References and Notes

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THE INGENIOUS, LIVELY AND CELEBRATED MRS. FULHAME AND THE DYER'S HAND

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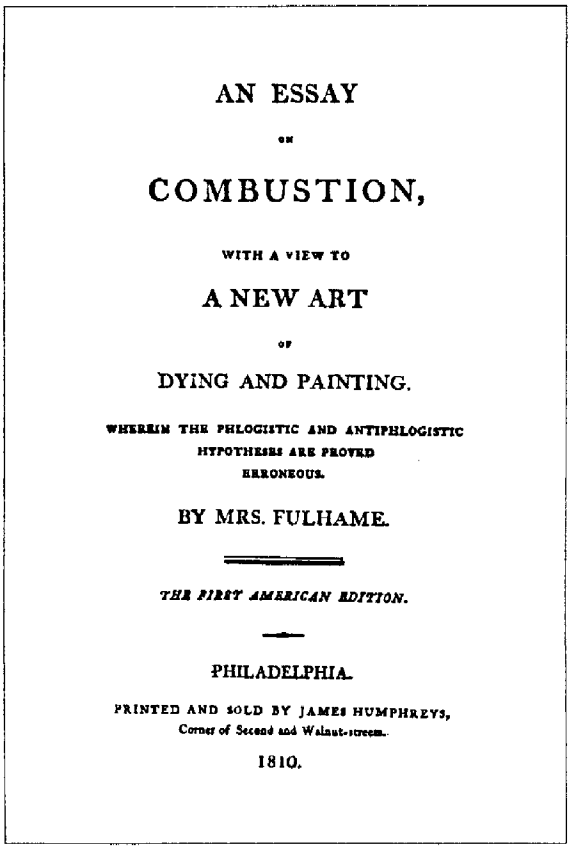
Recent revisionist scholarship still allows that 1794 was a crucial year for both Antoine Lavoisier and Joseph Priestley (1). It was also a crucial year for the less often celebrated Mrs. Fulhame - the intermittent labors of close to 14 years culminated in the publication of her *Essay on Combustion with a view to a New Art of Dying and Painting wherein the Phlogistic and Antiphlogistic Hypotheses are Proved Erroneous* (2). The *Essay* was to prove Mrs. Fulhame's only publication and what little we know of her must be inferred from the idiosyncratic preface and from the few personal references in the body of the book. As with Shakespeare's sonnets and their elusive lady:

My nature is subdued
To what it works in, like the dyer's hand;
Pity me then and wish I were renewed.

Not that the book was to pass unnoticed. The normally ungenerous Count Rumford conceded (3):

This agrees perfectly with the results of similar experiments by the ingenious and lively Mrs. Fulhame. It was on reading her book that



AN ESSAY

ON

COMBUSTION,

WITH A VIEW TO

A NEW ART

OF

DYING AND PAINTING.

WHEREIN THE PHLOGISTIC AND ANTIPHLOGISTIC HYPOTHESES ARE PROVED ERRONEOUS.

BY MRS. FULHAME.

THE FIRST AMERICAN EDITION.

PHILADELPHIA.

PRINTED AND SOLD BY JAMES HUMPHREYS, Corner of Second and Walnut-streets.

1810.

First American edition of Mrs. Fulhame's book.

I was induced to engage in these investigations; and it was by her experiments that most of the foregoing experiments were suggested.

while the normally charitable Priestley grumped (4):

... her theory is fanciful, and fabulous, as the story of the phenix itself.

a quotation to which J. R. Partington added the even less charitable and quite gratuitous footnote (5):

The phoenix, it may be noted, was a fabulous bird regarded as sexless.

The *Essay* received several reviews in French journals, one, by Coindet, running to 27 pages with detailed chapter-by-chapter summaries (6). A German translation appeared in 1798 and, as we shall see, an American edition in 1810.

The genesis of the book is described in the preface:

The possibility of making cloths of gold, silver, and other metals by chymical processes, occurred to me in the year 1780; the project being mentioned to Doctor Fulhame and some friends, was deemed improbable. However, after some time, I had the satisfaction of realizing the idea in some degree by experiment.

Though I was, after some considerable time, able to make small bits of cloth of gold and silver, yet I did not think them worthy of public attention; but by persevering, I at length succeeded in making pieces of gold cloth, as large as my finances would admit.

Some time after this period, I found the invention was applicable to painting, and would also contribute to facilitate the study of geography; for I have applied it to some maps, the rivers of which I represented in silver, and the cities in gold. The rivers appearing as it were in silver streams, have a most pleasing effect on the sight, and relieve the eye of that painful search for the course and origin of rivers...

So far it looks a suitably domestic hobby for the wife of a doctor of modest means, particularly one who describes herself as "averse from indolence, and having much leisure."

But this particular author was no ordinary housewife. Halfway through the preface the tone abruptly changes from insecuriosity to near bellicosity:

As to patrons, I have heard of such beings on the record of fame, but never saw one; on the contrary, it has been my lot to know of many whose malignant breath, as far as its deadly influence can extend, never ceases to blast the unsheltered blossoms of science. And as for a patent, had I even the means I should perhaps never attempt it; for if we may judge of the future by the past, I can safely affirm, that such an application would be vain.

Thus circumstanced, I published this essay in its present imperfect state, in order to prevent the furacious attempts of the prowling plagiary, and the insidious pretender to chymistry, from arrogating to themselves and assuming my invention in plundering silence; for there are those, who if they cannot by chymical, never fail by stratagem and mechanical means, to deprive industry of the fruits and fame of her labours.

Quickly the preface modulates to a rousing feminist diatribe:

It may appear presuming to *some*, that I should engage in pursuits of this nature; but averse from indolence, and having much leisure, my mind led me to this mode of amusement, which I found entertaining and will I hope be thought inoffensive by the liberal and the learned. But censure is perhaps inevitable; for some are so ignorant, that they grow sullen and silent, and are chilled with horror at the sight of any thing that bears the semblance of learning, in whatever shape it may appear; and should the *spectre* appear in the shape of *woman*, the pangs which they suffer are truly dismal.

There are others who suffer the same torture in a still higher degree; but by virtue of an *old inspiring tripod*, on which ignorance, servility, or chance, has placed them, assume a dictatorship in science, and fancying their rights and perogatives invaded, swell with rage and are suddenly seized with a violent and irresistible desire of revenge, manifesting itself by innuendos, nods, whispers, sneers, grins, grimace, satanic smiles, and witticisms uttered sometimes in the acute, and sometimes in the nasal obtuse twang, with an affected hauteur, and contempt of the *spectre*; shrugs, and a variety of other contortions attending.

Sometimes the goblin, which thus agitates them lurks latent, and nothing is perceived but hollow murmurs, portending storms: sometimes the lurking fiend darts with sidelong fury at the devoted object, which, if unarmed, falls a victim to the grisly monster.

But happily for human kind, the *magic tripod* drags none into its dizzy vortex, but those who are radically stupid and malicious, who are the beasts of prey destined to hunt down unprotected genius, to stain the page of biography, or to rot unnoted in the grave of oblivion.

But happen what may, I hope I shall never experience such desertion of mind, as not to hold the helm with becoming fortitude against the storm raised by ignorance, petulant arrogance, and privileged dulness.

With the marvellous phrase "ignorance, petulant arrogance, and privileged dulness" the storm subsides as suddenly as it began. To this point the Preface might seem to belong more to the history of feminism than to the history of chemistry. It is no doubt significant that the book was sold by Joseph Johnson, the famous liberal publisher of Thomas Paine, Richard Price, Joseph Priestley and Mary Wollstonecraft. Johnson's literary luncheons were famous, and it is tempting to imagine Mrs. Fulhame meeting the author of *A Vindication of the Rights of Woman* at one of these. And it is surely to Priestley that she refers in the passage:

But the British empire should not forget, that she owes her power and greatness to commerce; that she is, as it were, the hive of the arts, and should not, by the sulphureous vapour of oppression and neglect, compel her bees to swarm for protection to foreign climes, but rather permit them to roam in their native soil, and allow them, in the winter of life, to sip a little of the honey of their own industry.

It is, however, the last paragraph of the Preface that assures Mrs. Fulhame's *Essay* its modest place in the history of chemistry:

Finding, the experiments could not be explained on any theory hitherto advanced, I was led to form an opinion different from that of M. Lavoisier, and other great names. Persuaded that we are not to be deterred from the investigation of truth by any authority however great, and that every opinion must stand or fall by its own merits, I venture with diffidence to offer mine to the world, willing to relinquish it, as soon as a more rational appears.

November 5th, 1794

With diffidence? November 5th is, of course, Guy Fawkes' Day and in Mrs. Fulhame's skeptical view both M. Lavoisier and "Gunpowder Joe" Priestley were due for their comeuppance.

Whatever had been the modest promptings for her experiments, by the time she came to publish the *Essay on Combustion*

Mrs. Fulhame had become at least as much interested in chemical theory as she was in the production of "cloths of gold". The introduction, with its summaries of Beccker (sic), Stahl, Lavoisier, Macquer, Scheele, and Kirwan reveals a well-versed author, though the only source cited is the second edition of Kirwan's *Essay on Phlogiston*. There is no mention of Kerr's translation of Lavoisier's *Traité* that had appeared several years earlier.

While she leans to the views of Lavoisier and the anti-phlogistonists she by no means follows the party line:

... the antiphlogistic account of calcination and reduction is no less complex, erroneous, and repugnant to the simplicity of nature: for when we consider the various sources, whence they derive the oxygen, which oxygenates bodies; and the long list of metallic reducers, which they suppose; it must be allowed, that if simplicity be a recommendation, the hypothesis is destitute of advantage.

The principal basis for her criticism lay in her firmly held belief that "the hydrogen of water is the only substance, that restores oxygenated bodies to their combustible state; and that water is the only source of the oxygen, which oxygenates combustible bodies." These principles she felt she had established by experiment.

The main part of the *Essay* describes these numerous, meticulous, and numbingly tedious experiments. We can vouch for their tediousness since we have repeated quite a number of them with results approximating hers. Where differences occur they may be attributed to the indeterminate purity of many of Mrs. Fulhame's reagents rather than to her (or our) lack of skill and scrupulosity. The nature of the experiments is well described in the teutonic title of the German translation of her book published in Göttingen in 1798: *Versuche über die Wiederherstellung der Metalle durch Wasserstoffgas, Phosphor, Schwefel, Schwefelleber, geschwefeltes Wasserstoffgas, gephosphortes Wasserstoffgas, Kohle, Licht und Sauren* (7). In general she exposed metallic salts in aqueous solution, in the dry state, and occasionally in ether or alcohol solution to the action of the various reducing agents. Her apparatus was generally of Priestleyan simplicity, though occasional recourse was made to the apparatus of Nooth and others.

It would be an act both of supererogation and of penance to summarize all her experimental findings. Rather we will state and comment on her own "Conclusion(s)" as listed in the final chapter of the book:

1. Neither the Phlogistians, nor Antiphlogistians, account in a satisfactory manner for the increase of weight, which bodies acquire during combustion.

There are no quantitative data in the *Essay* so Mrs. Fulhame's objections are qualitative. They are hard to fathom and would seem largely prejudicial. One has already been mentioned: the putative complexity of Lavoisier's explanations. A second objection is based on Priestley's and Kirwan's conviction that "since the dryest oxygen gas contains a large proportion of water, ... and since the whole of the gas, except the caloric, and light, is absorbed, it necessarily follows, that the increase in weight which bodies acquire during combustion, depends not only on the oxygen, but also on the water, contained in vital air".

2. Their account of the formation of water, acids, and oxids, is erroneous; for it has been shown that the oxygen of water alone oxygenates combustible bodies.

Mrs. Fulhame showed experimentally that water was essential to most of the reductions she studied. Little reaction occurred in the dry state and even when the "ultimate particles" were separated in ethereal and alcoholic solution reaction remained slow or negligible as compared with the reaction in aqueous solution. She attributed any marginal activity in ether and alcohol to the difficulty of getting the solvents water-free. From the seeming necessity of the presence of water to the singular and necessary intermediacy of water was, for her, a short and logical step. We shall return to this in conclusion 5.

3. Combustible bodies, as hydrogen, phosphorus, sulphur, charcoal, light, etc. are capable of reducing the metals in the ordinary temperature of the atmosphere; and indeed I might add, at a much lower temperature, as I frequently experienced.

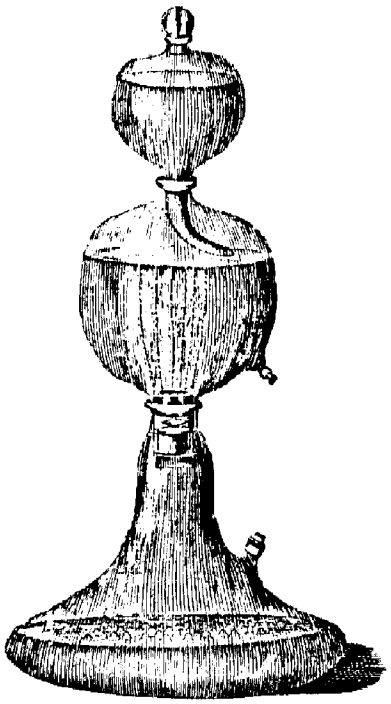
This was by far the most important of Mrs. Fulhame's generalizations as was pointed out by J. W. Mellor in one of the very few subsequent commentaries on her work (8). Previously, such reductions had tended to be carried out at high temperatures, often in a furnace. By means of several hundred qualitative experiments she showed that many metal ions in aqueous solution could be reduced at or near room temperature. Not surprisingly most of the metal salts reduced were those of metals with either positive or small negative reduction potentials. It is highly unlikely that zinc or even iron could be reduced by hydrogen at neutral pH and we must ascribe Mrs. Fulhame's observations to impurities in the metals, the hydrogen, or the silk. In a number of cases she made the acute observation that several of the reduced metals disappeared on exposure to air - one of the earliest examples of the dynamic nature of oxidation and reduction. On another occasion she encountered and explains correctly the passivation of iron. Not surprisingly, she was fascinated by the sequences of colors observed in the reductions and ascribed them to decreasing degrees of oxidation. She even speculated that these intermediate degrees of oxidation might be related to the colours metal ions give to glass.

4. Combustible bodies do not reduce the metals by giving them phlogiston, as the Phlogistians suppose; nor by uniting with, and separating their oxygen, as the Antiphlogistians maintain.

This would appear to be a general dissent while that in conclusion 1 was restricted to matters of weight.

5. Water is essential both to the reduction and oxygenation of bodies, and is always decomposed in these operations.

Many late 18th century chemists seemed reluctant to relinquish the idea that air, earth, fire, and water were, in some fundamental way, elemental. Even after Cavendish, Watt and Lavoisier had established the compound nature of water around 1783, many of them were loath to admit water as a mere chemical compound like any other. Or, to speak anachronistically, that oxygen pulled on its hydrogen atoms one bond at a time. We have seen how Priestley and Kirwan had claimed that even completely dry dephlogisticated air still contained water. Others "saw" water lurking in all sorts of strange and unverifiable places. Mrs. Fulhame is virtually obsessed with the idea that water played the central role in her oxidations and reductions and, by extension, in calcination and reduction in general. Throughout the book she insists on the mechanistic intermediacy of water: the metal [ion] gave its "oxygen" to the hydrogen contained in the water while at the same time the hydrogen gas was combining with its incipiently deprived oxygen. She describes this process as being due to the operation of a double, as opposed to the more common single, affinity. At one point she seems to claim that two quantities of water appear where only one existed before, but the logic of her arithmetic escapes the modern eye. Furthermore she herself seems to implicitly recant this bizarre notion in conclusion 8 below. Her basic concept is clearly a mechanistic/catalytic one and, as J. W. Mellor has observed, well ahead of its time (8).



A Nooth apparatus used by Mrs Fulhame in her experiments. Originally made to carbonate water, gases chemically generated in the lower chamber are bubbled through the liquid in the upper chamber, where they can react with the liquid or with various solutes.

6. Water does not contribute to metallic reduction merely by dissolving and minutely dividing the particles of metallic salts, and thus removing the impediment opposed to chymical attraction by the attraction of cohesion: for were this the case, metallic solutions in ether and alcohol, in which that impediment is equally removed, should be as readily and effectually reduced, as metallic solutions in water are.

This conclusion is self-explanatory.

7. When one body is oxygenated, another, at least, is restored at the same time to its combustible state; and v.v. when one body is restored to its combustible state, another at least is at the same time oxygenated.

The language and the conclusion, taken in isolation, are pure anti-phlogistonism.

8. Quantities of air, and water, equal to those decomposed in the different species of combustion, are constantly a forming. Thus nature, by maintaining this balance of power between combustible and oxygenated bodies, prevents the return of original chaos.

When Joseph Priestley first stumbled on the ability of a sprig of mint to revitalize "injured air" in 1772, he was quick to grasp its importance in maintaining Nature's balance. His subsequent work tended, not untypically, to cloud the issue (perhaps literally) and it was not until 1780 when he and Jan Ingenhousz shared "the same summer and the same sun" that the essential chemical component of the photosynthetic cycle was put on a firm footing. Mrs. Fulhame frequently comments on the reversibility of her reductions and emphasizes their complementarity. In the closing paragraph of her *Essay* she uses the word equilibrium in a surprisingly modern way and ends with the fine, if maligned, image of the phoenix rising from her ashes:

This view of combustion may serve to show how nature is always the same, and maintains her equilibrium by preserving the same quantities of air and water on the surface of the globe; for as fast as these are consumed in the various processes of combustion, equal quantities are formed, and rise regenerated like the Phenix from her ashes.

An American edition of Mrs. Fulhame's Essay was brought out in Philadelphia in 1810 (9). Its chief additional interest lies in a curious "Advertisement" by the American Editor:

The interesting contents of the subsequent pages, by the very ingenious Mrs. Fulhame, are assuredly deserving of more attention, than they have hitherto received; for although published so far back as the year 1794, little notice has been paid to the numerous experiments, by which she has opposed the doctrines of combustion, &c. advanced by the respective advocates of the phlogistic and antiphlogistic theories. How successfully she has executed this, must be left to the candid inquirer after truth, who, provided the end be attained, does not stop to consider from what source it is derived.

Whether it be that the pride of science, revolted at the idea of being taught by a female, I know not; but assuredly, the accomplished author of this essay, has sufficiently evinced the adequacy of her acquirements, in the promulgation of opinions subversive of a part of the highly esteemed edifice, raised by the efforts of Lavoisier and others.

The anonymous Editor goes on to lament the near oblivion into which Mrs. Fulhame's book had fallen in England and hoped for a better fate for it "in this favoured land, where freedom of inquiry is so sedulously cherished". He was to prove a poor prophet. The advertisement concludes:

I cannot doubt the justice of the opinions deduced by Mrs. Fulhame from her numerous and well conducted experiments: and although it may be grating to many, to suppose a female capable of successfully opposing the opinions of some of our fathers in science; yet reflection will serve to satisfy the mind devoted to truth, that she has certainly thrown a stumbling block of no small magnitude, in the way of sentiments we have been taught to consider as sacred.

PHILADELPHIA,
February 14th, 1810.

As with the earlier Guy Fawkes' Day dateline, one wonders if February 14th were a mere coincidence.

Who was this anonymous, informed, opinionated, articulate, non-male-chauvinistic American Editor? James Woodhouse, who spoke approvingly of the celebrated Mrs. Fulhame, is one possibility. A more likely one is Thomas Cooper (10, 11). He was certainly opinionated, articulate and widely, even extravagantly, informed. Cooper had once run a bleaching and dyeing works in Manchester, and he was to compile and edit *A Practical Treatise on Dyeing and Callicoe Printing* published in Philadelphia in 1815. This was only one of several semi-hack publications on topics such as cookery, gas lights, lunatic asylums, etc., that Cooper published in the period 1808-1820. More substantial were his editions of Jane Marcet's *Conversations on Chemistry* and Thomas Thomson's *System of Chemistry* and his editorship of the *Emporium of Arts and Sciences*. Furthermore, Cooper had been living in Joseph Priestley's house in Northumberland at about the time Priestley was writing the first edition of his *The Doctrine of Phlogiston Established*, with its somewhat condescending opinion of Mrs. Fulhame's theories. Most importantly, in 1792 Thomas Cooper had also been published by Joseph Johnson shortly before he was to bring out Mrs. Fulhame's *Essay*. Cooper's *A Reply to Mr. Burke's Invective* is informed, opinionated, fearsomely articulate, and at times explicitly non-male-chauvinistic (12):

... I have repeatedly considered the subject of the *Rights of Women*, and I am perfectly unable to suggest any Argument in support of the political Superiority so generally arrogated to the Male Sex, which will not equally apply to any system of Despotism of Man over Man ... The fact is, that we behave to the female sex, much in the same Manner as we behave to the Poor. We first keep their Minds, and then their Persons in Subjection

... I have read the Writings of Mrs. Wollstonecroft, of Mrs. Barbaud, of Mrs. Montague, etc., in England ... I have conversed with Madame Condorcet, Madame Robert, Madame Lavoisier, etc., in Paris. What these Women are, other Women might become. I have often felt my own Inferiority, and often lamented the present iniquitous and most absurd notions on the Subject of the disparity of Sexes ... Let the Defenders of male Despotism answer (if they can) "THE RIGHTS OF WOMAN" by Miss Wollstonecroft.

On these, as on so many other matters, Thomas Cooper was, as he lamented late in life, "a man 50 years ahead of his time" - closer to 150 years perhaps in some things. In chemistry, however, Cooper tended to run behind the times, perhaps out of loyalty to his beloved Priestley, and in his 1811 Inaugural Lecture as Professor of Chemistry at Dickinson College he was still reluctant to admit the virtually total ascendancy of the antiphlogistonists though he did, rather grudgingly, render Lavoisier his due.

Thomas Cooper had another 30 years of turbulent and well-documented life ahead of him (13). Mrs. Fulhame drops from the pages of history. Her *Essay on Combustion* survives as a lively chronicle and idiosyncratic abstract of those paradigmatically fluxional times:

Nor shall this peace sleep with her, but as when
The bird of wonder dies, the maiden phoenix,
Her ashes new-create another heir
As great in admiration as herself.

References and Notes

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THOMAS DUCHÉ MITCHELL AND THE CHEMISTRY OF PRINCIPLES

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That Lavoisier's work constitutes, in some fundamental sense, a true chemical revolution has never been doubted by chemists, whether his contemporaries or those later generations blessed with the gift of historical, albeit whiggish, hindsight. Historians of science, on the other hand, have been less certain and a small, but vocal, literature has evolved debating the exact revolutionary content of Lavoisier's work, whether it was indeed a true revolution, and even the question of whether scientific revolutions exist in the first place (1). At times, and with more than a little exaggeration, one is tempted to compare this state of perpetual historical uncertainty with David Donald's evaluation of the state of American Civil War history - namely

Thomas Duché Mitchell

that "there must be more historians of the American Civil War than there were generals fighting it and, of the two groups, the historians are the more belligerent"(2).

It has been said that the art of revolution is really the art of making explicit the implicit and, on my better days, I delude myself that this simple aphorism is able to account for both the elements of continuity and discontinuity present in all such conceptual upheavals. If this characterization is even approximately acceptable, then there is one very fundamental aspect of the older chemistry which Lavoisier's work failed to transform immediately and that is the question of how to theoretically rationalize the specific or intrinsic properties of matter. For though, as I will argue later, Lavoisier implicitly provided the techniques which would lead to the modern viewpoint, he did not himself explicitly confront this issue, let alone revolutionize it.

As even a superficial glance at 19th century chemistry textbooks (and some of the better 20th century textbooks) will show, this problem lies at the very core of chemistry's identity as an independent science (3). Whereas classical physics deals with the general properties common to all matter, such as mass, inertia, the laws of motion, etc., it is chemistry which deals with the individuality of different kinds of matter; with their specific properties; with why they possess the colors, textures, odors, and flavors they have; and with why they can be interconverted into certain kinds of materials with equally mysterious arrays of specific properties, but not into others.

The modern interpretation of this problem is based on the atomic-molecular theory and the hypothesis that these properties are in some manner the emergent result of the number, kind, and arrangement of a substance's component atoms or, in more reductionist terms, of its ultimate electronic composition and structure. But from the time of the Greeks until the end of