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Historical Article

Lavoisier's *Traité élémentaire de chimie*: At the Intersection of Chemistry and French

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Abstract. Communication through language is crucial to properly disseminate knowledge and new discoveries in all disciplines. *Traité élémentaire de chimie* by Antoine Lavoisier is regarded as the first modern chemistry textbook and can be utilized as a teaching tool for interdisciplinary studies within the fields of chemistry and French. A contemporary rereading of Lavoisier's text offers insight into the chemistry being performed in the eighteenth century which was recorded and shared using eighteenth century French language. A reexamination of this historical text provides a variety of pedagogical exercises that can be used across the two disciplines. From chemical principles to unit conversions to shifts in French orthography, *Traité élémentaire de chimie* possesses a wealth of knowledge that can be enjoyed by a wide audience within the humanities and natural sciences. Lavoisier's *Traité élémentaire de chimie* can be employed in several different courses providing chemical principles for science courses while serving as a historical French writing sample for advanced French composition courses.

Keywords: chemical education, eighteenth century studies, pedagogical tools, interdisciplinary chemistry-French studies

Antoine Lavoisier is often regarded as a key figure in chemistry given his significant contributions to the field in the late eighteenth century and his text, *Traité élémentaire de chimie (Traité)*, is regarded to be the first modern chemistry textbook.[1-5] In 1789, the original text was published in French and has since been translated to several languages, including English in 1790. The historical text *Traité* not only serves as a record of the chemistry that was being performed at the time but also provides a glimpse into the evolution of the French language as we know it today. This article seeks to present a concise introduction of how the traditional text can be used as a tool for the interdisciplinary study of chemistry and French through the evaluation of both chemical and French language concepts. An anachronistic reexamination of this text through multiple lenses offers readers more avenues to incorporate *Traité* as a teaching tool in a given course. *Traité* can be used as a pedagogical tool to teach some of the fundamental concepts of chemistry and the orthographical shift used for the *imparfait* (imperfect) tense in the French language. A contemporary rereading of *Traité* offers a number of teaching exercises that can be easily incorporated into the curriculum of a General Chemistry course or an upper-division French Composition course.

A petit background of Lavoisier's text is presented to provide insight into the enormity of the project that sought to reorganize chemical knowledge in the eighteenth century. *Traité élémentaire de chimie* was conceived as a teaching textbook, originally published in two volumes. The first volume (Tome Premier) is divided up into two parts: Part One (Première Partie) primarily discusses the formation and decomposition of aeriform fluids (gases), the combustion of simple bodies, and the formation of acids across 17 chapters. Part Two (Seconde Partie) primarily consists of tables and observations concerning the combination of acids with bases and the formation of neutral salts. While the first volume often attracts more attention given its quest to present chemical information is an orderly manner, the second volume (Tome Second) contains Part Three (Troisième Partie) which describes the instrumentation and operations of chemistry during the eighteenth century. Lavoisier specifically included Part Three at the end of *Traité* to provide readers information on how the experiments and measurements were carried out after an appropriate foundation of chemistry had been presented. In addition to the tables of data presented in this part, an appendix containing terms and definitions is provided as reference. Part Three concludes with illustrations of labware and experimental setups which provide reference as to how the experiments were performed during the time period. Of notable interest, the illustrations found in *Traité* were composed by Lavoisier's wife, Marie-Anne Paulze.[6]

From a pedagogical standpoint, Lavoisier's chapter on combustion (*Chapitre IX. – De la quantité de Calorique qui se dégage des différentes espèces de combustion*) is suitable for the presentation of important concepts in chemistry and the French language. We will explore this chapter as a tool to teach about the foundations of the Law of Conservation of Mass, traditional French units of mass, and the orthography used during the time period (eighteenth century). For flexibility, it should be noted that Lavoisier's text will be used as a reference when discussing key principles in modern chemistry and will not be based on the complete historical timeline for the Law of Conservation of Mass. This afforded liberty will allow the concepts to be rationally connected to one another while retaining its historical essence. At the introductory level, a combustion is a type of chemical reaction in which a substance combines with oxygen to form one or more oxygen-containing compounds; the reaction often causes the evolution of heat and light in the form of a flame.[7] Lavoisier explored the combustion of several substances which included *le phosphore* (phosphorus), *le carbone* (carbon), *l'hydrogène* (hydrogen), *la cire* (wax), et *l'huile d'olives* (olive oil) which confirmed the results of earlier experiments leading to the proposal of the Law of Conservation of Mass. The Law of Conservation of Mass states that matter is neither created nor destroyed in a chemical reaction (*e.g.*, combustion reaction).[7] Lavoisier was able to carefully measure the mass of each reactant before the reaction occurred and the mass of products obtained after the reaction completed. In each instance, Lavoisier obtained a mass of products which was equal to the mass of the starting reactants. Although never specifically written, "matter is neither created nor destroyed during a chemical reaction"; these observations led Lavoisier to include this underlying principle as a central theme in his text. This phenomenon was termed the Law of Conservation of Mass and this law helped contribute to the particulate nature of matter that scientists accept today. In fact, Lavoisier's results in *Traité* were cited by John Dalton as he proposed Atomic Theory in the early nineteenth century which states that each element is composed of tiny indestructible particles called atoms, that all atoms of a given element have the same mass and other properties, and that atoms combine in simple, whole-number ratios to form compounds.[8] To further illustrate the significance of Lavoisier's observations, consider the reaction between hydrogen (H_2) and oxygen (O_2) yielding water (H_2O) as shown in Scheme 1. For clarity, this reaction is described using a balanced chemical equation (Scheme 1) which was not included in Lavoisier's original text. The large numbers found in front of hydrogen and water are called coefficients and tell the reader that there are two equivalents of each substance. The absence of a coefficient is understood to be one equivalent. The balanced chemical equation displays the same number of atoms on each side of the reaction arrow, reminiscent of Lavoisier's observations that matter is neither created nor destroyed during a chemical reaction.

The pictorial representation of the combustion of hydrogen using Lewis Dot Structures is shown in Figure 1. This representation shows that all the atoms in the starting materials that constitute hydrogen gas and oxygen gas at the beginning of the reaction can be found in the resulting water products. Similar to the previ-

$$2\,H_{2\,(g)} + O_{2\,(g)} \longrightarrow 2\,H_2O_{\,(g)}$$

Scheme 1. Balanced chemical equation of hydrogen combustion.

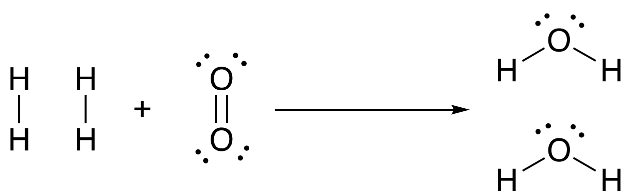

Figure 1. Pictorial representation of hydrogen undergoing combustion.

Table 1. Lavoisier's table of data describing the recorded masses of reactants and products of hydrogen combustion.

	livres	onces	gros	grains
Quantité de gaz hydrogène brûlé[a]	1	–	–	–
Quantité de gaz oxygène employé pour la combustion[b]	5	10	5	24
Quantité d'eau formée[c]	6	10	5	24

[a]Amount of hydrogen burned [b]Amount of oxygen gas used for the combustion [c]Amount of water formed.

ous example, Lavoisier's observation can be paired with another related concept (Lewis Dot Structures) discovered later, to reaffirm that matter is neither created nor destroyed. The results from various combustion reactions performed by Lavoisier helped lay the foundation for Atomic Theory.

Taking a more quantitative approach, the masses of the reactants and products were reported using the, now obsolete, Traditional French Units of Measurement (based on the Apothecaries' System), more specifically units of mass.[9] A subsection of Lavoisier's data table for the combustion of hydrogen is provided in Table 1 with English translations provided in the footnotes.

The table reports that Lavoisier reacted 1 *livre* of hydrogen gas in the presence of 5 *livres* 10 *onces* 5 *gros* and 24 *grains* of oxygen gas. The resulting mass of water, 6 *livres* 10 *onces* 5 *gros* 24 *grains*, is equal to the sum of the masses of hydrogen and oxygen consumed during the combustion. This observation was used to establish the foundation of the Law of Conservation of Mass.

From a historical standpoint, the Traditional French Units of Mass offer students the opportunity to learn about mass units used during the eighteenth century, well before the introduction of the International System of Units (SI Units). Historically, the mass units used during the eighteenth century varied from region to region giving rise to several different mass systems. In fact, in the 1790 English translation of *Traité*, *Elements of Chemistry* by Robert Kerr, a conversion table between the *livre* and the English troy weights is presented.[10]

$$1\ livre \bullet \frac{16\ onces}{1\ livre} \bullet \frac{8\ gros}{1\ once} \bullet \frac{72\ grains}{1\ gros} = 9216\ grains$$

Equation 1. Use of dimensional analysis for the conversion of one *livre* to *grains*.

Mathematical exercises using traditional French units can be employed to assist students in further developing their math skills and recognizing the interconversion of units. This can be accomplished by using another chemistry concept, dimensional analysis which is a method for unit conversions. For example, the *livre* can be divided into 16 *onces* where one *once* can further be divided into 8 *gros*. One *gros* can be further divided into 72 *grains*. Equation 1 shows the mathematical conversion of one *livre* to grains based on the historical conversions used by Lavoisier.

Not only can Lavoisier's text provide information about the science being performed and how it was recorded, but it can also serve as a historical record of French language evolution. Among the impactful information Lavoisier presented throughout his chapter on combustion, an "unusual" spelling motif seems to recur in Lavoisier's writing. An excerpt of *Chapitre IX* is presented with the unusual spellings underlined:

> *Mais quand on voudroit supposer que l'acide phosphorique retient encore une quantité considérable de calorique, comme le phosphore en contenoit aussi une portion avant la combustion, l'erreur ne pourroit jamais être que de la différence, & par conséquent de peu d'importance.*

> But when one wanted to suppose that phosphoric acid still retains a considerable caloric quantity, as phosphorus also contained a portion of it before the combustion, the error could never be anything but the difference, and consequently of little importance.

Upon reading the language used by Lavoisier in the excerpt above, the "unusual" spelling occurs when he uses the *imparfait* (imperfect) tense describing the retention of heat by phosphoric acid. The verbs conjugated in the *imparfait* tense are "incorrect" by today's standards but are spelled correctly for that time period. Each of the words are conjugated in the third person subject pronoun *imparfait* tense, referring to ongoing past events without reference to a time of starting or finishing.[11-13] Table 2 provides information about the words and their conjugations.

There is a distinct difference in spelling between the historical *imparfait* conjugation and the conjugation of today's age. Before the release of *la sixième édition du Dictionnaire de l'Académie Française* (sixth edition of

Table 2. Table of words and their third person subject pronoun *imparfait* conjugations.

Infinitif (infinitive)	English Definition	*Imparfait* Conjugation (historical)	*Imparfait* Conjugation (modern)
Vouloir	want	*vouloit*	*voulait*
Contenir	contain	*contenoit*	*contenait*
Pouvoir	can, to be able to	*pouvoit*	*pouvait*

the French Academy's Dictionary) in 1835, the *imparfait* tenses were spelled with *–oi–*, a digraph corresponding to the phoneme /ɛ/.[14] With the release of *le Dictionnaire*, words spelled with the digraph *–oi–* were respelled using the digraph *–ai–* which effectively changed the spelling of numerous words including all the *imparfait* conjugations.[15] The change was proposed by *l'Académie Française* to better match the sound the of the spoken word and its spelling.[16,17] *L'Académie Française* is the governing body of the French language and its origins can be traced back to the seventeenth century when it was established by Cardinal Richelieu under the rule of King Louis XIII.[18]

In summary, Antoine Lavoisier's *Traité élémentaire de chimie* can be utilized as an interdisciplinary teaching tool to bridge chemistry and the French language together as it provides ~~a~~ historical perspective of chemistry while highlighting the orthographical changes within the French language. The text can serve as a reference for teaching fundamental scientific concepts, historical aspects of French society, and how the French language is an ever-evolving language. This article seeks to encourage others to explore crossovers between the physical sciences and humanities which can inspire students to broaden their breadth of studies. Lavoisier has had a tremendous impact on modern chemistry and his text provides a glimpse into the history of, not only science, but of the French language as well. Given the availability across the internet, at no charge, *Traité* is a valuable resource for students of both chemistry and French and those who have an interest in interdisciplinary studies.

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