Chemistry for Beginners. Women Authors and Illustrators of Early Chemistry Textbooks

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Abstract: Before women could participate directly in the creation of scientific knowledge, they worked privately as translators, illustrators, and authors of science books. In the early nineteenth century, Jane Marcet in Britain, and later Almira Lincoln Phelps in the U.S., recognized the need for experimental training of beginners and, to compensate for the lack of experiments, produced meaningful drawings for their textbooks. By using a fresh narrative, a pleasing style, and beautiful drawings of their own, they wrote "chemistries for the beginners" that were both instructional and entertaining. Engraved in the tradition of the nineteenth century illustration, Jane Marcet's *Conversations on Chemistry* and Almira Lincoln Phelps' *Chemistry for Beginners*, originally written for the education of women, were immensely successful and lasted longer than many of the more specialized contemporary works.

Introduction

In the early nineteenth century, before the rise of professional science, many talented women served science as popularizers [1–4]. Some were teachers writing introductory textbooks on a variety of topics, often producing their own illustrations. For example, botanical artists not only created original drawings in pen and ink for their books, but learned the crafts of hand coloring and engraving as well. As the century went on, women did scenic and technical drawings for geological survey reports, drew paleontological and topographical plates, colored maps, etc., working privately with their scientific husbands and friends. Their drawings show patience, dedication, and attention to detail [5, 6].

Until the advent of photographic book illustration (around 1880), drawings were the basis for woodcuts, lithographs, and copper engravings [7]. The first great books in natural sciences and cartography were all illustrated by woodcuts. In this intaglio process, the lines that make up a picture were drawn on the smooth surface of a piece of softwood such as cherry or pear wood. After the wood was cut away, the lines of the drawing would stand out in relief and could be inked for printing. Copper engravings, the oldest of all intaglio processes (early fifteenth century), gave more delicate lines and much finer details. Once engraved, the image was transferred to paper and hand-colored afterward.

The authors and illustrators of chemistry and natural philosophy books were science educators writing textbooks appropriate for classroom or private teaching. With the growing popularity of scientific lectures, and later the study of science in academies and seminaries, there arose a demand for introductory science books, easy to read, with illustrations to attract the interest of students or casual readers. This was the task some authors set for themselves, especially those interested in the science education for women. So was Jane Marcet (1769–1858), remembered for her famous *Conversations on Chemistry* published anonymously in 1806 [8]. Mrs. Marcet gave an up-to-date review of chemical theory, and for the first time, used hands-on laboratory experiments for training beginners. Indeed, the title page of *Conversations on Chemistry. In which the Elements of that Science are familiarly explained and illustrated by Experiments and Plates* emphasized this rather unusual departure for that day. In the US, Almira Hart Lincoln Phelps (1793–1884), prepared textbooks for her pupils at the Troy Female Seminary and later the Patapsco Female Institute *(Familiar Lectures on Botany, Chemistry for Beginners, Familiar Lectures on Chemistry).*

In those early years, Mrs. Phelps stressed the importance of experiments, "let them be ever so simple," in teaching of chemistry. In the Preface of *Chemistry for Beginners: with engravings by Mrs. A.H. Lincoln Phelps,* she wrote: "It is desirable that teachers should be able to make some experiments, but some teachers who use this book have neither space nor time for experiments. I have endeavored to give such drawings as might compensate, as far as possible, for the wants of experiments" [9]. The idea of using illustrations to help the student to understand the experiments is reinforced through the text. For example, explaining the pneumatic cistern, she wrote: "Should some of the pupils not have the advantage of doing chemical experiments as they proceed in their studies, they may obtain an idea of the manner in which gases are collected, from the figure here presented."

Indeed, it seems that at a time when experimental instruction in schools was scarce and its value not yet recognized, women created and used illustrations to facilitate the study of chemistry. How have women implemented the equipment and laboratory practices of the day into their textbooks? What can the illustrations tell us today about the early nineteenth century chemist's tools and surroundings and the progress of instruments as the century went on? This article revisits some of the introductory chemistry textbooks written and/or illustrated by women. The drawings in some other "old chemistries" [10, 11] are examined as well.

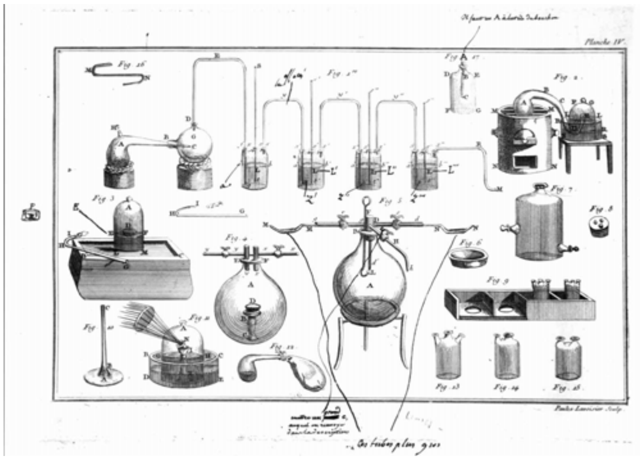

Figure 1. Lavoisier's combustion experiment (Plate IV) with Madame Lavoisier's ink notations (reproduced by permission of the Division of Rare and Manuscript Collections, Cornell University Library).

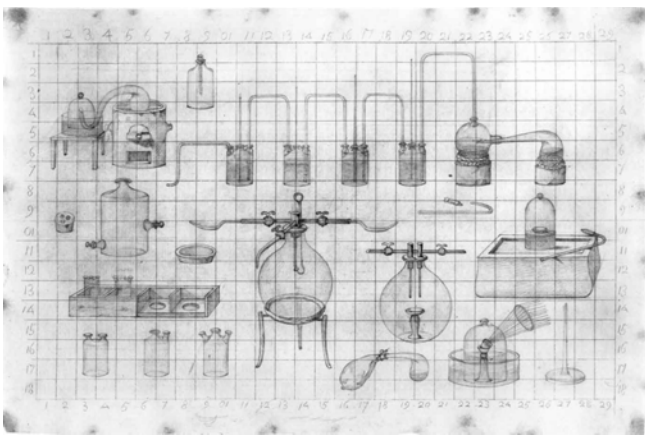

Figure 2. Plate IV, Madame Lavoisier's pencil sketch (reproduced by permission of the Division of Rare and Manuscript Collections, Cornell University Library).

The nineteenth century's textbooks stemmed from Lavoisier`s *Traité élémentaire de chimie* [12] (translated into English under the title *Elements of Chemistry)*, a landmark in the history of chemistry. Because of the importance of this text, 1789 (the year of the book's publication) was recently proposed as the year when modern chemistry really began [13]. Lavoisier conducted conclusive experiments on the nature of combustion and oxidation. By employing quantitative methods, he overthrew the phlogiston theory then in vogue, and explained combustion as a combination with oxygen. The *Traité,* a synthesis of Lavoisier's "new chemistry," was illustrated by his wife, Marie Paulze Lavoisier. Many of her drawings, especially those concerning the composition of atmospheric air and water, found their way into the next century's textbooks and encyclopedias.

Madame Lavoisier, illustrator of Lavoisier's famous Traité élémentaire de chimie

"Take a large balloon [Figure 1, Pl. IV] of crystal or white glass... to which a cap of brass is accurately fitted with emery."[12**]**

In the third part of the *Traité,* Lavoisier gave a detailed description of the chemical operations and of all the instruments, "a tour of the laboratory" [14]. Enhanced by his wife's beautiful illustrations, the tour became historical. It opens with common utensils such as mortars and pestles, crucibles, spatulas, sieves, and funnels, and also a collection of glassware, stills, and retorts (a description of the plates in the figures is given in ref. 15). Small items such as clay dishes, hooked iron wires ″made red hot to set on fire very inflammable bodies," as well as the most sophisticated combustion apparatus are displayed. To burn phosphorus, Lavoisier used the apparatus shown in Plate IV (Figure 1). One of the tubes that pass through the cap is connected to an air pump, the other to a *gazometer* (gas-holder) filled with oxygen. A porcelain cup in the *balloon* (a glass globe) holds the phosphorus that will be set on fire ″by means of a burning glass.″ The brass cap was sealed with fat lute—a mixture of fine clay and boiled linseed oil used to hermetically seal the joints—and allowed to dry for some days [16]. But, in Lavoisier's opinion, mercury was ″the most proper″ metal for the subject of conclusive experiments on oxidation. Figure 1 shows his classic experiment on the oxidation of mercury in ″common air.″ The apparatus consists of a retort (A) having a crooked glass tube BCDE

> ″melted on to its beak, and which is engaged under the bell-glass FG standing with its mouth downwards in a basin filled with water or mercury. The retort is placed upon the bars of a furnace MMNN or a sand-bath and, by means of this apparatus we may, in the course of several days, oxydate a small quantity of mercury in common air; the red oxyd floats upon the surface, from which it may be collected and revived, so as to compare the quantity of oxygen gas obtained in revivification with the absorption which took place during oxydation″

wrote Lavoisier [12].

Madame Lavoisier was a gifted painter and engraver. Her drawings for the thirteen copperplate illustrations were detailed and true to life. There is nothing amateurish about Madame Lavoisier's work; she held herself to very rigorous standards. Assisting in the laboratory and recording Lavoisier's observations on the ongoing experiments (her large, almost masculine handwriting stands out in many pages of the *Registres de Laboratoire*), she obviously was familiar with the instruments [17].

As Duveen showed, drawing the illustrations for the *Traité* was painstaking work [18]. First, she would sketch the apparatus, then copy the sketches onto squared paper (the pencil sketch of Plate IV is shown in Figure 2) and, via wax paper, would transfer the drawings to the copperplate and insert the lettering. In the margins of the plate (Figure 1), one can see Madame Lavoisier's ink notations"*″Ces tubes plus gros″* she wrote, referring to the two tubes (MM and NN) connected to the *gazometers*. The third tube, leading to an air pump, has to be marked by a C *(″mettre a grand C, auquel on renvoye d'autre(?) description*). In agreement with the convention of the eighteenth century illustration, the instruments in this plate, as well as the other drawings (now part of the Lavoisier Collection at Cornell University Library), are marked with fine closely spaced lines to show that they are three-dimensional [19]. In spite of the general reluctance of women to put themselves forward, Madame Lavoisier signed the plates with her own name: *Paulze Lavoisier sculpsit* (engraved by Paulze Lavoisier).

Figure 3. Lavoisier and his wife in the laboratory (bas-relief of Lavoisier's monument, reproduced from Massain, R. Chimie et chimistes; Magnard: Paris, 1961, p 137).

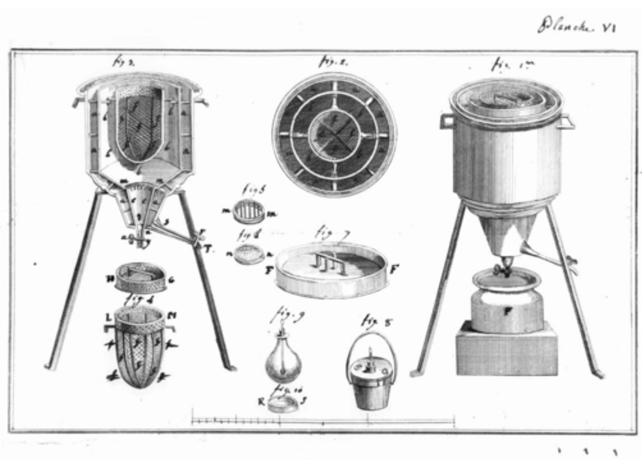

Figure 4. Lavoisier and Laplace's ice calorimeter (Plate VI) with Madame Lavoisier's ink notations (reproduced by permission of the Division of Rare and Manuscript Collections, Cornell University Library).

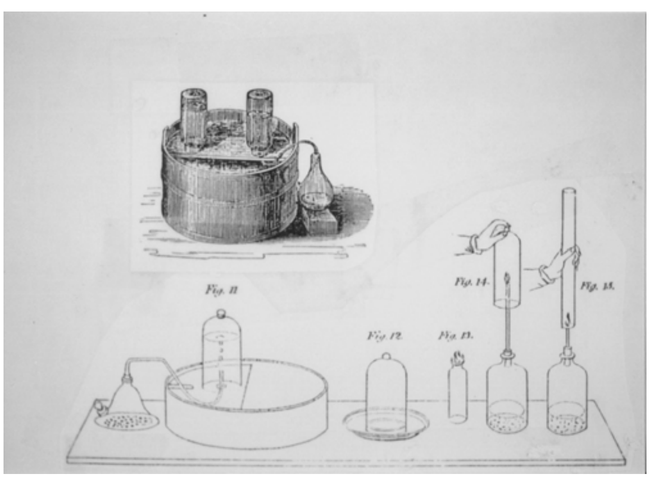

Figure 5. Preparation and properties of hydrogen (Plate VI) in Mrs. Marcet's Conversations on Chemistry [8b] and a simplified apparatus given in [27].

The experiment on the oxidation of mercury, as shown in Figure 1, became an emblem of Lavoisier's work. Not just many nineteenth century textbooks, but contemporary portraits, engravings, and monuments carry this image as well. One of the two scenes set in bas-relief into the pedestal of Lavoisier's monument in Paris (erected in 1900) portrayed Lavoisier, along with the retort and bell jar, over the pneumatic trough, performing the famous combustion experiment (Figure 3). Madame Lavoisier is shown at a small table taking notes. Unfortunately, this laboratory scene, inspired by Madame Lavoisier's sketches, disappeared with the pedestal when the statue, together with many bronze monuments in Paris, was confiscated for the German war efforts [20].

The first instrument that allowed very accurate measurements of the specific heat, combustion heat, etc., the ice calorimeter devised by Lavoisier and Laplace, is shown in Figure 4. As Madame Lavoisier's very accurate drawing shows (see the internally displayed calorimeter in Figure 4), the instrument is composed of three concentric parts called "capacities." The heat given off by the body can be determined by measuring the weight of the melted ice, that is, the volume of water collected from the middle capacity. The inserted letters (**a, b,** and **c**) delimit the three capacities. Madame Lavoisier shadowed the instrument delicately to show the calorimeter in perspective, and the result is beautiful. Indeed, this plate is her most accomplished drawing, showing both artistic and technical skills in its arrangement and execution.

The illustrations in the *Traité* are faithful representations of Lavoisier's instruments, many of them now part of the impressive collection on exhibit at the *Musée des Arts et Metiers* in Paris. Among the instruments is the flask (Figure 1) used by Lavoisier in his large-scale synthesis of water. For the illustrations, Madame Lavoisier probably used the set-up of the large-scale experiment carried out in 1784 and 1785 by Lavoisier and Meusnier in the presence of a great number of scientists [21].

Jane Marcet, author and illustrator of *Conversations on Chemistry*

Caroline. And what was the greatest quantity of water ever formed in this apparatus?

Mrs. B. Several ounces; indeed, very near to a pound, if I recollect right; but the operation lasted many days.

Emily. This experiment must have convinced all the world of the truth of the discovery. (Jane Marcet [8])

Indeed, the controversy over the nature and composition of water was over and, at the beginning of the new century, all the world had been convinced that water was a compound substance. Together with Hales, Priestley, and Cavendish, Lavoisier, ″the celebrated French chemist″ [8], entered the chemistry textbooks. While demonstrating the properties of hydrogen, Mrs. B., the witty tutor of Caroline and Emily in Mrs. Marcet's Conversations on Chemistry, set forth Lavoisier's experiments on both the decomposition and formation of water. In Conversation VIII ("On Carbon"), the decomposition of water (on charcoal instead of iron) is shown, and Mrs. B. explains how the vapor conveyed through the red hot charcoal is decomposed, and how the hydrogen gas that results from the decomposition is collected in the receiver.

Mrs. Marcet's Conversations is an informal dialogue between a teacher and two pupils, penned in an elegant and delightful style, and interspersed with beautiful illustrations [22–25]. Her drawings, (transferred to woodcuts by the well-

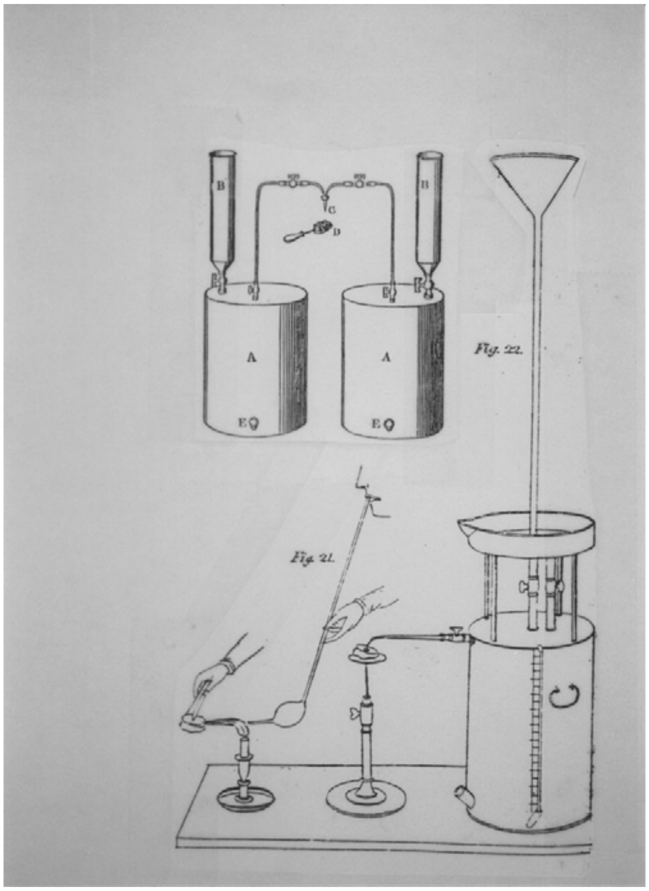

Figure 6. Combustion of metals (Plate IX) in Mrs. Marcet's Conversations on Chemistry [8b] and the oxy-hydrogen blowpipe [27] (top).

known engraver William Lowry), together with the attractive narrative, make the conversations come to life, creating and sustaining the illusion of experiments actually being performed. We are drawn into the narrative and participate in the ongoing experiments (Figure 5). With Mrs. B., we prepare hydrogen and see ″the violence these (the sulfuric acid and the iron filings) act on each other,″ feel the hot mixture and see the bubbles of hydrogen as they are rising in the glass receiver. And when, instead of the expected detonation, the kindling of hydrogen produces only a ″hissing noise with a flash of light,″ we are disappointed as much as is Caroline. But the experiment goes on, Mrs. B. procures a fresh supply of hydrogen that ″will be wanted for the experiment,″ and makes a "philosophical candle." Inverting a receiver over the flame, she shows the ″very fine dew, which is pure water″ on the internal surface of the glass. Caroline is actually happy to see it, and she does not refrain from expressing her sentiments:

Caroline. Yes, indeed; the glass is now quite dim with moisture. How glad I am that we can see the water produced by this combustion.

Emily. It is exactly what I was anxious to see; for I confess I was a little incredulous.

The last property of hydrogen that Mrs. B. illustrates in this plate is ″a curious effect produced by the combustion of hydrogen gas,″ the production of musical tones. She inverts over the flame a tube of about two feet in length, open at both ends and the girls can immediately hear the ″strange noise, something like the Aeolian harp, but not so sweet″ produced by the formation and condensation of small drops of water on the sides of the tube.

In later editions of her book, Mrs. Marcet included many of the new discoveries. For example, in the 1809 London edition [1a] she added to Plate VI (Figure 5) ″the apparatus for the decomposition of water by the Voltaic battery,″ an illustration missing in some of the later American editions [26]. In others, for example in Jones' 1832 edition of New Conversations on Chemistry, Adapted to the present State of Science, On the foundation of Mrs. Marcet's Conversations on Chemistry, the book was updated and many interesting illustrations were added [27]. For example, the drawings given in Figure 5 (top), are entitled "A tub as a pneumatic cistern, and hydrogen procured by means of a florence flask and phials." The author suggests ″a simple and cheap contrivance,″ a common sweet-oil flask instead of retorts and alembics, ″whilst a common tub or bucket will make a good pneumatic cistern, and tumblers and phials answer as receiver for the gases.″ However, many of the drawings are too simplified and individual drawings are replaced for the plates. The progress of the experiments, so clearly shown in Mrs. Marcet's original illustrations, is not achieved in these late editions, thus their pedagogical value is reduced.

Mrs. Marcet's woodcuts show the different kind of equipment in use in the early nineteenth century. Furnaces, ″the chemical instruments most frequently employed which present themselves first to view upon entering a laboratory″ [28], are much less frequent in her illustrations than before, giving way to patent lamps. Patent lamps were used for boiling water, and for the distillation of wine. In Plate X (not shown), there is also an alcoholic blow-pipe, a flaming jet of alcohol, showing that safety in the laboratory was not yet an issue. The illustrations show a variety of vessels in use: flasks, retorts to prepare oxygen and hydrogen, alembics, and ″a cucurbit covered with a conical receiver″ used for the sublimation of sulfur and for distillation. Some of them may be new and strange, others, for example the wine glass used as receiver of the distillate, are certainly familiar. Some of Mrs. Marcet's original plates, for example the one illustrating the combustion of metals (see Figure 6), are limited to two successive experiments. This figure gives Mrs. Marcet the opportunity to show how a blow-pipe is used to increase the rapidity of combustion. In the first drawing, there is Mrs. B., blowing upon a piece of charcoal (we see only her hands and chin). She is present in other experiments as well, for example blowing soap bubbles through a pipe attached to a bladder. The presence of a person in the drawings brings in an altogether human dimension absent in today's textbooks. The stream of oxygen comes from a blow-pipe adapted to a gas-holder. The gas is forced out when ″a stream of water is thrown unto the vessel through a long funnel.″ In later American editions, Hare's oxy-hydrogen, or compound, blow-pipe was added, and its qualities—power of combustion and fusion—highly extolled.

The illustrations reflect the wide range of topics encompassed by the Conversations. Mrs. Marcet followed Lavoisier's scheme of classification of the elements, as laid out in the 1796 English translation of his Traité, considering light and caloric as "imponderable agents." For example, one of the plates shows Pictet's apparatus for the reflection of heat,

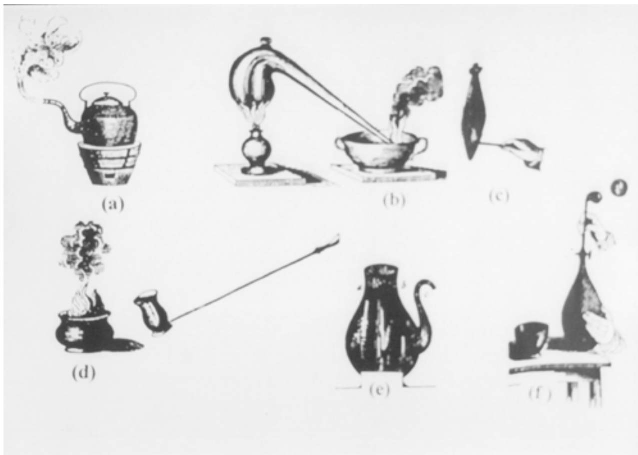

Figure 7. Familiar objects in Mrs. Phelps' Chemistry for the Beginners [9].

while another is dedicated to the germination of beans and shows an apparatus illustrating the mechanism of breathing.

Conversations on Chemistry is as instructional as it is entertaining. The immense success of the book may be accounted for by the coherence of the text, the freshness of the dialogues, and the experimental demonstration of the chemical theories through meaningful drawings. This approach was not paralleled by any contemporary textbooks. While some of them, for example William Nicholson's First Principles of Chemistry (1792) or Chaptal's Elements of Chemistry (the fourth American edition of James Woodhouse, 1807) gave detailed descriptions of the vessels employed in chemical operations (crucibles, cucurbits, mattrasses, retorts, alembics, and, of course, furnaces), they failed to support them with drawings [28, 29]. In other works, for example in Samuel Parkes' introductory textbook, The Chemical Catechism, with Notes, Illustrations, and Experiments, an important number of experiments ″as may be performed with ease and safety,″ are described, but no drawings are given to help the reader to understand the experiments [30].

Almira Hart Lincoln Phelps, teacher, author and illustrator of science books for beginners

″The young ladies of the Seminary of Troy N.Y. who are in the habit of performing chemical experiments in their daily exercises and at the public examinations, have by means of a suitable apparatus, exhibited some splendid experiments, to illustrate the burning of hydrogen and carburetted hydrogen.″ (Almira Lincoln Phelps, [9])

Mrs. Phelps was one of the early proponents of science education for women [31, 32]. It was for the instruction of young ladies of the Troy Female Seminary, New York, that Mrs. Phelps decided to publish her lectures, first in botany, and later in chemistry and natural philosophy. The plan of instruction in her textbooks was similar to that of her mentor, Amos Eaton at the Rensselaer School, based on experimental and demonstrative lectures [33]. The two textbooks in chemistry, Chemistry for Beginners (1834) and Familiar Lectures on Chemistry (1838), were written at a time when a great number of chemistry textbooks were already published in Philadelphia (e.g., [34–37]). Her books [9, 38] were less technical and scholarly than many of these textbooks, but had a great number of beautiful illustrations from original drawings. The books were written in a format appropriate for classroom teaching, and illustrated with proper examples.

Mrs. Phelps was an apostle of applied chemistry. She made many references to everyday living: ″This science bears an important relation to housekeeping in a variety of ways, as in the making of gravies, soups, jellies and preserves, bread, butter and cheese, in the washing of cloths, making soap, and the economy of heat in cooking, and warming rooms.″ wrote Mrs. Phelps in the Introduction to Chemistry for Beginners. She wished to educate ″good women rather than fine ladies,″ stressing that the young ladies who study chemistry should pay particular attention to ″all those facts in housekeeping which may be explained by chemical principles, such as the action of yeast upon flour, and of pearl ash upon sour dough, the change of cider into vinegar, the advantage of keeping a vessel covered in order to hasten the boiling of water, etc.″ The drawings show her emphasis on the practical applications. As Amos Eaton, a popular lecturer, and later professor of chemistry, at the Rensselaer School in Troy used to say: ″I turn everything in science in common talk. I illustrate the most abstruse part by a warming pan, a bread-tray, a tea-pot, a soap bowl, or a cheese press″ [39]. Instead of showing complicated apparatus, Mrs. Phelps preferred to show familiar objects in her drawings: an ordinary kettle of boiling water and the vapor that passes off into the atmosphere, a tobacco pipe fitted to the mouth of a bladder for blowing bubbles in soap suds, wine glasses, tumblers, deep plates, pots, and special vessels for volatile oils (see Figure 7). In Figure 7b, Mrs. Phelps explains how "phosphuratted hydrogen" is prepared, and how the gas rises into air and ignites spontaneously. The drawing shows even the ″pale wreath of smoke becoming fainter and larger as it rises,″ and Mrs. Phelps tells us about the ″lights sometimes seen over bogs and marshes which the ignorants believe to be wandering spirits,″ and emphasizes the importance of knowledge in removing superstitious fears from the mind. In Chemistry for Beginners, Mrs. Phelps often makes references to the dangers involved in the experiments. In Figure 7d for example, illustrating the heat produced by "chemical affinity," she shows how the glass containing the sulfuric acid to pour upon the "chlorate of potash," is fastened to the end of the rod to avoid explosion. At the same time, she shows in her drawings some dangerous, but highly entertaining demonstrations, for example the firing of a hydrogen gun, ″which often causes both terror and amusement in the lecture room.″ (Figure 7c).

The illustrations show a close attention to details, such as the coil of wire that supports a stick of phosphorus in the eudiometer (an apparatus for testing the purity of the air), and the brilliant jets of fire produced by the combustion of phosphorus in chlorine gas. The instruments' shadows add to the sense of reality of the drawings, and give them a certain majesty (Figure 8).

Mrs. Phelps illustrations show that though furnaces and chafing dishes of hot coals, alembics and tubulated retorts, tin pots, and leaden tubes were still widely used, there were also some new and more-sophisticated apparatus entering the scene of the laboratory. One of them, shown in Figure 8d, is Woulfe's apparatus used for the preparation of "liquid muriatic acid" (a solution of hydrochloric acid) from common

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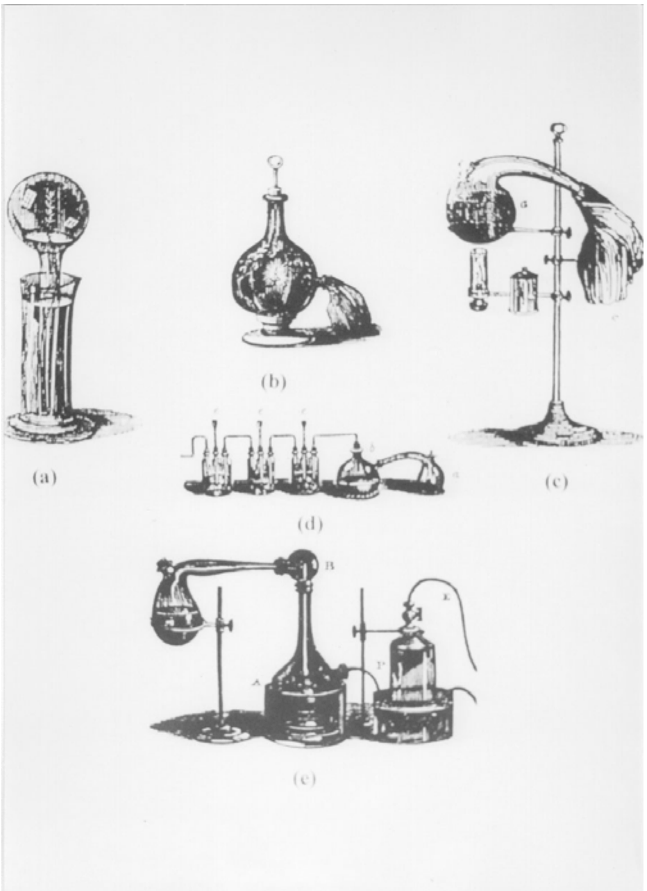

Figure 8. Phosphorus and its properties in Mrs. Phelps' Chemistry for the Beginners [9].

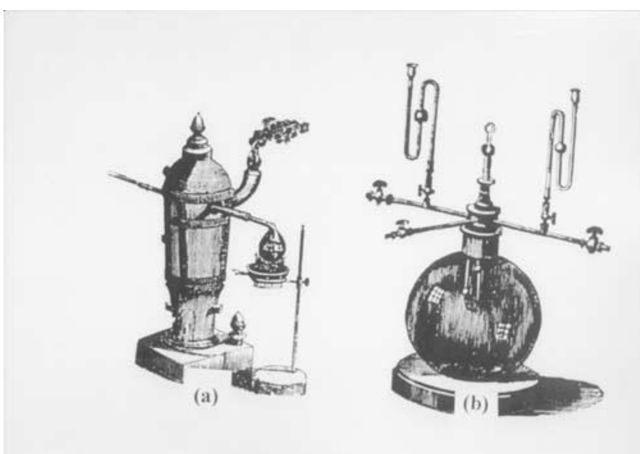

Figure 9. Illustration of Lavoisier's experiments on the formation and decomposition of water in Mrs. Phelps' Chemistry for the Beginners [9].

salt and sulfuric acid. The three bottles shown in the drawing contain water that was saturated with the gas. For those wanting to know more about the apparatus, Mrs. Phelps makes reference to the Dictionary of Chemistry that she had translated from French and completed with new entries from the best French and English authors [30]. Another apparatus was used for the preparation of "chlorate of potash" by saturating a solution of sulfate of potash with chlorine gas (Figure 8e). The saturated solution of chlorate of potash is then filtered while hot, using an ingenious apparatus invented for this purpose by Dr. Hare. The illustrations of Lavoisier's experiments on the formation and decomposition of water are, of course, part of both Mrs. Phelps' books (Figure 9). Because of the curious form of the furnace used for heating the gun-barrel that contains the "small bits of iron," and the unusual set-up, the apparatus looks quite eccentric (Figure 9a). The figure that illustrates the synthesis of water was copied from the work of Hare [31], to whom Mrs. Phelps felt greatly obliged. Mrs. Phelps resumes the description of this figure because "the explanation of this figure being given in the words of a learned chemist, the beginner may not understand it all."

Conclusion

In the Preface of Chemistry for Beginners, Mrs. Phelps expressed her belief that learned chemists, that is, professors at colleges and universities, ought not to be expected to devote their time to teaching chemistry for beginners. ″Those can do this as well, who have not made the attainment they have done, who are not as capable of being useful in the higher walks of science,″ wrote Mrs. Phelps.

For adapting chemistry to the comprehension of beginners, Mrs. Marcet, Mrs. Phelps, and many of the women authors who followed in their steps used illustrations to help pupils to visualize experiments that they could not perform at the time [42–43]. Due to the simplicity of the language, the elements of fiction bringing chemistry to life, and the meaningful illustrations, the books were easy to read, and more entertaining than other manuals on the market. In the Preface of her Familiar Lectures on Botany, the most successful of her textbooks [44], Mrs. Phelps defined the essential qualities of a beginner's textbook: ″In order that a school book should be pleasant to the teacher and profitable to the learner, three things are requisite:

1st A clear and methodical arrangement of subjects,
2nd Perspicuity of language
3rd A pleasing style, and interesting illustrations."

Without any doubt, the introductory chemistry textbooks written and illustrated by Jane Marcet and Almira Lincoln Phelps fulfilled these requirements.

Acknowledgments. The author is most grateful to Dr. Marco Beretta for his helpful information on Lavoisier's statue and on different Lavoisier documents. Thanks are also due to Dr. Jeff Cavalieri for kindly providing the illustrations from the American editions of Jane Marcet's Conversations on Chemistry in his possession, and to the librarians of McGill's Osler Library of the History of Medicine, for permission to browse through ″old chemistries.″ The author is grateful to Dr. Brian T. Newbold and Dr. John Bout for revising the manuscript.

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