Inspiring air

A history of air-related science

Pere Grapí
CEHIC, Universitat Autònoma de Barcelona, Spain

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To Avel·lina

For rapidity of working and delicacy of measurement eudiometers leave nothing to be desired; indeed, as regards delicacy, it may be doubted whether amongst all the apparatus for measurement in this exhibition, there is one which can, like some of these instruments, give a distinct value, in weight or volume, to the one fourteen-millionth part of a gram of matter. Their drawback is their fragility, and any improvements tending to diminish this would doubtless be welcomed by chemists.

Edward Frankland's address to the Section of Chemistry in the Conferences held in connection with the Special Loan Collection of Scientific Apparatus, 1876.

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Acknowledgments

The gestation of this book began in the 2003-2004 academic year when I was the advisor of a research paper written by three of my final year high school students. That research was about making a replica of Volta's pile and reproducing some of the accompanying historical experiments. At that time, I was involved in the approach of the history of science to science education for secondary school students and science school teachers, and the replication of historical instruments and experiments had proved to have didactical value.

From that time onwards, I became increasingly interested in exploring the emergence of electricity, in the form of sparks, in the practice of chemistry. I therefore felt obliged to familiarize myself with the contributions of prominent figures such as Beccaria, Volta, Monge, Berthollet, Lavoisier, Priestley, Cavendish or van Marum. At the end of the eighteenth century, Volta's eudiometer was the most emblematic representation of the electrification of chemistry. The examination of Priestley's contribution in this field led me to a deeper knowledge of another important non-electrical eudiometrical device, the nitrous air eudiometer. My retirement from science teaching in 2012 provided me with the time required to complete this book. I hardly need to say that my first thanks go to Maria Rosa, Olga and Càndida, those three former students who were able to remake Volta's pile. Quite unwittingly, they gave me the opportunity to focus my attention on eudiometers instead of other instruments.

I also wish to express my appreciation to many others who have contributed to this project. Bruno Cavalchi, Francis Gires, Jørgen From Andersen, Antoni Quintana, Marta Quintana and Encarna Aihcart gave me complete freedom to photograph, or have provided me with photographs, of the eudiometers under their care. The librarians of the *Fons Històric de Ciència i Tecnologia* at the Universitat Politècnica de Catalunya, Barcelona, and of the *Biblioteca Panizzi*, Regio Emilia, who facilitated access to their documentary fund. Of course, I am also indebted to the published work of so many scholars quoted in this book. Special thanks are due to Agustí Nieto-Galan for his comments and suggestions to improve the final version of this work. Last but not least, I thank my wife Avel·lina for her support and understanding during the composition of this work, which detracted from the time we could otherwise have shared together.

Introduction. Instruments and procedures in practical chemistry

Sources and objects in the practice of chemistry

This is a work about eudiometers, a family of instruments originally devised to check the goodness (i.e. salubrity) of common air. The presentation of each eudiometrical device includes descriptions that are as close as possible to the textual sources (original publications, laboratory notebooks and monographs) and accompanied by the corresponding illustrations. Ideally, one should pay close attention to the following points when describing the functioning of any experimental device: material equipment, reagents, and the series of experimental procedures involved in that functioning. These procedures can be classified as manipulative (experiment setup, laboratory operations, step-by-step procedure, the practical skills required, the gathering of qualitative and quantitative data); cognitive (processing and interpretation of data, detection of errors and the setting of results) and communicative (experimenters' comments, the recording of incidents and the drawing of conclusions).

Unfortunately, verbal and non-verbal sources usually lack a complete description of the abovementioned particulars, largely due to partial or missing accounts of experimental procedures that were neglected or considered too complex to be recorded by writings or drawings. It has been claimed that the experience, understanding and skill provided by work on the replication of historical experiments can enrich the understanding of the textual sources. Replication may become unavoidable when an instrument no longer exists. Furthermore, replication may provide gestural knowledge that constitutes a resource in its own right, complementary to the textual and material sources.[1] In order to compensate for these

[1] Gooding, 1989, pp. 63-67; Sibum, 1995, pp. 27-28; Höttecke, 2000, pp. 344-347, 358; Usselman *et al.*, 2005, pp. 42-43. The replication of historical experiments and instruments is a field that has mainly been pursued from the perspective of the history of physics rather than that of the history of chemistry. Nevertheless, the following case studies deserve to be mentioned: the replication of Kirchhoff's and Bunsen's flame spectroscope (Henning, 2003); the replication of the Herme's tree, an alchemical recurrent image (Principe, 2000); the replication of Liebig's *kaliapparat*

unavoidable limitations of verbal and non-verbal sources, the descriptions of each eudiometrical device have been developed from original documents in the most understandable way for the reader.

Scientific practice and its related apparatus received little attention from historians of science during the twentieth century. The history of science was mainly regarded as the history of theory, according to which instruments were considered as materialized theories that might help to quantify concepts. However, in the 1990s, instruments ceased to be passive in the eyes of historians of science. For instance, in her paper on the integration of Lavoisier's calorimeter in his chemical system, Lissa Roberts was already adopting this approach of including scientific instruments as an essential factor in scientific practice for providing insights that remained unperceived if the history of science was regarded as an enterprise organized solely around the development of theory.[2] The landmark publication in 1994 of a volume of *Osiris* on *Instruments*, edited by Albert van Helden and Thomas L. Hankins, marked a pragmatic turning point in the interest of historians of science for the material culture of science. Instruments ceased to be perceived as unproblematic or uninteresting and were brought into focus within the history of science.[3] In 1985, Robert G. W. Anderson wrote a chapter devoted to *Instruments and Apparatus* for the book *Recent Developments in the History of Chemistry*, edited by Collin A. Russell. According to Anderson, things had gone particularly badly for the chemical apparatus in the field of the history of chemistry. The few existing uncritical accounts of chemical devices had not been sufficient for understanding the experimental practice of chemistry.[4] Anderson placed the works of the previous twenty years into various categories: general, instruments of particulars chemists, instruments with a particular function, catalogues of collections and instrument making. The fact was that by the end of the twentieth century very few historical studies of chemical instruments were regarded as

(Usselman *et al.*, 2005) and the replication of Lavoisier's and Laplace's calorimeter (Heering, 2005).

[2] Roberts, 1991, p. 200.

[3] van Helden & Hankins, 1994, pp. 2-3; Bensaude-Vincent, 2000, p. 189; Taub, 2009, pp. 339-340.

[4] Anderson, 1985, p. 217. Fifteen years later he was not much more optimistic yet, Anderson, 2000, p. 5.

recommendable for potential researchers in this area.[5] Nevertheless, the publication at the turn of the century of the collective work *Instruments and Experimentation in the History of Chemistry*, edited by Frederic L. Holmes and Trevor H. Levere, reflected to some degree the turning point in the 1990s and brought chemical instruments and experiments to the fore. Subsequent to these contributions, it is worth mentioning the publication in 2002 of the collective work *From Classical to Modern Chemistry. The Instrumental Revolution*, edited by Peter J.T. Morris, which dealt with the replacement of traditional methods in chemistry by automatic machinery in the 1950s and 1960s. With regard to eudiometry, there are very few indications or references to primary or secondary sources. Apart from the general *A History of Chemistry,*[6] the following works have been indispensable for me in the writing of this book: *An Historical Account of the Development of Methods for Determining Oxygen,*[7] *Eudiometrie, 1772-180,*[8] *Measuring Gases and Measuring Goodness*[9] and *Priestley's Quest for Airs and Ideas.*[10]

Chemical knowledge depended on a permanent merger of hand and mind; it was practice-laden as well theory-laden. Broadly speaking, experimental devices with their procedures are inexorably linked to the contemporary conceptual frameworks. Instruments can determine theory because they determine what is possible, and what is possible can condition what can be thought, i.e. theory.[11] Thus, instruments cannot be separated from changes in the conceptual frameworks or from the context in which they evolved. This central idea has inspired and guided the development of this book.

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[5] The most relevant include Maurice Daumas' *Lavoisier, Théoricien et Expérimentateur*, Paris, Presses Universitaires de France, 1955; Ferenc Szabadváry's *History of Analytical Chemistry*, Oxford, Pergamon, 1966 (reprinted by Gordon and Breach Science Publishers, 1992); Jon Eklund's *The Incompleat Chymist*, Washington, Smithsonian Institution Press, 1975 and Frederic L. Holmes', *Eighteenth-Century Chemistry as an Investigative Enterprise*, Berkeley, Office for the History and Philosophy of Science and Technology, 1989.

[6] Partington, 1961-1970, Vol.3

[7] Benedict, 1912, pp. 3-68.

[8] Watermann, 1968.

[9] Levere, 2000.

[10] Boantza, 2013a, pp. 145-170.

[11] van Helden & Hankins, 1994, p. 4; Beretta, 2002, p. 23.

Each chapter of the book seeks to go beyond a mere inventory of eudiometers presented in chronological order. The aim is firstly to explore and comprehend how eudiometers work, the materials used in making them and the reagents employed in each eudiometrical test, all with especial attention paid to the experimental procedures involved over the course of the test. Secondly, as previously stated, eudiometers took on a life of their own in many different contexts; human and animal health, quantification, gas analysis, chemical theory, medical therapeutics, plant and animal physiology, atmospheric composition, chemical compound composition, gas lighting, chemical revolution, experimental demonstration and the chemical industry. Thus, in order to understand eudiometers, it is essential to stress the interplay between the instruments themselves and their contextual environment.

The first chapter is devoted to establishing the foundations of eudiometry and to presenting the origins of the nitrous gas (nitrogen monoxide) test; in particular, to the figure of Priestley, who in 1772 designed that first chemical eudiometrical test. Two years later, in Italy, Landriani and Fontana repeated Priestley's test and provided it with an instrumentalist format. These first steps in eudiometry were promptly followed by the contributions of Magellan and Gérardin with their own instruments. This not only set in motion a competition in the production of nitrous gas eudiometers but also led to the emergence of a number of problems that the test would have to surmount in the near future.

Some of these drawbacks could be overcome using hydrogen instead of nitrous gas. Chapter Two deals with the spark eudiometer conceived by Volta in 1778 and based on the detonation of a mixture of common air with hydrogen. Actually, the development of this eudiometer was a joint venture involving many actors and subsequently engendered diverse versions of the instrument, the latest ones being characterized by their modular structure. Volta and his eudiometer were involved in a core issue of the chemical revolution, the composition of the product (water) arising from the ignition that took place inside the instrument, one of the phenomena that revealed the potential of Volta's eudiometer as a gas mixture analyser.

The nitrous air eudiometer experienced its most impressive rise during the 1780s with the contributions made by Priestley, Fontana, Cavallo, Magellan, Cavendish, Lavoisier and, above all, Ingenhousz. The developments of the instrument, as well as the growing criticism it received during that decade, form the content of Chapter Three. The Dutch physician Ingenhousz emerged as the leading eudiometrist thanks to his efforts to standardize the instrument both materially and procedurally, as well as to make it profitable for research beyond that of

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Abbreviations

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During the year 1792 Lavoisier had decided to publish a new collection of *Mémoires de physique et de chimie*. The process of publication was truncated on 28 November 1793 when the National Convention ordered to arrest Lavoisier. The *Mémoires* were never actually published. Madame Lavoisier decided in 1805 to bind the surviving printed material of 1793 and to donate copies to institutions and friends. For the complex origins and circulation of the *Mémoires* see Beretta (2001b).

LO Lavoisier, A.L. 1864-1893, *Oeuvres*, Paris: Imprimerie Impériale, 6 vols.

VO Volta, A. 1918, *Le Opere di Alessandro Volta, Edizione Nazionale*, Milano: Ulrico Hoepli, 7 vols.

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