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Historical Experiments in Textbooks: Implications for Chemistry Teaching[+*]

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I. Introduction

Much has been discussed about the relevance of the history of science (HS) in teaching contexts, because in addition to enhancing the understanding of the contents, HS favours learning about processes of scientific developments, revealing it as a human activity, with a historical and contextual character (BARBOSA; AIRES, 2017; TOLVANEN, 2014; MARTINS, 2006; PEDUZZI, 2001). As Moura and Guerra (2016, p. 733-734) state:

> *scientific practices are not restricted to performance skills, such as manipulation of instruments and variables, interpretation of data and graphs, but to the association between these performances and cultural and socio-institutional factors capable of producing valid meanings in the scientific community.*

However, it must be recognized that not all history of science favours this broad appreciation of scientific practices, and historiographies written from an outdated perspective can distance us from today's educational objectives (PORTO, 2019).

As highlighted by Santos and Porto (2013), the research in science teaching is committed to the social development of the country. Referring specifically to Chemistry teaching, these authors argue that "researchers in this area have contributed significantly to

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[+] Experimentos históricos nos livros didáticos: implicações para o ensino de química

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the processes of teacher training, discussion and elaboration of public policies and the development of teaching proposals for basic education" (SANTOS; PORTO, 2013, p. 1570). Among the public policies affected by teaching research, we can mention the National Textbook Program (PNLD), an instrument by which the Federal Government acquires and distributes the books that will be available to students from public schools. For each public notice, part of the criteria for selecting the works that will integrate the PNLD considers the results of research in teaching, so that the aim is to create an inducing effect of improvements in the quality of these materials (SANTOS; PORTO, 2013, p. 1574).

Despite this, the history of science is still commonly misrepresented in teaching and, especially, in textbooks (SILVA JUNIOR; SILVA, 2022; HIDALGO; QUEIROZ; OLIVEIRA, 2021; TARGINO; BALDINATO, 2016; HEERING; WITTJE, 2012; VIDAL; CHELONI; PORTO, 2007; MARQUES, 2006). Even with some improvement in the historical approach to each new edition of the PNLD textbooks, such as the insertion of historical elements in the main text and the recognition of the participation of some women in HS, the vision of the male, European and white scientist, who works alone and discovers facts about the functioning of nature, following rigorous procedures based on experimentation, still prevails. In addition to going against the sense of humanization and not promoting empathy, this type of narrative inhibits history of science from being used as a means to facilitate the understanding of how science itself is done.

Other studies point out that Basic Education teachers use the textbook as the main source of consultation and reference in their classes (TURIN; AIRES, 2016; LEITE; GARCIA, 2018). This certainly raises questions about initial teacher education, but it reflects a social and political reality in which most teachers teach subjects for which they did not have adequate training. According to the most recent Basic Education School Census, 31.7% of high school chemistry teachers teach the subject without having adequate training. This percentage is even higher in other disciplines such as physics (46%) and sociology (60.7%) (BRASIL, 2023). Thus, the problems in the historical approach presented by the books deserve attention as an object of research and should also motivate the production of complementary materials to be consulted by teachers.

The contextualization that refers to the development of scientific theories comprises a significant part of chemistry teaching. Thus, a closer look at the historical experiments that contributed to the consolidation of these theories can favour their learning (HEERING; WITTJE, 2012).

Chang (2011, p. 317) defines "historical experiments" broadly, as "experiments that arise from the study of past science, not from current science and its pedagogical preliminaries". This definition contemplates the occasions when textbook authors propose to narrate episodes in the history of science, but in agreement with Heering (2000), Chang argues that the study of historical experiments neglected by modern textbooks can also provide valuable learning about science.

In this work, we propose to identify representations of historical chemistry experiments in textbooks and compare them with their respective historical originals. Our considerations will be directed to the scope of teaching and teacher training, seeking to illustrate how a greater attention dedicated to the history of science can contribute to the learning of science in Basic Education.

II. Methodology

This research work has a bibliographic and documentary character. The first stage consisted of mapping the occurrence of historical experiments represented in the six chemistry didactic collections approved by the 2018 National Textbook Program (PNLD).

Each collection consists of three volumes and we had access to the digital versions of all of them[2]. In this way, we went through the 18 chemistry books of the PNLD, page by page, with the objective of locating historical chemical experiments whose relevance is recognized by the authors of the textbooks, to the point of reserving space in the book for some type of imagery representation. We then catalogued the experiments that had at least one illustrated representation, whether by photography, schema, drawing or engraving, which were accompanied by a description and associated with the name of some researcher in a way that refers to the history of science, configuring what we call a historical experiment. Based on this selection criterion, textual-only descriptions of experiments were not included in our research. On the other hand, we observed that the representations of some devices, such as Daniell's cell, Crookes' tube and Volta's pile, met the criterion and were therefore included in our analysis, although they are not described in the books as elements of some experimental proposal in the history of chemistry.

We assigned a letter from A to F to identify the collections and added the numerals 1, 2 and 3 to identify the volumes within each didactic collection. Thus, code D3, for example, will serve to refer to the third volume of the "Química Cidadã" collection, following the same logic for all other works analyzed. Chart 1, below, brings the data from the Chemistry collections approved by PNLD 2018 that we considered in this work.

We tabulated the collections in which each of the experiments is portrayed and, from this list, we selected the most recurrent ones to deepen in the second phase of the research, considering the historical originals.

We then conducted a search on Google Scholar, Capes Journals, Scielo and the

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[2] Access to digital books was made available by the publishers themselves in the context of the Covid-19 pandemic, as a resource to facilitate situations of Emergency Remote Teaching.

Brazilian Digital Library of Theses and Dissertations in order to find which of these experiments have already been studied from the perspective of the contemporary historiography of science (KRAGH, 1989; ALFONSO-GOLDFARB; BELTRAN, 2004). We worked with two of the experiments that receive representations in all collections, namely, the Daniell's cell and Rutherford's gold foil.

The selection of secondary sources on the experiments were made on the platforms mentioned, searching for the conventional name attributed to the experiment and also for the name of the scientists associated with the expressions "experiment" and "history of science". We searched the equivalents of these key terms in order to include sources available in English and Portuguese. We proceeded to read the articles found and also the historical originals in which the experiments were reported.

Chart 1 – Didactic collections analyzed.

Code	Title	Authors	Publisher	Year
A	Química	Martha Reis	Ática	2016
B	Vivá - Química	Vera Lúcia Duarte de Novais Murilo Tissoni Antunes	Positivo	2016
C	Ser Protagonista - Química	Aline Thaís Bruni Ana Luiza Petillo Nery André Amaral Goncalves Bianco Luiz Henrique Rodrigues. Julio Cezar Foschini Lisbon Kátia Santina Lia Monguilhott Bezerra Paulo A. G. Bianco Rodrigo Marchiori Liegel Simone Garcia de Ávila Simone Jaconetti Ydi Solange Wagner Locatelli Vera Lúcia Mitiko Aoki	SM	2016
D	Química Cidadã	Eliane Nilvana Ferreira de Castro Gentil de Souza Silva Gerson de Souza Mól Roseli Takako Matsunaga Salvia Barbosa Farias Sandra Maria de Oliveira Siland Meiry França Dib	AJS	2016

		Wildson Luiz Pereira dos Santos		
E	Química	Carlos Alberto Mattoso Ciscato Emiliano Chemello Luis Fernando Pereira Patricia Barrientos Proti	Moderna	2016
F	Química	Andréa Horta Machado Eduardo Fleury Mortimer	Scipione	2016

Source: The authors.

The next step was to report how each experiment is described in the textbooks to then point out the similarities and divergences of these descriptions in relation to the original experiments. From these notes, we present possible implications for the learning of these chemistry themes in high school, considering contemporary references that discuss contributions of the history of science to science teaching.

In the next sections, we begin with considerations about the role of experiments in science and teaching and then present the results of the analysis of textbooks. We list the historical experiments found in the PNLD collections and deepen the analysis of the two experiments that appear in all collections.

III. Role of Experiments in the Construction of Science and Teaching

Experimentation plays an important role in the development of the natural sciences. In common sense, however, there is a view that overvalues the experiment as an instance of revealing truths about the functioning of the world, as something that offers objective data independent of previous theories (HODSON, 1988).

This distorted view is called the empiricist and inductivist view. According to it, all science begins with some kind of unbiased observation about the world. Then these observations are mediated by experiments, which are understood by the inductivist as observations performed with variable control, in order to avoid interference with the phenomenon. Repetitive and predictable experimental results would authorize the formulation of theories and the enunciation of scientific laws, produced by inductive reasoning (CHALMERS, 1993). Gil-Pérez and collaborators (2001) warn that this distorted view often affects teachers and scientists themselves.

One of the theses defended by Chalmers (1993) in contrast to this view is that some theory always precedes observation, as it directs the researchers' gaze and guides the construction of the experiments themselves. When someone organizes materials in an experimental assembly, that person expects to detect something, and such an expectation of result stems from a theoretical inclination. This understanding already appeared in the philosophy of Gastón Bachelard, who described the instruments used in experimental practices as a kind of embodiment of theories. According to Lopes (1996, p 260), for Bachelard, "the instrument itself is a materialized theory".

Martins e Buffon (2017) argue that the correction of errors is essential in the formation of scientific thinking. Studying the execution of experiments sometimes involves studying where the experiment failed and what means scientists found to circumvent these failures. Now, to say that an experiment failed is admitting that there was a theoretical expectation prior to its realization. This indicates, therefore, that the experiment derived from theory and not the other way around.

The philosophy of science of the late twentieth century no longer states with such certainty whether theories always precede experiments. Hacking (1982) points out that different sciences over time have different relationships between theory and experiment. Thus, updating the debate, “We can say that there is no well-defined relationship between theory and experiment, however, there is a consensus that Science cannot be built without both” (MOURA, 2014, p. 34).

While in science the experiment plays a role in the improvement of theories, in teaching it has different functions. According Lôbo (2012), experimental practice is a powerful didactic resource. Experiments can be used by teachers “for teaching science, teaching about science and teaching children how to do science” (HODSON, 1988, p. 58).

Jardim and Guerra (2017) present a bibliographic review about historical experiments in physics teaching divided into categories that include: the study of instruments; narratives; diaries; adapted reconstruction of historical apparatuses; and science museums. According to the authors:

> *when we turn to the History of Science in an attempt to understand how Science is built, we can see that experiments play a very important role in this process, being taken, throughout history, as symbols of decisions in controversies and scientific advancement (JARDIM; GUERRA, 2017, p. 246)*

These researchers also state that the focus of the analyzed work "falls on the experiment itself, that is, on the analysis of the materials and equipment used, on the techniques directly related to the collection and interpretation of data, on the questions that the experiment intended to answer [...]" (JARDIM; GUERRA, 2017, p. 254). Despite this, the authors point out that, usually, in education, the discussion about processes related to the historical context, such as the validation of results and modes of publication is not considered relevant.

There are research groups that work with the recreation of experimental apparatuses with pedagogical objectives. Professor Peter Heering, at the University of Oldenburg, Germany, conducted a programme of analysis of experimental practice in teacher education. The so-called Replication Method used is based on three phases: reconstruction of the experimental apparatus; replication of the original experiment; and contextualization of the previous steps. This approach aims to understand how the experiment was originally carried out, its required skills and the difficulties involved in experimenting (HEERING, 2009).

In addition to familiarizing students/teachers with the historical aspects of the original experiment, the project also aimed to promote the understanding of key points of the nature of science and enabling prospective teachers to use these points in the classroom (HEERING, 2009).

Heering e Wittje (2012, p. 152) state that:

> *The traditional history of science focused mainly on the development of theories and gave little attention to experimental practice. Experiments served mainly as a tool for theory confirmation. Yet, even in these approaches, few cases are found that discuss the actual way in which theoretical knowledge as well as procedures of knowledge production were communicated.*

According to these authors, there is a gap in the history of traditional science regarding the study of experimental practice. The Replication Method proved to be efficient in dismembering the process of conducting experiments and achieving pedagogical objectives by generating a deeper understanding of concepts and their development process (HEERING, 2009).

In this work, we do not propose the replication of historical experiments, but a closer look at them by teachers, and we argue that historical knowledge about the contexts and practices related to some experiments of interest, taken as case studies, can favour a better perception of whole science (ALLCHIN, 2004), with potential pedagogical benefits for students and for the society they integrate.

We observe in this proposal a convergence on the notion that HS contributes to learning about the processes of science construction. However, there is a risk of assuming Nature of Science (NoS) as a stable and well-defined set of aspects, such as: the provisional character of scientific knowledge; its empirical nature; the distinction between observations and inferences; and the characterization of the scientific method as a myth. The acceptance of this list of aspects has been referred to in contemporary literature as a consensual view of NoS (ROZENTALSKI, 2018).

It should be noted that there are criticisms and alternatives to this consensual view, such as the “family resemblance approach” introduced by Irzik and Nola (2011) and developed by Dagher and Erduran (2016), in addition to the proposals of Allchin (2011) and Martins (2015). We refer to the work of Rozentalski (2018) for a review of this debate on

NoS. Here, our intention is to only highlight the role and implications of experiments in science and in chemistry teaching.

In the next session, we will begin the analysis of high school textbooks in relation to the historical chemical experiments found.

IV. Textbook Analysis

Chart 2, below, records the representations of historical experiments that we found when scrutinizing each of the volumes that make up the chemistry collections approved in PNLD 2018.

Chart 2 – Map of the location of historical experiments in didactic collections.

Experiment	**Scientist Assigned**	**Didactic collections**					
		A	**B**	**C**	**D**	**E**	**F**
Cell	John Frederic Daniell (1790-1845)	A2 p. 241	B2 p.225	C2 p. 200	D3 p. 207	E2 p.137	F2 p. 217
Gold Blade	Ernest Rutherford (1871-1937), Hans Geiger (1882-1945) and Ernest Marsden (1889-1970)	A1 p.149	B1 p.89	C1 p.83	D1 P. 163.	E1 p.89	F1 p.148
Electron Discovery	Joseph J. Thomson (1856-1940) and Jean Perrin (1870-1942)	-	B1 p.86	C1 p. 80	D1 p. 159	E1 p. 88	F1 p. 142
Pressure Tower	Evangelista Torricelli (1608-1647)	A1 p. 24	B1 p. 260	C1 p. 168	D1 p. 109	E1 p. 236	-
Pile	Alessandro Volta (1745-1827)	A1 p.137	B2 p. 221	C2 p. 199	D3 p.205	E2 p.114, 136	-
Crookes tube	William Crookes (1832-1919)	A1 p. 138	B1 p.86	C1 p. 79-80	-	E1 p.87 E3 p. 159	
Animal electricity	Galvani (1737-1798)	A1 p.137	B2 P -220	-	D3 p. 203	E2 p. 114	-
Emitted Radiations	Ernest Rutherford, George B. Kaufmann (1888-1949), and Frederick Soddy (1877-1956)	A1 p. 145	B1 p. 88 B3 p. 15	-	-	E3 p. 161	-
Uranium Salts	Antoine-Henri Becquerel (1852-1908)	-	-	-	-	E3 p.160	F1 p. 143
Obtaining Oxygen	Joseph Priestley (1733-1804)	-	B1 p. 38	C1 p. 185	-	-	-
Mass Conservation	Antoine Lavoisier (1743-1794)	A1 p.84	-	-	-	E1 p. 26	-
Cell	Georges Lechanché (1839-1882)	A2 p. 250	-	-	D3 p. 217	-	-

Primitive Earth	Stanley Miller (1930-2007) and Harold Urey (1893-1981)	A3 p. 248	-	-	-	E3 p.244	-
Calorimeter	Antoine Lavoisier and Pierre-Simon Laplace (1749-1827)	-	-	C2 p. 55	-	-	-
Obtaining Oxygen	Antoine Lavoisier	-	B1 p. 38	-	-	-	-
Combustion in closed container	Antoine Lavoisier	A1 p. 85	-	-	-	-	-
Lamp	Thomas Edson (1847-1931)	-	B2 p. 273	-	-	-	-
Electrolysis	Humphry Davy (1778-1829)	-	B2 p. 267	-	-	-	-
Proton Discovery	Eugen Goldstein (1850-1930)	A1 p. 139	-	-	-	-	-
Spectroscope	Joseph von Fraunhofer (1787-1826)	A1 p. 156.	-	-	-	-	-
Obtaining Aluminum	Charles Hall (1863-1914) and Paul Heroult (1863-1914)	-	-	-	-	E2 p.152-153	-
Oil Drop	Robert Millikan (1868-1953)	-	B2 p. 274.	-	-	-	-
Synthesis of Polyethylene	Reginald Gibson (1902-1983) and Eric Fawcett (1908-1987)	-	-	-	-	E3 p. 55	-
Prancing kite in the storm	Benjamin Franklin (1706-1790)	A1 p.137	-	-	-	-	-

Source: The authors.

We found a total of 24 experiments that fit the criteria presented in the methodology. Only two of them appear in all collections.

The scientist most often mentioned was the Frenchman Antoine Lavoisier, with four different experiments, one of them together with his compatriot Pierre-Simon Laplace. According to Vidal, Cheloni and Porto (2007), textbooks, in their entirety, associate Lavoisier with the notion of the conservation of masses in chemical transformations, but few advance beyond this point on the philosopher's contributions. Lavoisier is still often presented as “the father of chemistry” (VIDAL; CHELONI; PORTO, 2007), as we see, for example, in volume A1 (p. 82), in which it is stated that “The scientist considered the ‘father’ of modern chemistry in the West is Lavoisier, who did several experiments with chemical reactions [...]”.

Although this type of reference is inadequate according to the modern historiography of science, this common sense association can help to understand Lavoisier's constant presence in high school chemistry textbooks.

Another scientist with more than one experiment represented was New Zealander Ernest Rutherford. All collections describe the gold foil experiment, which would have contributed to the elaboration of his atomic model. In addition to this, volumes A1, B1, B3 and E3 also present an experiment in which Rutherford inserts a radioactive material into a lead block with a small hole and directs its emissions between two plates, one being positively charged and the other negatively charged. In this test, the researcher would observe deviations when the radioactive emission beams collide with a fluorescent shield, which would have contributed to the characterization of alpha and beta radiation.

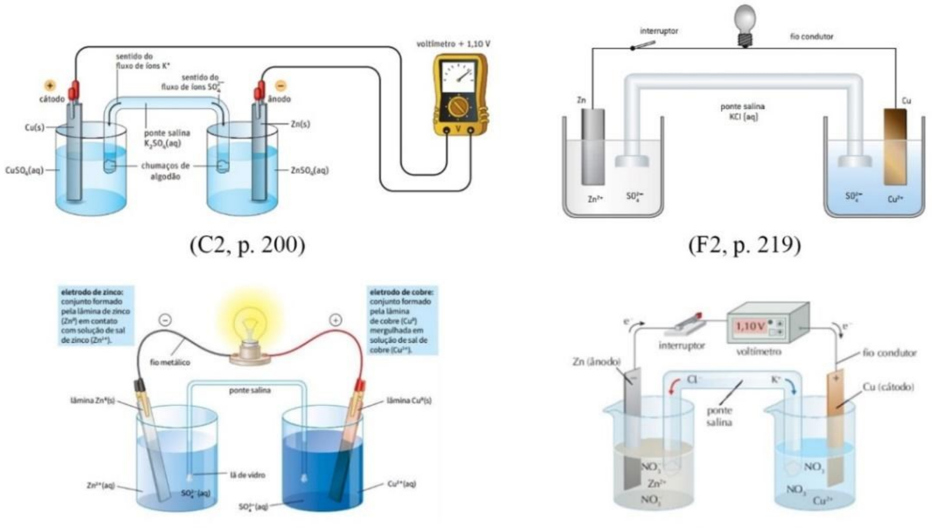
The experiments involving electrochemistry are also noteworthy since they correspond to eight of the total 24 historical experiments found. This area of chemistry has great importance in the high school curriculum and is applied in many procedures and materials of everyday life (BRAGA, 2019). According to research carried out by Marcondes and colaborators (2017), one third of teachers justify the teaching of electrochemistry because it is mandatory in the school curriculum, but about 76% point out the relationship of the theme with everyday issues. As we will see when analyzing the case of Daniell's cell, below, it is curious to observe that the representations of this device in the textbooks distort the original in such a way that no similarity is perceived between Daniell's cell and a common battery, widely present in the students' daily lives.

We highlight collection B as the one with the highest number of historical experiments, with a total of thirteen distributed in its three volumes. Collection F, on the other hand, has the lowest number of experiments, totaling four.

V. Daniell's Cell

The so-called Daniell cell appears in all the analyzed collections. As part of the electrochemistry content, highly valued in the Basic Education curriculum, this representation of an electricity-generating system from chemical reactions seems to play a fundamental role in explaining concepts considered important, such as oxidation-reduction reactions.

In four of the six collections (B, C, E, and F), the assembly is illustrated with two containers, one containing a copper sulfate solution and a copper metal plate, the other containing a zinc sulfate solution and a zinc metal plate. The plates are connected by conductive wires to an electrical device that evinces the passage of current. The solutions are connected by a salt bridge, usually containing potassium chloride solution, to allow the transport of ions between the solutions. The schematics presented in these four collections can be seen in the following assembly (Fig. 1).



(C2, p. 200) (F2, p. 219)

(B2, p. 225) (E2, p. 137)

Fig. 1 – Schematics assigned to Daniell's cell.
Source: Authors' montage based on illustrations from collections B, C, E and F.

The F collection also brings a schematic representation that does not include an apparatus attached to the metallic wire. This absence represents a conceptual error expressed in the collection, as it short-circuits the system, which would render it unusable as a cell (Fig. 2).

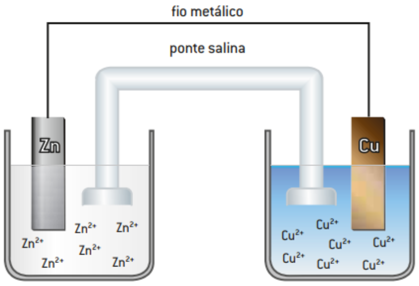


Fig. 2 – Schematic assigned to Daniell's cell. Source: F2, p. 217.

A third representation of this same collection shows the photograph of what would be a cell by Daniell (Fig. 3). In it, the electrodes are not in different containers, but in the same beaker, separated by a white cylindrical container not identified by the book. As we will see later, this representation is more similar to the original device built in the nineteenth century.

Fig. 3 – Photograph of the assembly of a Daniell Cell. Source: F2, p. 217.

In Collection A, the description of the operation of the cell is similar to the first descriptions we illustrated in this section. However, an important difference is that the schematic containing the two containers and the salt bridge is not directly attributed to Daniell (Fig. 5). On the page preceding this illustration, the book describes the operation of the two electrodes separately and also illustrates them separately (Fig. 4).

Collection D, in addition to not attributing the scheme with the salt bridge and independent electrodes to Daniell, brings a representation of how the cell was originally built (Fig. 6). The image, however, is not accompanied by any explanation that elucidates its operation or identifies its components.

Another important piece of information addressed in this volume is that the salt bridge "can be replaced by an ion-permeable porous membrane" (D3, p. 207).

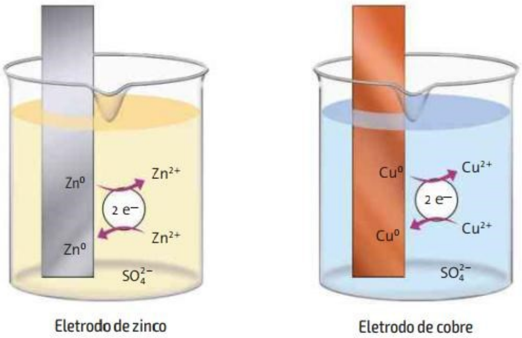


Fig. 4 – Zinc and copper electrodes. Source: Authors' montage from A2, p. 241.

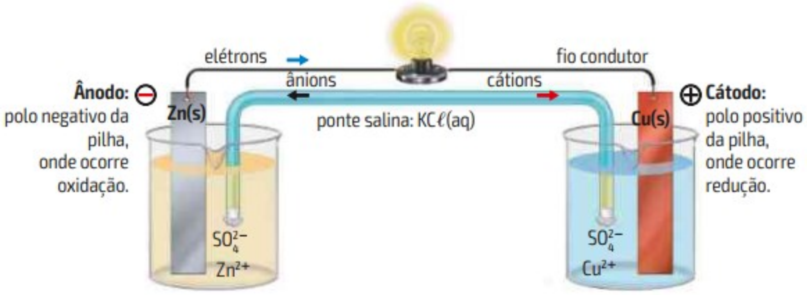


Fig. 5 – Diagram of a cell with zinc and copper electrodes. Source: A2, p. 242.

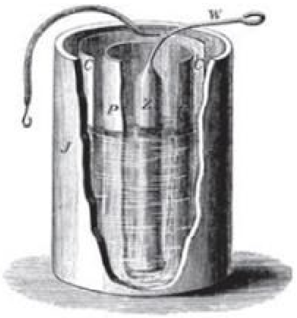


Fig. 6 – Engraving of a cell built by Daniell. Source: D3, p. 207.

In addition to the photograph presented in collection F (Fig. 3), this is the only mention we found of the possibility of a porous membrane or Daniell's cell having a different shape than that presented with two separate cups. Despite this, we did not observe greater concern from the authors of the collection to explain the differences and similarities between the original construction and the following electrochemical cell schemes, also used to explain the operation of the electrodes.

As Costa and Porto (2021) have found in this case, there are evident differences between the models presented in textbooks and the original device, made by John Frederic Daniell in the 1830s.

Daniell's work in building and perfecting the cell was described by him in a series of letters sent to Michael Faraday (1791-1867) between 1836 and 1839 (COSTA; PORTO, 2021). The letters were entitled “On Voltaic Combinations” and were published in the form of articles in the Royal Society's journal Philosophical Transactions. Daniell also published the book “An Introduction to the Study of Chemical Philosophy”, with the first edition in 1839 and the second in 1843.

Daniell's original apparatus was formed by an amalgamated zinc rod in the center, inside a porous cylindrical container containing a dilute solution of sulfuric acid. This vessel was inside a second cylinder, made of copper and containing a saturated solution of copper sulfate. This larger cylinder also housed a perforated container containing solid copper sulfate, whose purpose was to keep the solution constantly saturated (COSTA, 2021). Fig. 7, below, was extracted from an original communication by the author.

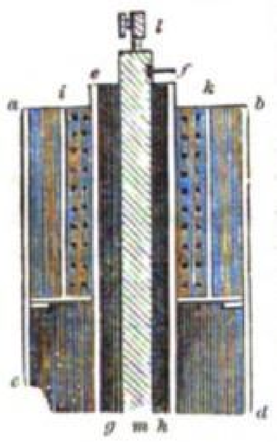


Fig. 7 – Schematic cut of a Daniell cell. Source: Daniell (1843, p. 505).

Daniell's goal was to overcome the limitations of the Volta pile, known at the time, by creating a battery that would allow obtaining a continuous and long-lasting current, and that would have practical use, in addition to replacing the use of corrosive substances such as concentrated sulfuric acid and nitric acid.

The original device created by the chemist underwent a series of tests and modifications until reaching its final version with high applicability. Daniell performed tests with different electrode pairs, such as zinc and silver and zinc and platinum, before opting for zinc and copper electrodes (DANIELL, 1836), which became the convention in textbooks. His experiments with current under high temperature also brought about structural changes in the cells.

The way most textbooks present the experiment misrepresents one of Daniell's most fundamental concerns which refers to utility: the cell in two cups is not useful beyond laboratory work and its assembly makes it difficult to associate several cells in series, as the original pile was normally used (Fig. 8). There are records that it was possible to associate up to 70 cells of the historical pile (COSTA, 2021).

The main use of the device created by Daniell was in the supply of electric telegraphs. The demand for this communication apparatus in the nineteenth century was considerable and, until then, there was no adequate constant current source for its operation. Daniell's cell allowed the large-scale development of telegraph networks across Europe, the United States, Africa and Asia (COSTA, 2021).

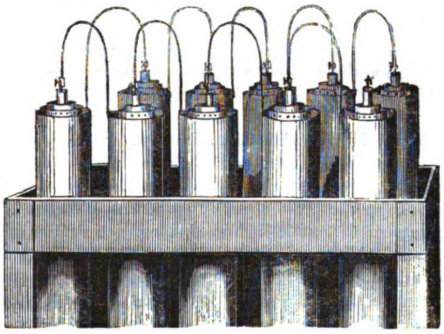


Fig. 8 – Association of 10 cells (piles) in series. Source: Daniell (1843, p. 505).

Interestingly, Daniell's original cell is also more similar to the batteries used in everyday life today than the didactic model presented by the books. Ausubel, in his theory of meaningful learning, points out the importance of using subsumers, that is, previous knowledge that the students have, so that they better understand new content (DISTLER, 2015). Batteries are part of the daily lives of all students, but the batteries presented in chemistry textbooks do not offer the possibility of a relationship due to their significant visual differences.

Taking advantage of this didactic potential, Santos (2016) proposes the disassembly of alkaline batteries (Fig. 9), in an experiment of investigative nature, as a strategy to promote a relationship between the content studied in the classroom and the issues of students' daily lives. The author points out how this experiment can be significant for students' knowledge of the battery components.

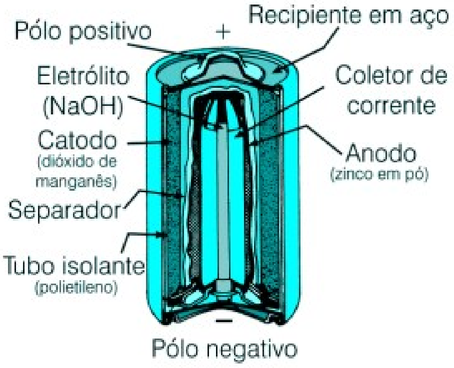


Fig. 9 – Schematic drawing of a MnO_2/Zn alkaline battery. Source:Bocchi et al. (2000, p. 6).

The salt bridge, presented as an essential part of the functioning of the textbook battery, simply did not exist in the original device. Daniell initially used ox oesophagal tissue to separate the solutions from the electrodes, but as he performed tests, he saw that this material could not withstand high temperatures and replaced it with a porous clay dish (COSTA, 2021). According to Velleca and colaborators (2002), the teaching of the cell with the salt bridge can provoke in students the misconception that electrons flow through the ionic solution of the bridge. Rocha (2018) also states that this misconception occurs not only in students of Basic Education but also in Higher Education.

Separation of the electrodes into distinct containers may also contribute to the misconception that oxidation and reduction processes may occur independently of each other. In a survey conducted by Gibin e Rodrigues (2020) with 23 students from different years of high school, three of the six groups of participating students presented in their responses the oxidation processes happening without the reduction process or vice versa, which is a serious conceptual error.

In line with the assumption that the history of science can improve the learning of scientific content, we note that the knowledge regarding the original assembly of Daniell's cell brings a number of advantages. The first to be highlighted is the opportunity for historical and social contextualization of this advent.

As already mentioned, Daniell was concerned with solving the demands of the time regarding the generation of constant current. This, among other motivations, led to the creation and improvement of the device that became an integral part of the development of society at the time.

Another important advantage is to facilitate the perception of the similarities between Daniell's cell, so present in electrochemistry classes, and alkaline batteries present in students' daily lives. The approximation of the theoretical contents of the class with the experience of students in other environments is an essential element to favour that the students establish links between their general knowledge and scientific knowledge, giving greater meaning to what they learn.

In the next session, we will observe part of the experimental work conducted by Ernest Rutherford's laboratory team and how their understanding brings other advantages to the teaching of chemistry.

VI. Rutherford's Gold Foil Experiment

A series of experiments conducted at the University of Manchester in England between 1908 and 1913 contributed to the development of Rutherford's atomic model. One of these was known as the golden-foil experiment, and it receives representations in all the analyzed didactic collections. The different atomic models are a constant theme in the study of the structure of matter for High School and are found in the first volume of all collections.

Collection A presents a schematic attributed to Rutherford and to the year of 1911, in which a sample of radioactive polonium is placed inside a lead box with a small hole, from which alpha particles exit. These particles target lead foils that also have small central holes, and then the particles smash into a gold foil. Just in front of this sheet there is a moving screen covered with zinc sulfide, which would shine in the regions where the particles collide (Fig. 10).

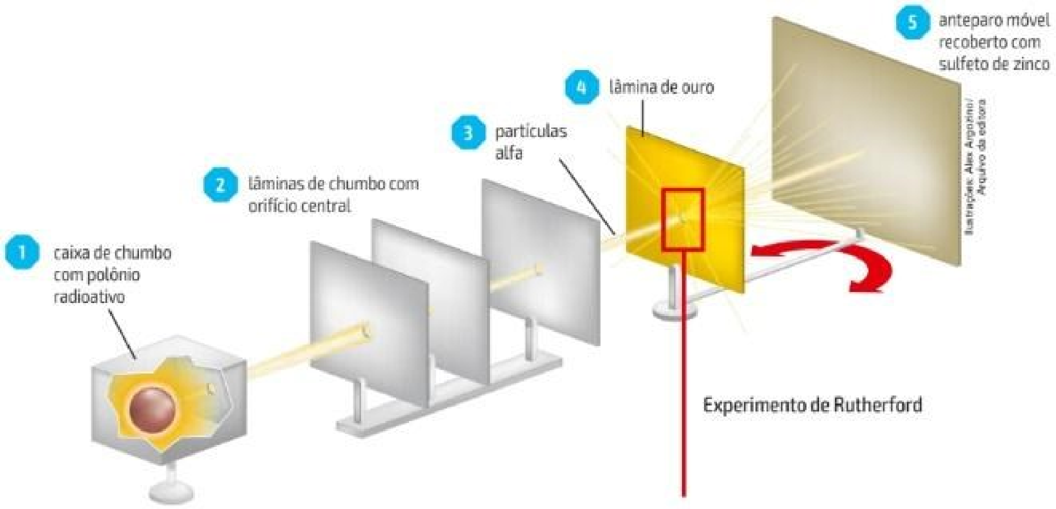


Fig. 10 – Schematic of the gold leaf experiment in collection A. Source: A1, p. 149.

Collection B presents a similar scheme (Fig. 11), which would have been carried out by Rutherford and collaborators. However, the gold foil in this representation appears surrounded by the fluorescent detector screen, which now has the shape of the letter C. The text of this collection does not make clear which radioactive material was used and in this, there is only one lead plate with an orifice, different from the previous scheme, which had three.

The representations of collections C, D and F are similar to the previous one, but in them, there are no lead foils between the alpha particle source and the gold leaf (Fig. 12).

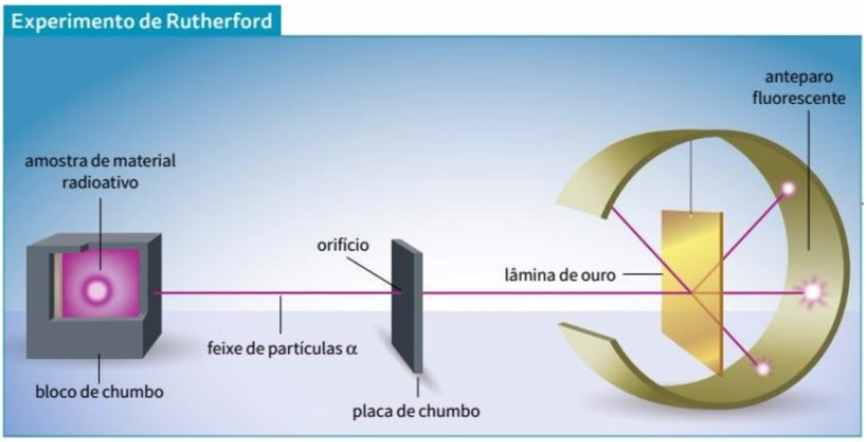
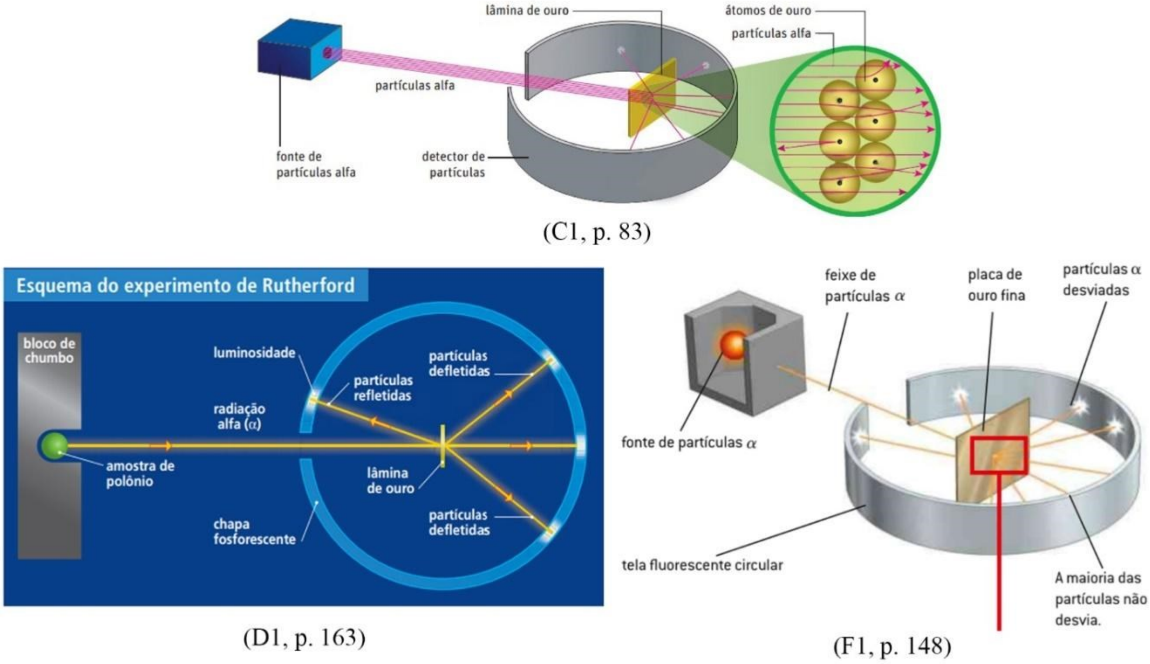


Fig. 11 – Schematic of the gold leaf experiment in collection B. Source: B1, p. 89.



(C1, p. 83)

(D1, p. 163)

(F1, p. 148)

Fig. 12 – Schematics of the gold leaf experiment. Source: Authors' montage based on illustrations from collections B, C, E and F.

Hans Geiger and Ernest Marsden are cited in collections C and F, respectively, as collaborators and as students who would have worked with Rutherford during the period in which the experiments were carried out.

From the images and descriptions, we can see that all the authors seem to refer to the same experiment, which would have been carried out by Rutherford or other members of the research group he coordinated at the University of Manchester. However, as we have seen, collection A links this event to the year 1911, while in collections D, E and F, the year assigned to the experiment is 1909.

Collection E also credits Geiger and Marsden, presented as students of Rutherford, and illustrates a different experimental assembly (Fig. 13). In this, the lead box containing the radioactive material (radio sample) and the gold foil are, somehow positioned within a circular "photographic plate". This representation includes a microscope coupled to such photographic plate, by means of which it would be possible to observe the particles that spread when colliding with the gold leaf. This collection is the only one to report that the experiment was conducted under a vacuum.

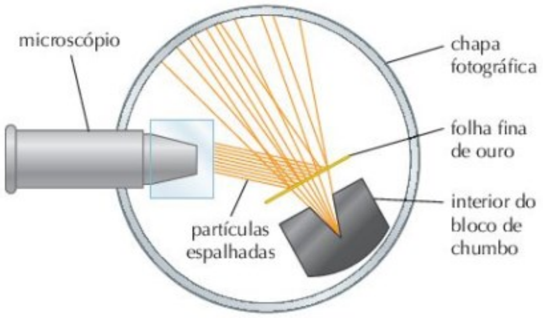


Fig. 13 – Schematic of the gold leaf experiment in collection E. Source: E1, p. 89.

Considering the representations found in the didactic collections, it seems important to highlight that the alpha particles are not visible to the naked eye. This implies that, in the experiment, the only way to detect them is through the scintillations they produce when colliding with some detector screen. Out of the six collections analyzed, only one (collection B) draws the reader's attention to this fact, and as we can see in the illustrations, the trajectories of the particles are clearly explained with colored lines, mixing visible elements (the apparatuses) and invisible elements (the particles and their trajectories) in the representations.

Johannes Wilhelm Geiger was a physicist born in Neustadt an der Weinstrasse, Germany. He graduated from the University of Munich and studied relations between matter and energy. After receiving his doctorate in 1906, he joined the team at Rutherford's laboratory in Manchester, where he carried out studies with alpha particles (DIAS, 2019). Geiger represented, therefore, a kind of associate researcher in the laboratory, who did not have the Professor status at the University, but who was also not, properly, a student under Rutherford's supervision.

Ernest Marsden was born in Rishton, about 40 km north of Manchester, in the United Kingdom. In 1906, he entered the University of Manchester, being heavily influenced by Rutherford's research on radioactivity. In the following years, Hans Geiger was his most direct advisor, and together they were responsible for conducting experiments on alpha particle reflection (LISENKO, 2019).

The historical reconstruction of this episode is not trivial and the first reflection that seems relevant to us is that the proposition of Rutherford's atomic model cannot be attributed to the simple interpretation of the results of a single experiment. Next, we will present four experiments performed and described by Geiger, two of them with the participation of Marsden, who contributed to the process of formulating Rutherford's atomic theory.

Searching for the keywords “α-particles”, “Geiger” and “Rutherford” in the database of the *Royal Society* of London, the first record found of an experiment similar to those presented in textbooks was published in 1908 (we will call it Experiment I), in a communication by Hans Geiger that described the assembly illustrated in Fig. *14*.

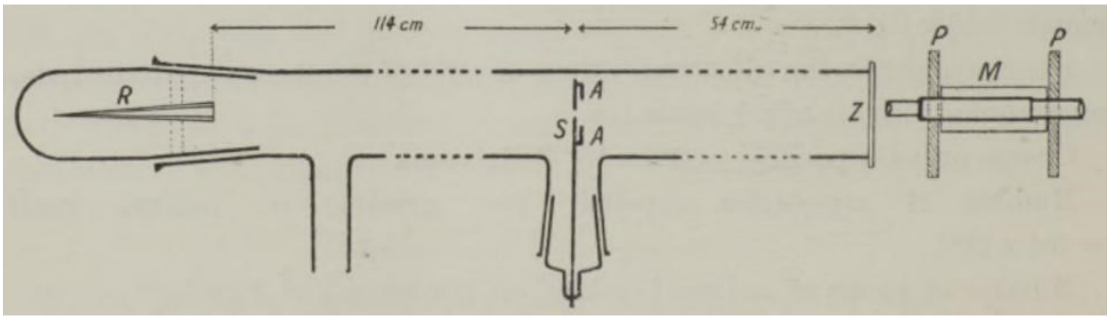


Fig. 14 – Experiment I. Source: Geiger (1908, p. 174).

The equipment consisted of a glass tube approximately 2 meters long and 4 centimeters in diameter. At one end of the tube, a source with radioactive material R was positioned (the radium bromide salt, RaBr2, was used), which emanated alpha particles. Following through the inside of the tube, particles passing through a small opening S collided with a phosphorescent screen Z at the end of the tube. The scintillations caused by the collisions were observed by the M microscope (GEIGER, 1908). When the system was under vacuum and metal sheets such as gold or aluminium were inserted into the AA holder, Geiger recorded that it was possible to observe that the number of scintillations was large in the direction of the center of the particle beam, and decreased as the microscope was moved to the ends.

Two years later, in 1910, Geiger published a new paper presenting a modified version of this experiment (we will call this Experiment III) as shown in Fig. 15. In this, the radioactive material (about 50 mg of $RaBr_2$) was placed at K and pushed through a column of mercury until it passed through bulb B, filling a conical tube A, the end of which measured approximately 2 mm in diameter. This refinement in the form of filling tube A with the radioactive material aimed to homogenize the sample and avoid the presence of air in the tube. The alpha particles then passed through the small opening D and caused scintillations in the zinc sulfide screen S. The metal sheets could be inserted both in D, shortly after opening, and in E, approximately 13 cm away from screen S. The scintillations on screen were observed by a microscope that could be moved vertically in order to observe the scintillations at various points on the screen S (GEIGER, 1910).

In this experiment, Geiger used gold foils with different thicknesses, the thinnest being 0.038 cm and the thickest 0.108 cm. He claimed that

> *Gold appeared to be the most suitable substance for such comparative measurements, since it can be obtained in very thin and uniform foils, and in addition its scattering power is higher than of any other material available (Geiger, 1910, p. 497).*

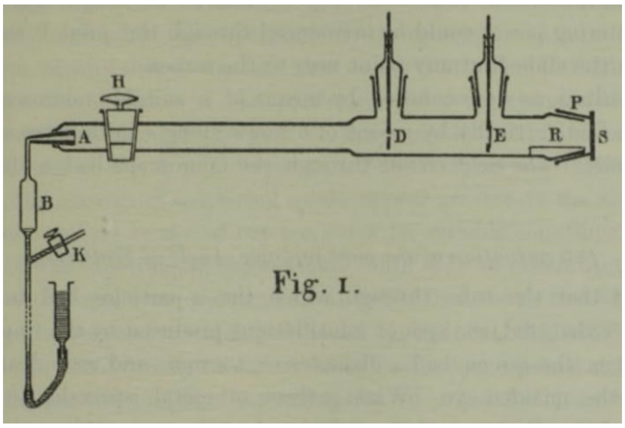


Fig. 15 – Experiment III. Source: Geiger (1910, p. 493).

This conclusion about the qualities of gold foils came from an earlier experiment, from 1909 (which we will call Experiment II, by chronology), conducted by Geiger and Marsden, who was still a graduate student integrating the laboratory team. This experiment consisted of a conical tube AB containing $RaBr_2$ and a gas under low pressure. The particles were emitted in the direction of the reflecting sheet R and the scintillations were seen on the zinc sulfide screen S through the microscope M. The lead plate P served to ensure that the alpha particles would not reach the zinc sulfide screen unless they were reflected by the sheet R (GEIGER; MARSDEN, 1909).

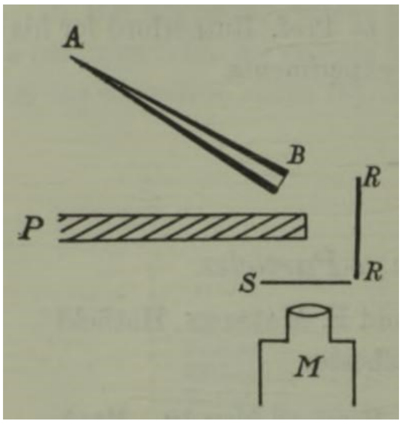


Fig. 16 – Experiment II. Source: Geiger and Marsden (1909, p. 496).

The experiment was carried out with metal sheets of different materials and the results can be seen in Table 3, with gold being the material that recorded the most scintillations per minute.

Table 3 – Results obtained by Geiger and Marsden in Experiment II.

1. Metal	***2. Atomic weight A***	***3. Number of scintillations per minute, Z***	***4. A/Z***
Lead	*207*	*62*	*30*
Gold	*197*	*67*	*34*
Platinum	*195*	*63*	*33*
Tin	*119*	*34*	*28*
Silver	*108*	*27*	*25*
Copper	*64*	*14.5*	*23*
Iron	*56*	*10.2*	*18.5*
Aluminium	*27*	*3.4*	*12.5*

Source: Geiger and Marsden (1909, p. 497)[3].

Another experiment (Experiment IV), more similar to that presented in textbooks, is

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[3] We find it curious to observe that the values indicated in column 4 of the Table do not correspond to the calculation of A/Z. In the text of the orignal article, the authors state that column 4 would indicate the *ratio* of the number of scintillations (Z) as a function of atomic weight (A) (GEIGER; MARSDEN, 1909, p. 497). The correct formula would therefore be Z/A. We believe that this is a typographical error perpetuated in the original document.

described in a publication by Geiger and Marsden dated of 1913 and aimed to verify the deflection angles of alpha particles already identified in previous experiments and considered by Rutherford in his 1911 publication, in which he elucidates his atomic theory (MELZER, 2012). We draw attention to these dates here. Rutherford's atomic model was formally presented in April 1911 in the article entitled “The scattering of α and β particles by matter and the structure of the atom” (RUTHERFORD, 1911). This occurred before, therefore, the publication of data related to the historical experiment that most resemble the one shown in chemistry textbooks.

The equipment used is schematized in Fig. 17 and has the following components:

F: Scattering foil (gold)
R: Lead block with radioactive material
M: Microscope
S: Zinc sulfide screen attached to microscope
D: Diaphragm used to collimate the alpha particles
A: Graduated movable circular platform
B: Cylindrical metal box
C: Conical airtight joint, responsible for rotating platform A
P: Glass plate that covers box B
T: Fixing tube of the RDF assembly

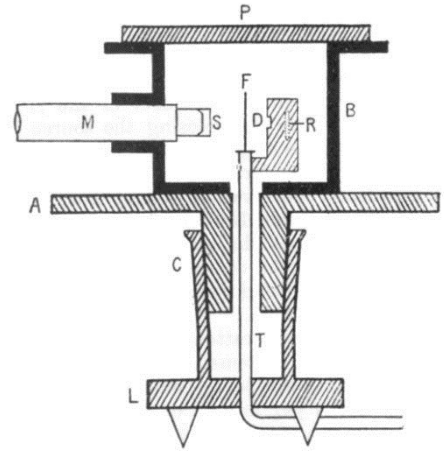

Fig. 17 – Experiment IV. Source: Geiger and Marsden (1913. p. 4).

In this experiment, which aimed to measure the deflection of alpha particles, the radioactive material used by Geiger and Marsden were radium salts. The assembly containing the lead block R, the diaphragm D and the metal foil F was fixed, while the other components of the structure could be rotated in the plane of the table so that the microscope could be positioned at different angles to the foil F. The entire system inside box B was under vacuum in order to minimize external influences on the propagation of the particles.

To carry out this experiment (and the previous ones) and collect data, the team needed a dark environment that would allow them to observe the scintillations caused by the shock of the particles with the zinc sulfide screen coupled to the objective lens of the microscope. It was necessary to visually count the number of scintillations recorded in front of the microscope lens in a given time interval, varying the angle of the observer in relation to the metal foil, which was fixed, and making new measurements at each inclination.

Considering this operational detail of the experiments, we emphasize that the trajectory of the alpha particles is not represented by lines in any of the illustrations present in Geiger and Marsden's communications. This detail suggests that the representations of current textbooks reduce the interpretative dimension of the results of the experiments, associating them with an objective correspondence with the reality of the studied phenomena (SOUZA, 2012). This act refers to distorted readings about science and its history already denounced by several authors (ALLCHIN, 2004; GIL-PEREZ *et al*., 2001; MATTHEWS, 1995).

Geiger and Marsden tested assorted metal sheets and found that silver and gold sheets generated better deflection results (GEIGER; MARSDEN, 1913).

According to Marques e Caluzi (2003), the account of the emergence of Rutherford's atomic model is important, but textbooks have serious errors in describing these experiments. These authors also claim that the books have difficulty relating the experiments to atomic theory.

We believe it is important to point out that the textbooks do not make clear which of the experiments conducted in Rutherford's laboratory they are referring to. Collections D, E, and F date the 1909 experiment. The experiment published this year is experiment II (Fig. 16), conducted by Geiger and Marsden, which has a very different assembly from the scheme presented in the books. Collections A and B state that the experiment in question was carried out in 1911. However, this was the year of Rutherford's communication in which he presents a theoretical mathematical model of how alpha particles should behave, together with an interpretation for the results of previous experiments, which served as the basis for the elaboration of his atomic theory (RUTHERFORD, 1911).

In table 4 we compared information about the experiment presented in the collections.

Table 4 – Comparative elements between textbook experiments.

Collection	**Year of experiment**	**Responsible Scientist**	**Radioactive material**	**Lead collimator**	**Particle Detector**
A	1911	Rutherford *et al.*	Polonium	3 Plate	Mobile rectangular screen
B	1911	Rutherford *et al.*	Not Informed	1 plate	Circular screen
C	Not Informed	Rutherford, Geiger and Marsden	Not Informed	Not applicable	Circular particle detector
D	1909	Geiger and Marsden	Polonium	Not applicable	Circular fluorescent plate
E	1909	Rutherford, Geiger and Marsden	Radio	Not applicable	Circular photographic plate + microscope
F	1909	Geiger and Marsden	Not Informed	Not applicable	Circular fluorescent screen

Source: The authors.

Unlike what we found represented in collections B, C, D, E and F, the circular screen described as having the objective of recording particle shock scintillations simply did not exist in this format in the original experiments. The zinc sulfide screen had a fixed position in experiments I, II and III, and the microscope used to observe these scintillations was mobile.

Collection E appears to present a schematic similar to experiment IV, with a microscope attached to a circular box. However, the authors of the collection identify a "photographic plate" surrounding the particle emitter system and the gold foil (Fig. 13), when originally the detector shield existed only in the objective lens of the microscope.

This version portrayed in E1 leaves many doubts about the assembly and about the phenomena involved because, in addition to not explaining the function of such a photographic plate, it also suggests that it would be possible for the researcher to directly observe the scattering of alpha particles through the microscope.

The lead plate with an opening used to collimate the alpha particles appears only in collections A and B. This item appears with this function in all original historical experiments, except for experiment III, in which the lead plate has the explicit function of preventing the particles from directly reaching the zinc sulfide screen.

There is also no consensus in the books regarding the composition of the radioactive material used in the emission of the particles. Collections A and D state that the material was polonium, but as we have seen, Geiger and Marsden used radium salts in their experiments, as pointed out by Collection E.

The lack of historical reliability in the presentation of these experiments reinforces some distorted views of science, pointed out by Gil-Pérez and collaborators (2001). One is the individualistic and elitist view, which portrays scientists as isolated geniuses working alone. The four experiments covered were conducted by Hans Geiger, who was already a doctor at the time, and two of these were also performed by Ernest Marsden, an undergraduate student. Rutherford was responsible for the laboratory, but not for carrying out the experiments. To him is attributed the interpretation of the results that, incorporated into a whole history of research and theoretical considerations, supported the proposition of a new atomic model (RUTHERFORD, 1911). Despite this, collections A and B do not name Geiger and Marsden, and only collections D and F point out that the experiments were conducted by the pair.

This point refers to the important discussion on collaboration and the role of research groups in scientific production. At the time in question, Marsden was a young undergraduate student and his work contributed to the development of a theory that is now considered very important in the history of chemistry. Like Marsden, undergraduate students have the possibility to actively participate in the construction of science through scientific initiation projects. Knowing these nuances of history can be a great incentive for students to consider scientific careers and engage in research projects.

Another distorted view of science that is reinforced by the textbook approach is the rigid or algorithmic view. In this, the process of building certain knowledge is reduced to the simple application of a sequence of steps of what would be the scientific method (GIL-PEREZ *et al.*, 2001). This view treats science with an inductivist character, overvaluing the role of experiments as precursors to theories. Although collections B, C, D and E mention that a series of experiments led to the results that Rutherford presented, these are still reduced to a simple assembly, which offered a direct result and easy interpretation. As we have seen, the experiments were laborious, demanding hours in the dark and the manual counting of scintillations, which required a great deal of effort from scientists.

According to Marques (2006), in years prior to Geiger's research, other scientists had already discussed alpha particle deflection results, which shows that this was not a novelty of Geiger's experiments. Rutherford (1911) also clearly explains in his article that he was already aware of the nuclear atomic model proposed by the Japanese researcher Hantaro Nagaoka (1865-1950), published in 1904 and which became known as the Saturnian Atom model. In this, the atom would be composed of a nucleus surrounded by electrons, as in the rings of the planet Saturn (BENEDETTI FILHO; MATSUMOTO, 2022; FIOLHAIS; RUIVO, 1996).

In all the collections analyzed, there is the idea that Rutherford formulated his atomic theory after and as a result of carrying out the experiments. This is not correct, since Rutherford (1911) states that experiments were in progress to strengthen and test the theoretical model already presented based on calculations. The textbook version promotes a historical inversion that reinforces the inductivist view of science, in which universal theories or statements are formulated from singular observations made by an impartial observer (CHALMERS, 1993). In the article, Rutherford presents a mathematical model of how the deviations of alpha and beta particles could be explained considering their unique interactions with the constituent atoms of the gold leaf and compares the theoretical values with the results obtained in the Geiger and Marsden experiments.

A central argument in Rutherford's model is that the behavior of alpha particles with respect to trajectory deviations could be interpreted by admitting the interaction of the particle with the central part of a single atom, and not as a cumulative effect of the interaction of the particles with many constituent atoms of the gold leaf. Due to the size of this central part and the thickness of the metal sheets used, it would be unlikely that the particle would collide with several atoms, but this contradicted the interpretive hypotheses proposed by his former advisor, Joseph John Thomson (1856-1940). Rutherford argued that the large trajectory deviations observed could only be explained by the single collision theory.

The atomic theory, however, is presented in 1911 in a preliminary form. Rutherford states that, for the theory, it was irrelevant to question whether the central part of the atom had a positive or negative charge. The fundamental thing was to admit that the size of this central part of the atom should be extremely reduced, on the order of 10^{-12} cm, and that the "sphere of influence" around this nucleus would have an opposite charge and radius of the order of 10^{-8} cm, which is 10,000 times larger than the central part of the atom (RUTHERFORD, 1911, p. 2). In the article, Rutherford explicitly and repeatedly admits that the positive sign for the central charge was adopted in the calculations for the sake of convenience.

As much as the descriptions of historical experiments found in the collections try to favour the learning of chemical concepts, we conclude that, at least in the cases analyzed, they simply distort history, or invent a new history of science. This goes against the educational guidelines that demand the approach of science as a historical, social and cultural enterprise (PORTO, 2019).

VII. Final Considerations

This research aimed to carry out an analysis of textbooks focusing on the representations of historical chemical experiments, pointing out divergences between the descriptions presented in the books and the original versions.

Comparing the results of the analysis of textbooks with historiographic articles and original historical documents, we identified distortions related to experimental assembly, materials used, procedures, socio-historical motivations and the relationship between experiments and theories in scientific practice.

Regarding Daniell's cell, our main source of reference was the article by Costa and Porto (2021) that details the improvement process and the motivations for building the device. As for Rutherford, we had difficulty locating secondary literature detailing his experimental approach. Thus, we consulted a greater number of historical originals to compose our analysis of the representations found in the textbooks.

In Daniell's case, the main differences refer to the experimental assembly of the cell. The original cell built by Daniell corresponded to a single cylinder containing the positive and negative poles separated by a semi-permeable membrane. In the textbooks, the cell is formed by two physically separated cups, each corresponding to a pole, which requires a salt bridge that simply did not exist in the original equipment. This difference in presentation also makes the picture of the device seen in chemistry classes difficult to compare with the student's everyday experience involving commercial batteries.

Regarding Rutherford's work, we highlight that textbooks present a single experiment as being responsible for supporting a new structure for the atom. Considering the historical records, we identified a series of experiments carried out to confirm and test ideas about the atom that were under debate. The assembly of the original experiments also has differences in relation to that presented by the textbooks. The latter appears to be a mixture or hybrid of several experiments conducted by Geiger and Marsden between 1908 and 1913.

The didactic implications of these distortions include conceptual problems with respect to oxidation-reduction reactions, the gap between students' daily lives and scientific activity, and distorted views of the nature of science.

We understand that textbook authors are committed to the historical dimension of science as they refer to the device as “Daniell's cell” or attribute the experiment to Rutherford. If the experiment described does not find a parallel in HS and if the device actually created by Daniell does not look like the one shown by the textbooks, we observe that the lack of historical fidelity compromises the learning about science that can be developed by students. The conceptual implications that derive from the versions of the experiments portrayed in the textbooks can be circumvented by a theoretical analysis of the original experiment, using HS as the guiding axis of the approach.

We argue, therefore, that there are considerable advantages to analyzing a scientific experiment by studying not only its results but also the motivations that led to it, the hypotheses and objectives involved, assembly and execution procedures, in addition to the socio-scientific context in which it is inserted.

Thus, we conclude that the superficial descriptions of historical experiments presented by textbooks may represent an obstacle to understanding the processes of scientific construction. For this reason, we understand that the textbook is not yet a sufficient source for teachers to learn about the history of science. Teachers concerned with this issue need to be supported by alternative materials, considering historiographic works and articles from the interface area between the history of science and science teaching as sources for their classes.

We hope that the historiographical notes gathered in this work can guide the review of future didactic works and that their authors can make better use of the history of science as an element capable of favouring the learning of concepts and science itself.

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