Lavoisier himself had lived  
365 he would have been able to help Priestley see the futility of phlogiston. Perhaps  
366 Priestley could have helped Lavoisier see the futility of the oxygen theory of acids.

367

368

369

370

371

372

373

374

375

376

377 **Volume 6 (1960)**

378

379 Volume 6 reveals an evolving relationship with the sponsors of *Chymia*. The  
380 Division of the History of Chemistry is now visibly listed as one of the sponsoring  
381 organizations.

*Edgar F. Smith Memorial Collection: University of Pennsylvania*  
*Division of History of Chemistry, American Chemical Society*

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# Chymia

ANNUAL STUDIES IN  
THE HISTORY OF CHEMISTRY

HENRY M. LEICESTER

EDITOR-IN-CHIEF

382

383 One of the jewels that appears in Volume 6, and then again in Volume 7, is the  
384 Masters thesis of Rhoda Rappaport (1935-2009). Her adviser at Cornell  
385 University, Henry Guerlac (1910-1985) (Dexter Award 1972, Sarton Medal 1973),  
386 was so impressed with the work that he submitted it as two articles to *Chymia*. The  
387 first was: "G.-F. Rouelle: An Eighteenth-Century Chemist and Teacher," (68-101).

388

389 While Rouelle was one of the most important figures in 18<sup>th</sup> century chemistry, he  
390 was overshadowed by Antoine Lavoisier in later historiography. Rappaport seeks  
391 to restore the luster to a truly shining star. She does this by exhaustive documentary  
392 research and insightful commentary.

393

394 There were no Professors of Chemistry in France in 1700. The leading teacher of  
395 chemistry in France in the 17<sup>th</sup> century was Nicolas Lemery (1645-1715), who  
396 wrote *Cours de Chimie* (1675). He taught private courses to interested students in  
397 pharmacy and medicine. The next notable French teacher of chemistry was  
398 Guillaume-Francois Rouelle (1703-1770). His private lectures and his public  
399 discourses at the Jardin du Roi were attended by the same group as noted for  
400 Lemery, but it also included most of the leading intellectuals in Paris. He was an

401 important member of the Salon d’Holbach where he met wits like Diderot.  
402 Rouelle never published a textbook, but his lecture notes contain the best chemistry  
403 in France during his lifetime. One of his most notable students was Antoine  
404 Lavoisier! A contemporary journalist-chemist, Louis-Sebastien Mercier (1740-  
405 1814) wrote of him:

406  
407           When Rouelle spoke, he inspired, he overwhelmed; he made me love an art  
408           about which I had not the least notion; Rouelle enlightened me, converted me;  
409           it is he who made me a supporter of that science [of chemistry] which should  
410           regenerate all the arts, one after the other . . . ; without Rouelle, I would not  
411           have known how to look above the mortar of the apothecary.<sup>2</sup>

412 The most notable French textbook of the middle 18<sup>th</sup> century was *Elemens de*  
413 *chymie theorique* (1749) by Pierre-Joseph Macquer (1718-1784). It was entirely  
414 based on Rouelle’s lectures! Another famous French teacher of chemistry was  
415 Gabriel-Francois Venel (1723-1775) who also studied with Rouelle and preached  
416 “his chemical gospel.”

417  
418 Rouelle was esteemed in France and was elected to the Academie des Sciences. He  
419 was also elected to the academies in Stockholm and Erfurt.

420 In his teaching Rouelle presented all the known facts of chemistry from  
421 predecessors like Boerhaave and Stephen Hales (1677-1761). He frequently  
422 improved on the work and his own laboratory was quite advanced for his time. A  
423 nice summary of the teaching of Rouelle is provided by Venel:

424  
425           The courses which M. Rouelle has given at Paris for about twenty years, are,  
426           even in the opinion of strangers, among the best of this kind. The order in which  
427           particular objects are presented, the abundance and choice of examples, the care  
428           and exactitude with which operations are performed, the origin of and relation  
          between the phenomena observed, the new luminous, broad insights suggested;  
          the excellent manual precepts taught, and finally, the good, sound doctrine  
          which sums up all the particular notions; all these advantages, I say, make the  
          laboratory of this capable chemist such a good school, that one can in two courses,  
          with ordinary dispositions, emerge sufficiently instructed, to deserve the title of  
          distinguished amateur, or of artist able to engage successfully in chemical  
          researches. This judgment is confirmed by the example of all the French chemists,  
          for whom the first taste for *chemistry* followed the first courses of M. Rouelle.<sup>125</sup>

423  
424  
425  
426  
427  
428

429 **Volume 7 (1961)**

430

431 The second part of Rappaport's thesis appears as: "Rouelle and Stahl – The  
432 Phlogistic Revolution in France."

433

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434

435 Many historians of chemistry have wondered how a fictive theory could have  
436 gained such currency when it was demonstrably false. Rappaport understood that  
437 "the phlogiston theory was so "**adaptable**" that to question its validity was to raise  
438 a host of difficult theoretical problems." Rouelle constructed a conceptual  
439 framework that borrowed from all the best ideas current in 1742. He had read  
440 Boyle's *Sceptical Chymist* and pondered what it meant to be an "elementary  
441 substance." His own scheme rested on vaguely Aristotelian notions that there were  
442 a set of sub-elemental "particles" that could be "bonded" to the *materia prima* to  
443 produce "elementary substances." These entities were not yet "observable." There  
444 were also a set of "chemical instruments" that could be added to any substance to  
445 produce the "observable substances" of the laboratory. The notion of chemical  
446 instruments is associated with the monumental *Elementa Chymiae* of Hermann

447 Boerhaave. One of the most important Boerhaavian instruments was “fire.”  
448 Rouelle treated “fire” as both an “element” and an “instrument.”

449  
450 (The basic quandary of theoretical chemistry is how to explain the complexity of  
451 the observable world in terms of some fundamental entities that could be combined  
452 in enough ways to represent actual chemical substances. One 18<sup>th</sup> century disciple  
453 of Isaac Newton, Roger Boscovich, postulated particles that interacted with one  
454 another according to a Byzantine potential. It was repulsive at short distances,  
455 attractive at long distances and highly variable in between.)

456  
457 Rouelle had also read Stahl’s *Philosophical Principles*. Naïve focus on phlogiston  
458 does not represent the essence of Stahl’s system. The physical world was  
459 envisioned at three levels: *principe, mixte and compose*. This “great chain of  
460 chemistry” was sophisticated enough to talk about the chemical world. (It was  
461 wholly incapable of quantitative discussion of measurable properties.) For Stahl  
462 there were four “elements:” fire, air, water and earth. (A return to the four element  
463 system after the two or three element system of the alchemists!) None of these  
464 elements inhabit the laboratory! It is the “mixts” that are observable. They are  
465 composed of the four “elements.” They are the substances that participate in  
466 chemical reactions.

467  
468 The fictive component “fire” was also called phlogiston. Not to be outdone, it was  
469 also an important “instrument.” It could be added to a mixt without changing the  
470 underlying “composition,” or it could change the composition and hence the  
471 chemical substance itself. (Remarkable stuff!) The chemical process most  
472 associated with phlogiston in the 18<sup>th</sup> century was the calcination of metals. It was  
473 claimed that adding “heat” to a metal released the phlogiston in the metal. (This  
474 wildly circular reasoning eventually led to the collapse of the phlogiston theory,  
475 but in the 18<sup>th</sup> century it was often the only accepted stance.) Exactly why the loss  
476 of phlogiston coupled with the obvious increase in the weight of the sample made  
477 sense was merely “bracketed.” Rouelle also attributed the color of matter to  
478 phlogiston. (Both Boerhaave and Lavoisier considered “light” to be an element!)  
479 The potential “virtues” of phlogiston could now include all observable properties  
480 of matter. For example, it could be a form of sound. Sonochemistry, like  
481 Photochemistry, is an important field of research.

482

483 Rouelle constructed an “element” he called “air.” It was also an instrument.  
484 Although elements were fictive, Rouelle refers to “free air.” He proposes that  
485 observable entities can be constructed of air. These mixts have the properties  
486 measured by Boyle: pressure and temperature. But, rather than increasing the  
487 springiness of the air, phlogiston is supposed to destroy this property?! Rouelle  
488 also asserts that the “free air” is necessary for “combustion.” (But all the elements  
489 are fictive; they cannot be isolated or observed!)

490  
491 Some chemical processes produce gas. Heating mercuric oxide, a red solid,  
492 produces liquid mercury, gaseous mercury and another gas. Where did this gas  
493 come from? In the 18<sup>th</sup> century, the red oxide of mercury needed to contain “air”  
494 already; it was the only starting material. Another philosophical possibility was  
495 that “heat” was an element that decomposed the mercuric oxide into two other  
496 substances, one of which was a gas. Why not call heat phlogiston? Some did!

497  
498 Another chemical process known in the 18<sup>th</sup> century was the dissolution of a metal  
499 in dilute hydrochloric acid. One of the products was “inflammable air.” This  
500 implied that the system initially contained both phlogiston and the element air.  
501 The metal seemed to disappear, while the gas appeared. (Some modern  
502 pedagogues have tried to “revive” the phlogiston theory by identifying  
503 “inflammable air” (H<sub>2</sub>) with phlogiston. This is a complete misunderstanding,  
504 since hydrogen can be observed and, by definition, phlogiston cannot!) Free air,  
505 like free phlogiston, is forbidden by the axioms of the system.

506  
507 The third “element” is water; not the stuff of which we are made, but the fictive  
508 principle. The incoherence of the discussion of this element is stunning. One of  
509 the known classes of substances is crystal hydrates: crystalline substances that  
510 contain water molecules at fixed sites. Green vitriol (FeSO<sub>4</sub>·7H<sub>2</sub>O) is one of the  
511 most fascinating substances of the 17<sup>th</sup> and 18<sup>th</sup> century. Is the water observable, or  
512 only fictive? It can be driven off by “adding heat.” It can be collected in a  
513 distillation apparatus. The principle of water is sometimes associated with  
514 “fluidity.” This implies that ice cannot contain the element water! Not to be  
515 outdone, many phlogistic philosophers proposed an element known as the frigorific  
516 particle. (When the number of “particles” needed to explain ordinary material  
517 reality exceeds the number of known chemicals, it is time to look elsewhere.)  
518 Rouelle chose to identify ice as the elemental form of water, but ice is observable!

519



520 Water is also viewed as a chemical instrument. Boerhaave definitely considered  
521 water as a promoter of menstrua. Remarkably, Rouelle claimed water promoted  
522 combustion! (Water is often a “product” of combustion when the reactant contains  
523 hydrogen. Mrs. Marcet’s *Conversations in Chemistry* includes the experiment  
524 where a golden plate is held over a burning candle. Water condenses on the plate.)  
525

526 The fourth “element” is “earth.” In the 18<sup>th</sup> century, books on Acids, Bases and  
527 Salts often assumed that “all acids are derived from one elemental acid,” and that  
528 they could be converted into one another by the addition or subtraction of an  
529 appropriate principle. (Is it any wonder that Lavoisier, a pupil of Rouelle,  
530 considered the “dephlogisticated air” of Priestley to be the “principle of acidity?”)  
531 Rouelle was influenced by the work of Johann Becher (1635-1682). He was one of  
532 the most knowledgeable chemists of the 17<sup>th</sup> century. He distinguished three types  
533 of “earths.” The first group was called “vitrifiable earth.” In fact, in the present the  
534 silicate minerals form an intelligible class. Becher did not know the atomic  
535 composition of these real substances, but he inferred that there was a common  
536 principle displayed in “flint.” The second class was “sulfureous earth.” Sulfides  
537 still constitute a coherent class of minerals: such as fool’s gold and cinnabar. The  
538 final group was “mercurial earth.” (Rouelle claimed that mercurial earth was  
539 actually a form of phlogiston! Solid, liquid, gas, fire: why not!) There are many  
540 mercurous minerals. But in the phlogistic system, these principles are not  
541 observable. (Once a certain form of confusion sets in, no observable fact can  
542 contradict a fictive notion.)  
543

544 In this “wonderland” ice is “water plus vitrifiable earth!” The ability to keep the  
545 fictive notions separate from the laboratory chemicals was impossible. Only  
546 confusion resulted. Becher was no fool, and Rouelle was the best French  
547 chemistry teacher of the 18<sup>th</sup> century. But their theoretical ideas did not lead to the  
548 future. Their practical chemistry was consistent with the age in which they lived  
549 and worked.

550  
551 Chemistry is more than mineral “bug collecting.” Rouelle thought deeply about  
552 actual “chemical reactions.” He envisioned the reactions that took place “in  
553 solution” as due to both the solvent and the solute. Sometimes this is true! When it  
554 did, two new substances were obtained, since both “mixts” were decomposed and  
555 then new mixts were assembled. Solvation can take many forms, and Rouelle tried  
556 to grapple with this.

557 The name most associated today with phlogiston is George Ernest Stahl (1659-  
558 1734). Stahl's version of phlogiston associated it with the sulfurous earth of  
559 Becher, while Rouelle joined Boerhaave in promoting the importance of the  
560 principle of "fire." (Impressive stuff: all chemistry can be attributed to the  
561 influence of phlogiston.) Another property associated with phlogiston by Stahl is  
562 smell. One can argue about the relative merits of essentially incorrect theories, but  
563 it is also possible to extract promising lines of experiment and discussion found in  
564 earlier works.

565

566 Rappaport identifies the coherent chemical system of Rouelle as a helpful way to  
567 "talk about real chemistry." Rouelle was thoroughly acquainted with the  
568 laboratory chemistry of the 18<sup>th</sup> century, and made many improvements on  
569 previous practice. Rappaport cites the concept of affinities, often associated with  
570 the work of Geoffroy, as an essential notion for Rouelle. While little of the work  
571 of Rouelle plays a part in "modern chemistry," he played an important role in the  
572 18<sup>th</sup> century as a great teacher and thinker. Lavoisier would not have made the  
573 progress that he did without the influence of his teacher. But Lavoisier had access  
574 to all the published chemistry of the 18<sup>th</sup> century and thoroughly understood the  
575 work of Boerhaave, Black and Macquer. He was also committed to a quantitative  
576 approach to chemistry. Words were important to him, and his advances in  
577 "nomenclature" were a true revolution, but it was his precision and his  
578 experimental creativity that distinguish Lavoisier.

579

580 In spite of efforts by historians to promote a "sharp break" with the chemical past,  
581 Lavoisier was a teacher of "caloric" (the principle of heat) and "oxygen" (not the  
582 atomic element but the principle of acidity.) Although the world lost one of its best  
583 when Lavoisier was sent to the guillotine, chemistry was freed to adopt observable  
584 chemical atoms and many observable compounds. There is no sense in denigrating  
585 the contributions of Lavoisier to the development of the science of chemistry, but  
586 the Kuhnian Revolution promoted by some historians fails to appreciate the full  
587 context of Lavoisier's life and work.

588

589

590

591

592

593

594 **Volume 8 (1962)**

595  
596 Frederick L. Holmes (1932-2003) was one of the leading historians of science in  
597 the 20<sup>th</sup> century. He received the Dexter Award in 1994 and the Sarton Medal in  
598 2000. He was the Avalon Professor of the History of Medicine at Yale. In Volume  
599 8 of *Chymia* he published an article from his graduate school years at Harvard.  
600

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601  
602 Claude Louis Berthollet (1748-1822) was a leading Académicien in 18<sup>th</sup> century  
603 France. He was a member of the Society of Arcueil and a collaborator of  
604 Lavoisier. Holmes’ article seeks to present Berthollet’s foundational work on  
605 chemical reactions in full historical context.

606  
607 By the end of the 18<sup>th</sup> century chemists had identified hundreds of acids, bases,  
608 salts and metals. Torbern Bergman (1735-1784) observed the results of mixing  
609 them. From his observations he organized all pairs of substances into ordered

610 affinities, based on precipitations or the evolution of gases from aqueous solutions.  
611 For example, sulfuric acid reacted with barium chloride to produce barium sulfate  
612 and hydrochloric acid. Reactions between two “salts” were considered to be  
613 “double displacement” reactions. This world of chemistry was extensive and  
614 produced hundreds of papers. But there were substantial questions about the  
615 quantitative realities of the concept of “absolute affinities.”

616  
617 (The conceptual framework of this chemistry produced two kinds of answers: yes  
618 or no. The notion that reactions could reach an intermediate state of “chemical  
619 equilibrium” was not yet accepted. And while solids, liquids and gases were  
620 known, the full concept of “chemical phases” was still in its infancy. Solutions  
621 created a real quandary. Did the concentration of the solute influence the  
622 “effective affinity?” Were there other factors, such as the temperature or the actual  
623 solvent, that affected the conditions for reaction?)

624  
625 (Berthollet was part of Napoleon’s “dream team.” He went to Egypt with him and  
626 pondered the wonders of the deserts full of salt and evaporating ponds. With “time  
627 on his hands” he observed chemical reactions on a massive scale. Back in France  
628 he directed major chemical industries, where issues such as profit and loss required  
629 control over the amount of reactants needed to produce the desired product. But he  
630 was also part of the Society of Arcueil. He carried out smaller scale experiments  
631 and discussed them with the brightest minds in France.)

632  
633 One of the experimental protocols employed by Berthollet was to use both water  
634 and ethanol to prepare solutions. This allowed him to separate salt mixtures, since  
635 some salts are insoluble in water but soluble in ethanol, or vice versa. Berthollet  
636 understood that the full experimental space was a three-phase system: solution,  
637 precipitates and gases. This required a closed system. He also understood that  
638 such systems rarely proceed to “completion.” For example, as a gas is evolved  
639 from the solution, its “effective affinity” in solution increases.

640  
641 (A higher level of understanding of such “complicated” systems required the  
642 construction of full chemical thermodynamics. This was only achieved much later  
643 in the 19<sup>th</sup> century by J. Willard Gibbs. For a simple two component system  
644 involving two phases, solution and gas, the condition of chemical equilibrium  
645 required that the “chemical potential” of each component needed to be equal in

646 both phases. If there was a chemical reaction involved as well, the Gibbs energy of  
647 reaction needed to reach 0.)

648

649 In 1803 Berthollet published his *magnus opus: Essai de Statique Chimique*. The  
650 “English” response was mostly negative because the Daltonian system promoted  
651 simple whole number compositions for “pure” chemicals. (Modern realities reveal  
652 that many inorganic systems can exist in variable “mixtures.”) French chemists,  
653 such as Gay-Lussac and Regnault, explored many systems where chemical  
654 equilibrium depended on the thermodynamic composition of the full system.  
655 Berzelius recognized that for chemical systems in solution, naïve notions that were  
656 useful for small polyatomic molecules in the gas phase did not rule out Berthollet’s  
657 experiments or his theories.

658

659 One insight that Holmes revealed was that Berthollet was not sufficiently clear  
660 about the difference between mixtures and compounds. Since the full  
661 thermodynamic theory of solutions was far from even being envisioned, it was just  
662 too early for this part of the theory to impact chemical thinking. Another common  
663 misunderstanding in the chemical world of 1803 was the existence of discrete  
664 diatomic molecules, such as NaCl, in solution. (The strong negative reception of  
665 the ionic notions of Arrhenius nearly 100 years later reflects this confusion.)

666

667 One class of observations that was available in 1803 was the color of the solution.  
668 While the reasons for color changes were not understood, the intensity of the color  
669 and its spectrum could be observed. End-point “indicators” are still an important  
670 part of volumetric analysis.

671

672 (Any real understanding of solutions required the concept of entropy. All things  
673 being equal, all fluids mix. Depending on the enthalpy of mixing, homogeneous  
674 solutions can separate. The free energy of solution depends on both the enthalpy  
675 and temperature times the entropy of mixing:  $\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$ .)

676

677 In the mid-19<sup>th</sup> century, chemists began to study the “rate” of chemical reactions.  
678 In addition, chemists began to understand that fluids are in constant motion. (This  
679 is now called “Brownian motion.”) As the particles of the solution undergo  
680 random fluctuations in their location and orientation, they interact with all the other  
681 particles in their first “solvent shell.” The number of possible local structural states  
682 is large, but the probability of any of them is determined by their local Gibbs

683 energy and the temperature. This means that a distribution of states is the normal  
684 situation.

685  
686 If one of the states is large enough to mimic the local crystal unit cell for a  
687 precipitate, it can “grow” until the solution is “depleted” of such local “seeds.”  
688 If one of the states mimics the “activated state” for a chemical reaction, it can also  
689 proceed towards the product. Crystallization is a random process of addition of  
690 unit cells to the crystal surface and random “evaporations” from the surface.  
691 Under the right conditions the crystal can grow to macroscopic dimensions. Under  
692 the right conditions the chemical reaction product can accumulate until the  
693 backwards fluctuations proceed at the same rate as the forward fluctuations. In this  
694 conceptual world, all chemistry is a dynamic process.

695  
696 Alexander W. Williamson (1824-1904) understood this “modern perspective”  
697 already in 1851: *Ann. Chem. Pharm.*, **77**, 37-49 (1851). Holmes points out that he  
698 gave the “first dynamic interpretation of chemical equilibrium.” This was long  
699 before Maxwell and Boltzmann formulated Statistical Chemistry! But it was  
700 achieved at University College London, where he joined Thomas Graham (1805-  
701 1869), the “Father of Colloid Science.”

702  
703 The final stages of the verification of the chemical Law of Mass Action were  
704 initiated by Marcellin Berthelot (1827-1907) in 1862. He chose reactions that were  
705 slow enough to reach equilibrium in macroscopic times. This work inspired Cato  
706 Guldberg (1836-1902) and Peter Waage (1833-1900) to pursue the rates of  
707 chemical reactions and the dependence on the concentrations of the reactants. In  
708 1864-1867 they published five classic papers on this topic and are generally  
709 credited with the formulation of the Law of Mass Action. The final touches were  
710 provided by Jacobus van't Hoff (1852-1911, Nobel 1901). His initial paper was  
711 published in 1877 and his classic book, *Etudes de Dynamique Chimique*, was  
712 published in 1883. (My copy is the 1896 English translation and revision.)

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719

720 **Volume 9 (1964)**

721

722 Volume 9 was delayed by the passing of Eva Armstrong. The 1964 issue was  
723 marked by both a simple Memoriam and a substantial Eloge by Claude Deischer.

724

IN MEMORIAM

Eva V. Armstrong, 1877–1962

Eva V. Armstrong, former Curator of the Edgar Fahs Smith Memorial Library in the History of Chemistry, and one of the architects of *Chymia*, passed away on May 10, 1962. The historians of science, her many colleagues and friends of the University of Pennsylvania, and all who were privileged to benefit from her services as librarian and curator, mourn her loss. To the memory of Miss Armstrong the Editorial Board dedicates this volume.

725

726



Eva V. Armstrong (1877–1962)

727

728

729 Eva V. Armstrong was the curator of the Edgar Fahs Smith Memorial Library in  
 730 the History of Chemistry at the University of Pennsylvania. She was one of the  
 731 founders of *Chymia*. In 1909 she joined Edgar Fahs Smith as his secretary. She  
 732 remained with him after his retirement in 1920 and helped curate his magnificent  
 733 collection of chemical books and ephemera. Upon his death she became the official  
 734 curator of the Collection. In addition, she was one of the most active historians of  
 735 chemistry in the world and received the Dexter Award of the Division of the  
 736 History of Chemistry in 1958.  
 737

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 741



742 The most prolific author published in *Chymia* was Martin Levey (1913-1970).  
743 Levey finally received his Ph.D. in the history of science in 1952. He served at  
744 many schools, but his favorite haunt was the Institute for Advanced Study at  
745 Princeton. He received the Dexter Award in 1965 for his “work on texts and  
746 archeological artifacts of the ancient and medieval Middle East. He knew 20  
747 foreign languages! He was the leading light of the Subdivision of Archeological  
748 Chemistry. Levey was Chair of HIST in 1967.

749

750 His publications in *Chymia* :

751 Volume 5

752 The Refining of Gold in Ancient Mesopotamia

753 A Study of Ancient Mesopotamian Bronze

754 Volume 6

755 A Group of Akkadian texts on Perfumery

756 Early Muslim Chemistry: Its Debt to Ancient Babylonia

757 Volume 7

758 Alberuni and Indian Alchemy

759 Studies in the Development of Atomic Theory

760 The Manufacture of Inks, *Liqs*, Erasure Fluids, and Glues – A Preliminary

761 Survey in Arabic Chemical Technology

762 Volume 8

763 The Aqrabadhin of Al-Kindi and Early Arabic Chemistry

764 Volume 9

765 Chemical Technology and Commercial Law in Early Islam

766 Some Black Inks in Early Medieval Jewish Literature

767 Chemistry in the *Kitab Al-Sumum (Book of Poisons)* by Ibn Al-Wahshiya

768 Volume 11

769 Chemical Notions of an Early Ninth Century Christian Encyclopedist

770 Chemistry in the Medieval Formulary of al-Samarquandi

771 Volume 12

772 Medieval Arabic Minting of Gold and Silver Coins

773 Arabic Mineralogy of the Tenth Century

774

775

776

777

778

779 **Volume 10 (1965)**

780

781 One of the most interesting characters in the history of HIST was Eduard Farber  
782 (1892-1969). He was born in Galicia and soon moved to Leipzig. After receiving  
783 his Ph.D. in 1916 he joined the Kaiser Wilhelm Institute fur Experimentalle  
784 Therapie in Berlin. While he avoided military service, he spent the war years in  
785 Budapest in a chemical plant. After the war he was Chief Chemist and Director of  
786 Chemical Research at Deutsche Bergin. With the rise of the Nazis, he emigrated to  
787 the United States in 1938. With his extensive industrial experience he was chosen  
788 to open a new industrial research laboratory in New Haven, CT. In 1943 he moved  
789 to Washington, D.C. as Director of Chemical Research for Timber Engineering  
790 Company. He retired in 1957 and for the rest of his life he pursued his passion for  
791 the History of Chemistry.

792

793 Farber became active in HIST when he moved to DC. He was Chair in 1955-56.  
794 He was especially prolific and published many books and papers on the history of  
795 chemistry. He received the Dexter Award in 1964 “for a long series of  
796 contributions to the history of chemistry, in particular his two books on the History  
797 of Chemistry, for editing the compilation *Great Chemists* (1961), and for many  
798 other books.” Volume 10 contains a long article on “Induced Oxidation-Reduction  
799 Processes, the History of a Chemical Paradox.”

800

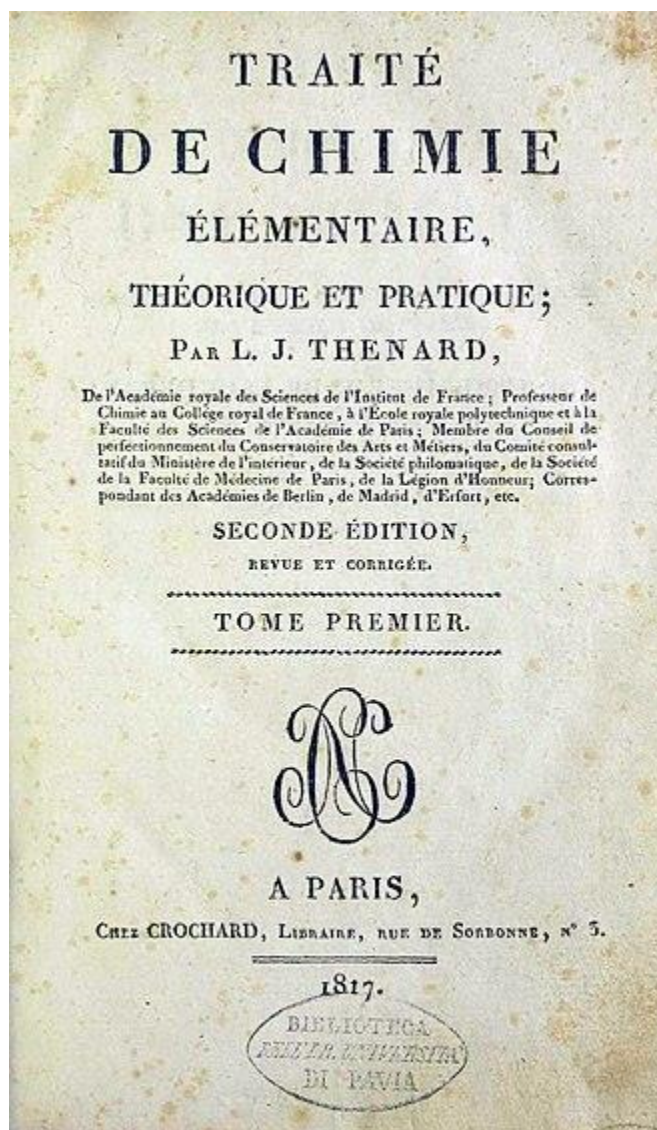
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801

802

803 One of the great historical frauds of the 20<sup>th</sup> century is the notion that Antoine  
804 Lavoisier discovered the element oxygen, O. Farber has provided a thorough  
805 historical account of the whole story. (This does not denigrate the important  
806 contributions made by Lavoisier.) One of Lavoisier's successors, Louis Jacques  
807 Thenard (1777-1857), became the most famous chemist in Paris by the time of his  
808 death and was made a Baron and a Peer of France. He was also one of the 72  
809 immortals inscribed on the Eiffel Tower. He was a great teacher and published the  
810 monumental book:  
811



812  
813  
814 While he was an admirer of Lavoisier, he admired chemical reality more.  
815

816 The philosophical system that dominated French chemistry in the 18<sup>th</sup> century  
817 viewed observable matter as a compound of fundamental matter and one or more  
818 “principles.” All gases needed to contain “caloric.” The product of the heating of  
819 mercuric oxide was viewed as “caloric plus an elemental substance.” Lavoisier  
820 initially called this elemental substance oxygine, the principle of acidity. Farber  
821 quotes from the classic *Chemisches Worterbuch* (1809) by Klaproth-Wolff:

822  
823           We still have not succeeded in preparing oxygen in isolated form;  
824           we know it only in its compounds, of which the simplest  
825           is the one with heat-substance or light-substance  
826           as oxygen gas.

827  
828 Farber also quotes from Thenard:

829  
830           A watch spring can be “burned” in oxygen.  
831           Where does the caloric come from that is developed?  
832           From the oxygen gas, since the iron is solid  
833           and the oxygen gaseous.  
834           Why so much caloric?  
835           Because the oxygen has great “affinity” to the iron.  
836           And why so much light developed?  
837           Because much oxygen gas is absorbed in a short time,  
838           and the heat produced, or the rise in temperature is very great.

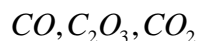
839  
840 By the 5<sup>th</sup> edition of the *Traite* in 1827 the text has been “corrected.”

841  
842           This was the way, since Lavoisier, to account for the production  
843           of heat and light at the moment of combustions and combinations  
844           which different substances can form with each other.  
845           However, this theory, as far as the production of heat is concerned,  
846           cannot be maintained today, because in order to reconcile it with facts  
847           one would be forced to admit the very improbable supposition  
848           that heat exists in the substances in two very different states;  
849           Dulong and Petit have pointed this out.

850  
851

852 Thenard was well aware that new thermodynamic measurements of heat capacities,  
853 including those by Lavoisier, could only be understood if heat was a form of  
854 energy, not a material substance. He also knew that all chemical reactions involve  
855 a “heat of reaction,” not just combustions. In addition, Thenard was thoroughly  
856 familiar with the work of Humphrey Davy that overthrew the “oxygen theory of  
857 acidity.” Not all acids contained oxygen, and many bases did contain oxygen; not  
858 the principle but the material element oxygen!

859  
860 Thenard and J.J. Berzelius (1779-1848) were then free to consider the whole issue  
861 of “oxidation.” Berzelius’ textbook *Lehrbuch der Chemie* (1827) dominated the  
862 mid-19<sup>th</sup> century and is still worth reading today. Farber discusses the presentation  
863 on the oxides of carbon:



865 Carbon monoxide is not an acid and is a gas, oxalic anhydride is a strong acid and,  
866 if it existed would be a solid, and carbon dioxide is a weak acid and is a gas. So  
867 much for the oxygen theory of acidity!

868  
869 Farber then considers the seminal work of P.J. Macquer (1718-1784) and his  
870 *Chymisches Worterbuch* (1790). Macquer coined the term “reduction” for the  
871 restoration of metal calces to the elemental metal. The unification of the chemistry  
872 of oxidation and reduction is certainly a landmark in the history of chemical  
873 philosophy. Farber also cites Lemery as adopting this language in his *Cours de*  
874 *Chimie* (1756).

875  
876 Chemistry is always “open to the future.” New substances are still being  
877 discovered in 2024. In the 19<sup>th</sup> century, higher oxidation states of some elements  
878 were observed, such as potassium permanganate:  $KMnO_4$ . Berzelius discusses this  
879 issue:

880         It is certainly very remarkable that a metal that is so closely related to  
881 the alkali-forming metals, and the oxide of which is one of the strongest salt bases,  
882                 becomes an acid in its highest oxidation stage.

883  
884  
885  
886  
887  
888

889 Eilhard Mitscherlich (1794-1863) commented on the isomorphism of many  
890 crystals:

891  
892 ... the green and red crystals observed by Scheele and by Chevreul  
893 have the same form as the crystals of oxidized-chlorate of kali.  
894 It seems therefore fitting to me that the oxidation stage of manganese  
895 that corresponds to sulfuric, selenic, and chromic acid  
896 be called manganic acid, and the highest oxidation stage of manganese  
897 be called permanganic acid (*acide hypermanganique*)  
898 and that of chlorine perchloric acid (*acide hyperchlorique*) ...  
899

900 Johann Wolfgang Dobereiner (1780-1849) studied the reaction of sulfuric acid with  
901 ethanol and manganese hyperoxide under conditions of heating with an alcohol  
902 lamp:

903 Now the reciprocal action of the components becomes violent,  
904 a tremendous rise of temperature occurs,  
905 and the products of the reaction flow in mass  
906 and press through the [condenser] tube.  
907 After a few minutes, the process is finished  
908 And one finds in the receiver:  
909 1) Heavy oxygen-ether  
910 2) A liquid consisting of water, acetic acid and some alcohol.  
911

912 Ten year later Justus Liebig (1803-1873) investigated the same reaction. He  
913 fractionated the initial distillate and isolated a series of oxidized ethanols. Modern  
914 formulae reveal acetaldehyde and acetic acid. The role of the oxides of manganese  
915 in these reactions was puzzling. The “secret” was the coupling with the pH.  
916

917 Thenard retained his interest in chemical reactions. He studied the reactions of  
918 solid barium oxide with oxygen in a heated vessel. He discovered that the solid  
919 adds a full half-equivalent of oxygen gas, but that further heating evolves the  
920 oxygen. (The higher entropy of the gas becomes dominant at high temperature.)  
921 Even more remarkable, when barium peroxide is dissolved in water no gas is  
922 liberated. He had discovered hydrogen peroxide! When certain other metal oxides  
923 were added to the solution, the pure metal was produced, obviously a “reduction  
924 process” carried out by “oxygen.” Real chemistry is much more complicated than  
925 the textbook (or monograph) version!

926 Farber next considers the history of ozone. Humans had experienced it whenever  
927 there was lightning. In the 18<sup>th</sup> century laboratory lightning could be created with  
928 massive friction machines. (In the 19<sup>th</sup> century Faraday used these devices.) When  
929 laboratory lightning was passed through pure oxygen gas, it lost some of its  
930 pressure, but none of its mass. The smell was very noticeable.

931  
932 With all the Professors in Europe, it fell to an obscure Canadian-American  
933 geologist, Thomas Sterry Hunt (1826-1892), to propose in 1848 that the new gas  
934 was a “polymer” of oxygen, O<sub>3</sub>. (Hunt went on to be a member of the US National  
935 Academy of Science, a founding member of the American Chemical Society, and  
936 twice its President.)

Rejecting the ordinary ideas of electronegative and electropositive relations, as not only baseless but erroneous in their tendency, I consider, with MM. Gerhardt and Laurent, that each class of compounds is derived from a normal species or primitive type by successive substitutions.—In considering such combinations as SO<sub>2</sub> and SeO<sub>2</sub>, which contain three equivalents of the elements of the oxygen group, it was necessary to admit a normal species which should be a polymer of oxygen, and be represented by O<sub>3</sub> = (OOO). The replacement of one equivalent of oxygen by sulphur would yield sulphurous gas (OOS), and a complete metalepsis would give rise to (SSS). The first compound is probably the ozone of Schönbein, which the late researches of Marignac and de la Rive have shown to be in reality only oxygen in a peculiarly modified form.<sup>40</sup>

937  
938 The great 19<sup>th</sup> century physicist, Rudolph Clausius (1822-1888) proposed that  
939 ozone was monatomic oxygen because it was so reactive. (While Clausius is one  
940 of my heroes for his contributions to Thermodynamics, he was highly mistaken  
941 about Chemistry in 1864.) He also referred to hydrogen peroxide as “antozone.”

942  
943 The confusion with regard to the composition of ozone was removed by Jacques-  
944 Louis Soret (1827-1890), the great Swiss chemist and spectroscopist. He studied  
945 the equation of state of the gas and determined the molecular weight of ozone.  
946 However, no bad idea in chemistry ever really disappears. Christian Friedrich  
947 Schonbein (1799-1868) insisted that ordinary oxygen was a compound of two  
948 different forms of oxygen: O(+) and O(-). Thus it could act as either an oxidant or  
949 a reductant. (The underlying phenomenon occurs every day in the upper  
950 atmosphere: diatomic oxygen absorbs sunlight and decomposes to atomic oxygen  
951 that then reacts to produce ozone.) One of the most important concepts in  
952 Chemistry is the full chemical context of any reaction. No isolated chemical can  
953 be fully described with regard to its possible reactions.

954  
955

956 Berzelius constructed a “chemical world” where all compounds can be viewed as  
957 due to electrostatic attraction due to the “polarity” achieved by compound  
958 formation. A classic example might be silver chloride:  $\text{Ag}^+\text{Cl}^-$ . (But, chlorine is  
959 not always the negative partner.) There are many known “pyrites:” compounds  
960 that contain  $\text{S}_2^{-2}$ . In sulfate salts, the sulfur is in an oxidation state of +6! In the  
961 mid-19<sup>th</sup> century, chemists were still bravely trying to understand the multitude of  
962 actual compounds. Ozone was a challenge. In hydrogen peroxide,  $\text{H}_2\text{O}_2$ , the  
963 oxidation state of the oxygen is -1. Depending on the other substances involved in  
964 the reaction, oxygen can end up with oxidation state 0, -1 or -2. It was known that  
965 hydrogen peroxide can “reduce” many metal oxides. Hydrogen peroxide is also  
966 known to “bleach” many substances. How can it do this? The thermochemistry of  
967 the “full reaction” determines the outcome. For the metal oxides, liberation of  
968 water,  $\text{H}_2\text{O}$ , and free oxygen gas,  $\text{O}_2$ , is so exothermic, and the entropy of the gas is  
969 so much larger, that the overall reaction “reduces the calx.”

970  
971 During much of the 19<sup>th</sup> century, solid compounds were only characterized by their  
972 empirical formulae. Potassium and oxygen form two different compounds:  $\text{K}_2\text{O}$   
973 and  $\text{K}_2\text{O}_2 = \text{“KO”}$ . The peroxide is very reactive. Schonbein claimed that the  
974 oxygen in the peroxide was in the (+) state. In potassium permanganate,  $\text{KMnO}_4$ ,  
975 the oxygens are in oxidation state -2. For Schonbein this was the (-) state. That  
976 oxygen is in a different state in hydrogen peroxide and in permanganate is clear.  
977 Schonbein never could quite explain why diatomic oxygen would form “at all”  
978 unless there was a “polarized state.” He can blame this on Berzelius!

979  
980 Hydrogen peroxide reacts with many chemical systems. Schonbein studied many  
981 of them. The “course” of the reaction also depended on the pH. This was before  
982 any coherent theory of acidic solutions existed. Ions in solution were forbidden!  
983 (A quick perusal of a “modern” table of Standard Reduction Potentials reveals that  
984 the behavior of manganese is highly sensitive to the acidity or basicity of the  
985 solution. Real chemistry requires a full accounting of all the species present in the  
986 system and their concentrations.)

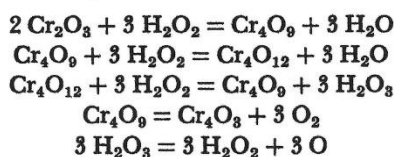
987  
988 Farber now joins the discussion. Schonbein was a good chemist and a careful  
989 experimentalist. He invoked concepts that attempted to rationalize “true  
990 observations.” Farber now points to a later scientist that invoked concepts  
991 developed by Robert Bunsen and Henry Roscoe: Friedrich Kessler (1824-1896).  
992 Kessler obtained his Ph.D. under Eilhardt Mitscherlich in Berlin. Many chemical



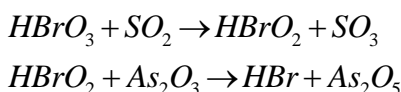
993 reactions are often taking place in a solution. The full set of “coupled reactions”  
 994 needs to be taken into account. When a particular substance can exist in multiple  
 995 oxidation states, it can “catalyze” other reactions! (Fe(II) is a classic chemical  
 996 catalyst.)

997  
 998 Sir Benjamin Brodie (1817-1880) carried out extensive studies of peroxides. He  
 999 understood that elements with multiple oxidation states could participate in many  
 1000 oxidation-reduction reactions. His scheme for chromium is:

1001 On the basis of extensive experiments, Brodie offers the following  
 “System of equations” (p. 851):



1003  
 1004 Farber cites the important contributions of Robert Luther (1867-1945). He was  
 1005 born in Moscow to German parents and was Professor of Chemistry at the  
 1006 University of Dorpat. He envisioned the role of an “acceptor” substance that  
 1007 facilitated the reaction of A and B. Wilhelm Ostwald (1853-1932, Nobel 1909) also  
 1008 got his start at Dorpat! Ostwald considered the reaction:



1011  
 1012 This chemical world was instantiated in a Table by Farber:

1013

TABLE 3			
<i>Actor</i>	<i>Inductor</i>	<i>Acceptor</i>	<i>Observer</i>
HNO <sub>3</sub>	Zn, Cd	HJ	
"	" "	Indigo	
HBrO <sub>3</sub>	SO <sub>2</sub>	AsO <sub>3</sub>	Schilow
"	CH <sub>2</sub> O	"	"
"	Fe	"	"
"	HBr	"	"
"	SO <sub>2</sub>	Indigo	Schaer
KMnO <sub>4</sub>	Mn	Oxalsäure	Kessler, Harcourt
"	CHOOH	"	Schilow
"	zahlreiche Reduktionsmittel	Indigo, Oxysäuren, HCl, H <sub>2</sub> O <sub>2</sub> u.s.w.	
Weinsäure	HClO	Cu	Milton
"	H <sub>2</sub> O <sub>2</sub> , O <sub>3</sub>	"	Schilow
"	O <sub>2</sub>	"	Traube
"	HClO	Au	Luther
Magnesium	J <sub>2</sub>	Alkohole, Äther	Zelinsky
"	Br <sub>2</sub>	"	"

For example: 1)  $\text{HNO}_3 + \text{Zn} = \text{ZnO} + \text{HNO}_2$   
 2)  $2 \text{HNO}_2 + 2 \text{HJ} = \text{J}_2 + 2 \text{NO} + \text{H}_2\text{O}$

1014

1015 Since Farber examined a century of chemical reactions and discussions, he could  
1016 recognize that Gay-Lussac had already arrived at a good general conclusion!

1017  
1018 “Always when the same elements can form different compounds of unequal  
1019 stability, which nevertheless can all exist under the same given circumstances, the  
1020 compound of less stability will be formed first. When conditions change so that it  
1021 cannot maintain itself, then the next more stable one will follow, and so on, until a  
1022 very stable compound is reached.” (*Compte Rend.*, **14**, 927-52 (1842))

1023  
1024 While Walther Nernst (1864-1941, Nobel 1920) is better known for his  
1025 contributions to Chemical Thermodynamics, Farber cites him as one of the  
1026 founders of Chemical Kinetics. The actual path of a chemical reaction influences  
1027 the rate just as much as the overall change in Gibbs energy.

1028  
1029 Farber concludes his discussion with a reference to the book by W.P. Jorrissen,  
1030 *Induced Oxidation* (1959). While it represents sixty years of research, it concludes  
1031 with a long list of “suggestions for further study!” Real chemistry, the kind Farber  
1032 needed to make industrial progress, is often far too complicated to be reduced to  
1033 Freshman Chemistry.

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1035  
1036  
1037  
1038  
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1054  
1055 Among the distinguished authors represented in Volume 11, an interesting paper on  
1056 Thermochemistry appears by Virginia M. Schelar of the University of Wisconsin.  
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1066

1067 The detailed historical analysis begins with the work of Germain Henri Hess  
1068 (1802-1850). A series of papers during the years 1839-1842 appeared in the  
1069 *Bulletin Scientifique, publie par l'Academie Imperiale des Sciences de St.*  
1070 *Petersbourg*. A key statement from this work is:  
1071

. . . no matter by which way a compound may come to be formed, the quantity of heat developed through its formation is always constant, the compound may come to be formed in a direct or indirect way, at once or in different periods of time. This principle is so evident that if I did not think it sufficient in itself I should not hesitate to present it as an axiom.<sup>2</sup>

1072  
1073 It is now called Hess's Law of Thermochemistry. It is an empirical induction  
1074 based on many experimental results.

1075  
1076 The underlying theoretical system was constructed by J.B. Richter and is called  
1077 Stoichiometry. When it is applied to heats of reaction, it allows the calculation for  
1078 reactions that either have not or could not be observed from a set of reactions that  
1079 have been studied.

1080  
1081 Gustav Robert Kirchoff (1824-1887) knew that the observed heat of reaction was  
1082 an explicit function of temperature. He carried out a full Thermochemical analysis  
1083 and derived Kirchoff's Law of Thermochemistry:

1084  
1085 
$$\left( \frac{\partial \Delta H_{rxn}}{\partial T} \right)_P = \Delta C_P(T, P) = \sum_i \nu_i C_{P,i}(T, P)$$

1086 It remains true today. Kirchoff produced this type of result in many areas of  
1087 Natural Philosophy. (The complete scientific and technological community needs  
1088 people like Kirchoff.)

1089  
1090 Schelar also discussed the evolution of the concept of "affinity." While many of  
1091 the concepts were still vague, and real Thermochemistry was necessary to  
1092 understand affinity, the work of Torbern Bergman (1735-1784) is still worth  
1093 reading today.

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1099

DISSERTATION

ON

ELECTIVE ATTRACTIONS.

By TORBERN BERGMANN.

LATE PROFESSOR OF CHEMISTRY AT UPSAL, AND  
KNIGHT OF THE ROYAL ORDER OF VASA.

---

Translated from the Latin by the TRANSLATOR  
OF SPALLANZANI'S DISSERTATIONS.

---

L O N D O N :

PRINTED FOR J. MURRAY, No. 32. FLEET-STREET,  
AND CHARLES ELLIOT, EDINBURGH.

M,DCC,LXXXV.

1100  
1101 Even more progress in this area was obtained by Claude Louis Berthollet (1748-  
1102 1822) in his monumental *Essai de Statique Chimique* (1803). He demonstrated  
1103 that the “effective affinity” depended on the “concentration of the chemical  
1104 species.” C.M. Guldberg and P. Waage published their foundational book: *Studies*  
1105 *on Chemical Affinities* in 1867.

1106  
1107 Schelar proceeds to discuss in detail the work of H.P. Julius Thomsen (1826-1909).  
1108 “Thomsen made about 3500 different calorimetric measurements.” Thomsen was  
1109 able to correlate his measurements of the heats of formation into a constitutive  
1110 theory based on chemical bonds. He also rationalized the work of Kirchoff with  
1111 actual data. As he studied more reactions and discovered the complexity of real  
1112 chemistry, he became more sophisticated in his understanding of chemical  
1113 thermodynamics. He needed to take the entropy of reaction into account.

1114  
1115 Remarkably, Schelar discusses the work of Marcellin Berthelot in adulatory terms.  
1116 (I own a real copy of *Thermochemie* (1897).) He refused to acknowledge entropy

1117 and confused heat with chemical work. The Helmholtz energy (or work function)  
1118 is equal to  $U-TS$ ! At  $T=0$ , entropy does not matter, but then, no one can get there!  
1119 While Schelar claims that “Berthelot defended his principle of maximum work  
1120 with great skill,” he ignored the complete work of J. Willard Gibbs that correctly  
1121 derived all the equations of Thermochemistry in 1878.

1122  
1123 Schelar goes on to discuss the work of Jacobus van't Hoff (1852-1911, Nobel  
1124 1901). She cites his classic book, *Etudes de dynamic chimique* (1884). (I own this  
1125 book as well.) The full theory of Chemical Thermodynamics produces expressions  
1126 for the Helmholtz energy  $A(T,V,\{n_i\})$  and the Gibbs energy  $G(T,P,\{n_i\})$ . The  
1127 condition of equilibrium for any physicochemical process can be expressed as:

1128  
1129 
$$\left(\frac{d\Delta G_{rxn}}{d\xi}\right)=0 \quad \Delta G_{rxn}(T,P,\{n_i\})=\sum_i \nu_i \mu_i(T,P,\{n_i\})$$

1130 where  $\mu_i$  is the chemical potential of substance  $i$  in the reaction, and the  $\nu_i$  are the  
1131 “stoichiometric coefficients for the reaction:  $n_i(\xi)=n_i(0)+\nu_i\xi$ . The quantity  $\xi$  is  
1132 called the advancement of the reaction. (Schelar notes that Gilbert N. Lewis was  
1133 fully aware of all these issues and published the monumental *Thermodynamics and*  
1134 *the Free Energies of Chemical Substances* (1923).)

1135  
1136 The most cogent discussion of the behavior of  $U$  and  $S$  near  $T=0$  is found in the  
1137 book by Walther Nernst (1864-1941, Nobel 1920): *The New Heat Theorem* (1918,  
1138 English 1926). He showed that  $U$  and  $A$  approach one another asymptotically as  $T$   
1139 approaches 0.

1140  
1141 It might be wondered how this interesting but clearly biased article was accepted  
1142 for publication in *Chymia*. The answer is actually easy to discern. The chapter on  
1143 “Physical Chemistry in the 19<sup>th</sup> century” in Aaron Idhe’s *The Development of*  
1144 *Modern Chemistry* (1964) looks familiar. My surmise is that Virginia Schelar did  
1145 much of the research for this chapter while she was a graduate student at  
1146 Wisconsin. Any article submitted by Idhe would be accepted.

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1151

1152 **Volume 12 (1967)**

1153

1154 Although this is the final issue of *Chymia*, outstanding articles were included. I  
1155 have chosen the one on Torbern Bergman.

1156

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1157

1158 Although Torbern Bergman (1735-1784) was intellectually in the same league as  
1159 Roger Boscovich, Gottfried Leibniz and Joseph Priestley, he is little known in  
1160 America. A key biographical source was written by Theodor Svedberg (1884-  
1161 1971, Nobel 1926) in 1922 in Swedish. J.A. Schuffle has kindly translated this  
1162 work and constructed a useful article.

1163

1164 Bergman's most known work is :

1165

1166

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1167

1168

1169 It was first published in Swedish in 1775.

1170

1171 Students flocked to Uppsala to work with Bergman. He was a great Analytical  
1172 Chemist and an inspiring teacher. One of my own favorite works is *An Essay on*  
1173 *the Usefulness of Chemistry, and its Application to the Various Occasions of Life*  
1174 (1784). It can be read with profit today, although it contains words like  
1175 "phlogiston."

1176



1177 Bergman tried to present his work as part of the ongoing progress of Chemistry.

1178

The tables which exist up to now are quite scanty with regard to the number of materials shown, and any substances which are included are compared with very few of the others. This is by no means to reproach the illustrious authors of these tables, for their preparation is a herculean labor of many years. A long time had to be allowed for this work, so that many reactions could be carried out with as much care as I could exercise and although rashness could have brought about completion of the table in much less time, the result would have been less trustworthy. I am aware of the fact that more than 30,000 selected experiments are required for my proposed outline, if it is to come anywhere near perfect completion. But meanwhile I have pondered this with myself, that besides the fact that the course of life is short and a state of good health uncertain, that I ought to publish the observations made by me up to now just as they are, however incomplete and imperfect they may be, so that they may not perish unpublished.

1179

1180

1181 Although “Affinity Tables” were produced throughout the 18<sup>th</sup> century, Bergman  
1182 managed to understand that the actual chemical conditions mattered. For example,  
1183 he knew that reactions carried out *via sicca* (the “dry” way) could result in different  
1184 orders of affinity than those carried out *via humida* (the “wet way in water”). These  
1185 distinctions were an essential part of alchemy.

1186

1187 The chemical “programme” followed by Bergman (and many others) seems obscure  
1188 today, but in the 18<sup>th</sup> century it was a coherent laboratory activity. It allowed working  
1189 chemists to both understand and predict chemical reactions. It was, by its very  
1190 nature, qualitative. But it was ordinal. (This is greater than X and less than Y.)

1191

1192 Uppsala was one of the most sophisticated cities in Europe in the 18<sup>th</sup> century.  
1193 Bergman participated in investigations of “atmospheric electricity” at the  
1194 Observatory of Uppsala University. It became obvious to his teachers that he was  
1195 destined for great things. He was allowed to read and comprehend anything he could  
1196 find. Finally, his parents needed to help him proceed at a sustainable pace.

1197

1198 Bergman wrote his first dissertation on “Twilight” in 1756. His Ph.D. dissertation  
1199 was on *Astronomical Interpolation* (1758). While astronomy might seem a strange  
1200 background for Chemistry, it was perfect for Bergman and he almost immediately  
1201 published a dissertation on *Universal Attraction*. His initial appointment was in  
1202 Physics, which to him was full Natural Philosophy.”

1203

1204 Another great Professor at Uppsala was Carolus Linnaeus, the founder of systematic  
1205 Natural History. He carried out both field biology and systematic classification.  
1206 (What do you suppose he would do with 30,000 chemical facts?!)  
1207

1208 The 18<sup>th</sup> century was also the “Age of Electricity.” Bergman followed the work of  
1209 Franklin and others avidly and published many experiments on electrical  
1210 phenomena.  
1211

1212 Bergman did not limit his scientific interests to the “latest leech,” (yes, he did study  
1213 leeches). In 1766 he published the monumental *Physical Description of the Globe*.  
1214 Svedberg, his biographer, called him the Father of Physical Geography. Abraham  
1215 Werner (1749-1817), the great German geologist, highly valued the work of  
1216 Bergman.  
1217

1218 Bergman’s world was filled with minerals. He published his *Outlines of Mineralogy*  
1219 in 1782. It is filled with chemical details. He was a master of the “blowpipe.” He  
1220 was the best qualitative chemical analyst of his era.  
1221

1222 Bergman was elected to the Swedish Academy of Sciences in 1764. Part of his  
1223 acceptance address is still worth reading:  
1224

A scientist strives to understand the work of Nature. But with our insufficient talents as scientists, we do not hit upon the truth all at once. We must content ourselves with tracking it down, enveloped in considerable darkness, which leads us to make new mistakes and errors. By diligent examination, we may at length little by little peel off the thickest layers, but we seldom get the core quite free, so that finally we have to be satisfied with a little incomplete knowledge.

1225

1226

1227 He went on to describe his procedures for protecting buildings from lightning.  
1228 Sweden was soon thankful.  
1229

1230 Not only did Bergman contribute great science to Sweden, he trained some of the  
1231 best from the next generation: Scheele, Gahn, Rinman, Afzelius, Arvidsson and  
1232 Gadolin.  
1233

1234 As Professor of Chemistry he was in constant correspondence with other leading  
1235 scientists such as Macquer and Priestley. “In 1780 he wrote a paper for the Royale  
1236 Academie de Science in Paris on the chemistry of indigo and its use in dyeing.”

1237 Although Bergman was mathematically sophisticated, and trained as a physicist, he  
1238 felt that practical application should be the ultimate goal of all scientific work. In  
1239 addition to winning a prize for this work, it led to the application of dyes to the  
1240 determination of the concentration of acids in aqueous solution!

1241  
1242 There was great confusion in the 18<sup>th</sup> century about the nature of “fixed air.” (CO<sub>2</sub>)  
1243 It was Bergman that demonstrated that the gas evolved from marble was identical  
1244 to the gas evolved in fermentation and isolated from the atmosphere. (Stahl had  
1245 conjectured that the “acid principle of air” was “sulfureous.” No incoherent  
1246 speculation can trump a real experimental demonstration. But history has largely  
1247 forgotten that Stahl should be forgotten and Bergman remembered.) The Swedes  
1248 celebrate Bergman as the Father of the Swedish mineral water industry. He taught  
1249 them how to prepare “carbonated water” and refused a patent or a royalty!

1250  
1251 Lavoisier is rightly celebrated for his efforts to rationalize the names of chemical  
1252 substances, but Bergman did much more in this area. His *Manual of Mineralogy*  
1253 contained a Linnaean system for Chemistry that assigned names based on  
1254 laboratory chemistry, not alchemical artefacts. Bergman corresponded with Joseph  
1255 Macquer and sent him his major books. Bergman preferred Latin names, just as  
1256 Linnaeus. But, once order had been created by Bergman and his French  
1257 colleagues, the system could be constructed in any language. (W.A. Smeaton has  
1258 beautifully discussed this issue in *Annals of Science*, **10**, 87-106 (1954).)

1259  
1260 Bergman was very interested in mineral crystals. He knew of the work of Nicolaus  
1261 Steno on the faces of crystals and applied it to “calcspar.” He discussed the growth  
1262 of crystals at the faces. The great French crystallographer, Rene-Just Hauy  
1263 appreciated the early work of Bergman and went on to both measure real crystals  
1264 from all the 32 possible groups and construct the essential rhombohedra for each  
1265 type.

1266  
1267 J.A. Schufle went on to publish a full book on Bergman: *Torbern Bergman: A Man*  
1268 *Before His Time* (1985). It is 547 pages long! Academic historians have not  
1269 warmed to this book because it was not written for them. (*Isis*, **78**, 131(1987))

1270  
1271  
1272  
1273

1274 While an occasional volume of *Chymia* can be purchased online, it is freely  
1275 available at JSTOR: <https://www.jstor.org/journal/chymia> . This HIST treasure  
1276 should be appreciated by all historians of chemistry.

1277

1278

1279