

# Inspiring air

## A history of air-related science

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Series on the History of Science



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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.*



# Table of Contents

|   |        |
|---|--------|
| <b>List of Figures</b>  | ix     |
| <b>List of Tables</b>   | xiii   |
| <b>Acknowledgments</b>  | xv     |
| <b>Introduction.</b>  |        |
| <b>Instruments and procedures in practical chemistry</b>                              | xvii   |
| Sources and objects in the practice of chemistry                                      | xvii   |
| The migration of instruments from<br>artisanal to academic chemistry                  | xxiii  |
| The instrumental view of the chemical<br>approach to experimental physics             | xxvi   |
| A new place to locate physico-chemical<br>instruments in the chemistry laboratory     | xxviii |
| <b>1. The nitrous air test and the first eudiometers</b>                              | 1      |
| The question of the goodness of air   | 1      |
| Priestley's experimental device   | 7      |
| Landriani's nitrous air eudiometer<br>and the imagined "Priestley eudiometer"         | 12     |
| Fontana's first generation of nitrous air instruments                                 | 21     |
| Instrumentalizing the nitrous air test.<br>The contributions of Magellan and Gérardin | 27     |
| Summary   | 35     |
| <b>2. The inflammable air test and Volta's eudiometers</b>                            | 37     |
| Volta's approach to the chemistry of airs   | 37     |
| Inventing the inflammable air eudiometer  | 39     |
| The development of the inflammable air eudiometer                                     | 43     |
| Volta's return to eudiometrical publications  | 56     |

|  |            |
|--|------------|
| Summary  | 65         |
| <b>3. Nitrous air eudiometers at work</b>  | <b>69</b>  |
| Fontana-Ingenhousz's second generation of nitrous air eudiometers  | 70         |
| Fontana-Ingenhousz's eudiometer as an essential instrument for monitoring the first studies on the influence of sunlight on plants   | 74         |
| Tiberio Cavallo and the assessing of nitrous air eudiometers   | 77         |
| Priestley's disdain for the Fontana-Ingenhousz eudiometer. The controversy over the effect of sunlight on air purification by plants | 79         |
| Cavallo vs. Magellan or Priestleyans vs. Fontanists. Two different approaches to experimental data processing                        | 83         |
| Jean Senebier. Criticisms from continental Europe  | 88         |
| Henry Cavendish. The nitrous air test and the Fontana-Ingenhousz eudiometer under scrutiny   | 90         |
| The nitrous air test in the hands and mind of Lavoisier  | 97         |
| Fontana's nitrous air test revisited   | 103        |
| The nitrous air test in the research for a therapeutic use of dephlogisticated air   | 106        |
| Replying to criticisms of Fontana-Ingenhousz's nitrous air test. The last calls for recognition of his eudiometer                    | 108        |
| The late nitrous air eudiometer of Adam Wilhelm Hauch  | 113        |
| Summary  | 115        |
| <b>4. Portable eudiometry.</b>   |            |
| <b>The cradle of the phosphorous eudiometers</b>   | <b>119</b> |
| The early portable nitrous air eudiometers of Ingenhousz, Saussure and Achard  | 120        |
| The portable phosphorous eudiometers of Achard, Reboul and Giobert   | 125        |
| A plausible source of inspiration for Giobert's eudiometer   | 137        |
| Summary  | 142        |
| <b>5. The alkaline sulphides based eudiometers</b>   | <b>145</b> |
| Scheele's experiments on air in the background of alternative eudiometrical tests  | 145        |
| The eudiometrical test of the wet paste made with iron filings and sulphur   | 148        |

|   |            |
|---|------------|
| Lavoisier. Enabling Scheele's alkaline sulphide solutions   | 152        |
| Reprising the inverted retort apparatus with solid potassium sulphide                             | 153        |
| Antoni de Martí Franquès. Improving the sulphide test   | 156        |
| The reception of Martí's eudiometrical test   | 163        |
| Summary   | 164        |
| <b>6. The evolution of the phosphorous eudiometer</b>   | <b>167</b> |
| The theoretical and experimental background of the laboratory bench phosphorous eudiometers       | 168        |
| Séguin and the fast combustion of phosphorous eudiometer  | 172        |
| Berthollet and the slow combustion of phosphorous eudiometer                                      | 179        |
| The oxygenometre of Georges-Frédéric Parrot   | 189        |
| Lazzaro Spallanzani. Between animal respiration and the updating of Giobert's eudiometer          | 191        |
| Summary   | 197        |
| <b>7. The metamorphoses of the nitrous gas test</b>   | <b>201</b> |
| Alexander von Humboldt: naturalist, explorer and chemist  | 201        |
| Humboldt's intensive work on chemistry in Paris   | 205        |
| Back on the other side of the channel: Davy, Hope, Pepys and Henry                                | 214        |
| Summary   | 230        |
| <b>8. Reinventing and consolidating eudiometers at the beginning of the nineteenth century</b>    | <b>233</b> |
| John Dalton. Laying the foundations for the reconversion of the nitrous gas test                  | 233        |
| Summary   | 252        |
| <b>9. From eudiometry to gasometry</b>  | <b>255</b> |
| Volta's eudiometer as a gas mixture analyser  | 255        |
| Gay-Lussac. A renewed version of Volta's eudiometer and the search for the nature of prussic acid | 262        |
| Bunsen. The birth of gasometry in the context of the cast iron industry                           | 267        |
| Regnault. Gasometry in the context of the research on animal respiration                          | 278        |

|   |            |
|---|------------|
| The agenda of gasometry in the<br>second half of the nineteenth century   | 286        |
| Summary   | 293        |
| <b>10. Concluding remarks</b>   | <b>297</b> |
| Preliminary observations  | 297        |
| Experimental procedures, material equipment<br>and resemblances among eudiometers   | 298        |
| Theoretical accommodation   | 302        |
| Eudiometers in context  | 304        |
| Eudiometers and the chemical revolution   | 306        |
| The didactic second life of some eudiometers  | 308        |
| <b>Appendix</b>   | <b>313</b> |
| I. Fontana's fourth nitrous air <i>macchina</i>   | 313        |
| II. Gérardin's nitrous air eudiometer   | 314        |
| III. Lavoisier's experimental results and<br>calculations for the determination of the<br>vital air content and the purity of the nitrous air | 316        |
| IV. The nitrous air eudiometer of Adam Wilhelm Hauch  | 318        |
| V. Achard's portable nitrous air eudiometer   | 318        |
| VI. Parrot's eudiometer (oxygenmeter)   | 321        |
| <b>Bibliography</b>   | <b>323</b> |
| <b>Index</b>  | <b>345</b> |



## List of Figures

|   |    |
|---|----|
| Figure 1.1 Two of the experiments by Mayow on respiration in a confined volume of air.  | 3  |
| Figure 1.2 The main parts of Savèrien's <i>queynomètre</i> .  | 4  |
| Figure 1.3 Priestley's glass receiver used to keep mice.  | 6  |
| Figure 1.4 Priestley's glass tube used in his nitrous air test.   | 12 |
| Figure 1.5 Eudiometer attributed to Priestley by Landriani.   | 15 |
| Figure 1.6 Landriani's eudiometer.  | 18 |
| Figure 1.7 Profile view of De Luc's barometric tap (stopcock), which was the basis for the design of Landriani's eudiometrical taps.  | 19 |
| Figure 1.8 (Left) Landriani's eudiometer, at the Museo Galileo. (Middle and right) Modern replica of Landriani's eudiometer with the bladder and the bottle to obtain nitrous air (above) and the mixing flask (below), at the Centro Studi Lazzaro Spallanzani, Scandiano. | 20 |
| Figure 1.9 The eight "macchinette" of Felice Fontana.   | 22 |
| Figure 1.10 (Left) Fontana's fourth "macchina", at the Museo Galileo. (Right) Modern replica of Fontana's fourth "machina", at the Centro Studi Lazzaro Spallanzani, Scandiano.   | 24 |
| Figure 1.11 The fifth "macchina" of Felice Fontana.   | 26 |
| Figure 1.12 Modern replica of Fontana's fifth "macchina" placed on a pedestal with a bucket, at the Centro Studi Lazzaro Spallanzani, Scandiano.  | 27 |
| Figure 1.13 Priestley's glass vials used for eudiometrical measurements.  | 28 |
| Figure 1.14 Magellan's eudiometers.   | 32 |
| Figure 1.15 Magellan's first eudiometer.  | 33 |
| Figure 2.1 Frontispiece of Volta's first letter to Father Campi showing the collection of marsh air samples.  | 40 |
| Figure 2.2 Volta's musket and electric pistol.  | 41 |

|  |     |
|--|-----|
| Figure 2.3 Volta's prototype of an inflammable air eudiometer.   | 44  |
| Figure 2.4 Volta's portable inflammable air eudiometer.  | 46  |
| Figure 2.5 Sketch drawing of a Volta-type eudiometer (1778).   | 52  |
| Figure 2.6 (Left) Sketch of a Volta-type eudiometer sent to Senebier in 1778. (Right) Sketch of an accessory tube for improving the accuracy of the eudiometer (1778).   | 55  |
| Figure 2.7 Final versions of Volta's eudiometer.   | 57  |
| Figure 2.8 A copy of the Volta-type eudiometer depicted in <i>Fig. 1</i> (ca. 1790).   | 59  |
| Figure 2.9. (Left) A copy of the Volta-type eudiometer depicted in <i>Fig. 6</i> , 115 cm height, with the narrow glass tube of <i>Fig. 5</i> . (Right) A view of the lower part of the same instrument.   | 62  |
| Figure 2.10 (Left) Sketch of Volta's eudiometer described in the <i>Encyclopédie Méthodique</i> . From <i>Recueil des planches du Dictionnaire de chimie et de métallurgie, faisant partie de l'Encyclopédie Méthodique par ordre de matières</i> (Paris, 1813), Huitième classe, planche xxvi. (Right) A copy of a Volta-type eudiometer at the IES Francesc Ribalta. | 64  |
| Figure 3.1 Fontana-Ingenhousz's eudiometer.  | 73  |
| Figure 3.2 Cavallo's eudiometer.   | 79  |
| Figure 3.3 Ingenhousz's device for observing the bubbles of air released from plants under water and in sunshine.  | 82  |
| Figure 3.4 Magellan's second eudiometer of 1783.   | 87  |
| Figure 3.5 Cavendish's nitrous air eudiometer.   | 92  |
| Figure 3.6 Ingenhousz's apparatus for dispensing and breathing oxygen regularly.   | 107 |
| Figure 3.7 Ingenhousz's apparatus for generating nitrous air.  | 110 |
| Figure 4.1 Achard's portable phosphorous eudiometer.   | 127 |
| Figure 4.2 Reboul's portable phosphorous eudiometer.   | 132 |
| Figure 4.3 Giobert's portable phosphorous eudiometer.  | 136 |
| Figure 4.4 Guyton's experimental device with the inverted retort.  | 140 |
| Figure 5.1 Scheele's experimental device using a wet paste of iron filings and sulphur.  | 149 |
| Figure 5.2 Hales' experimental device.   | 151 |

---

|  |     |
|--|-----|
| Figure 5.3 Guyton's potassium sulphide eudiometer.   | 154 |
| Figure 5.4 Modern replica of Marti's eudiometer by Antoni Quintana-Marí.   | 162 |
| Figure 6.1 (Left) Lavoisier's experimental device for the combustion of phosphorous. (Right) Crooked iron wire used for igniting the piece of phosphorous. | 175 |
| Figure 6.2 Lavoisier's eudiometrical tube.   | 178 |
| Figure 6.3 Eudiometrical device based on the slow combustion of phosphorous.   | 187 |
| Figure 6.4 Spallanzani's phosphorous eudiometer.   | 192 |
| Figure 6.5 Sketch drawings of Giobert (Left) and Spallanzani's (Right) phosphorous eudiometers.  | 193 |
| Figure 6.6 Modern replica of Spallanzani's eudiometer exhibited at the Centro Studi Lazzaro Spallanzani, Scandiano.  | 194 |
| Figure 7.1 Davy's eudiometer.  | 217 |
| Figure 7.2 Hope's eudiometer.  | 221 |
| Figure 7.3 Pepys' eudiometer.  | 225 |
| Figure 7.4 Henry's eudiometer.   | 229 |
| Figure 8.1 Apparatus that belonged to Dalton.  | 241 |
| Figure 8.2 Gay-Lussac's nitrous gas eudiometer.  | 251 |
| Figure 9.1 Henry's eudiometrical apparatus.  | 261 |
| Figure 9.2 Gay-Lussac's eudiometer (1).  | 263 |
| Figure 9.3 Gay-Lussac's eudiometer (2).  | 264 |
| Figure 9.4 The closed end of Bunsen's eudiometric tube showing the two platinum wires bent into the curve of the tube.                                     | 270 |
| Figure 9.5 Bunsen's copying machine for the graduation of the eudiometric tube.  | 271 |
| Figure 9.6 Bunsen's laboratory setting for eudiometric analysis.   | 273 |
| Figure 9.7 Pneumatic trough with a glass window.   | 274 |
| Figure 9.8 Regnault's eudiometrical apparatus.   | 280 |
| Figure 9.9 Regnault's eudiometrical apparatus.   | 281 |
| Figure 9.10 Three steps in Regnault's protocol for collecting air samples.   | 285 |

|   |     |
|---|-----|
| Figure 9.11 The Orsat gas analyzer.   | 291 |
| Figure 9.12 The Hempel simple absorption pipette for liquid reagents.       | 292 |
| Figure 10.1 Phosphorous eudiometers from French textbooks of chemistry (1). | 309 |
| Figure 10.2 Phosphorous eudiometers from French textbooks of chemistry (2). | 310 |
| Figure 10.3 Phosphorous eudiometers from French textbooks of chemistry (3). | 311 |
| Figure 10.4 Phosphorous eudiometers from French textbooks of chemistry (4). | 311 |
| Figure 11.1 The fourth “macchina” of Felice Fontana.                        | 314 |
| Figure 11.2 Gérardin’s eudiometer.  | 316 |
| Figure 11.3 Hauch’s nitrous air eudiometer.                                 | 319 |
| Figure 11.4 Achard’s portable nitrous air eudiometer.                       | 320 |
| Figure 11.5 Parrot’s eudiometer (oxygenmeter).                              | 322 |

## List of Tables

|  |     |
|--|-----|
| Table 1 Results of the sixth series of experiments based on equal parts of common and inflammable air.     | 53  |
| Table 2 Experimental results of the determination of oxygen of a sample of common air.                     | 209 |
| Table 3 Composition of three oxides of nitrogen.   | 237 |
| Table 4 Summary of the diminutions in volume observed in the ignition of mixtures of oxygen and hydrogen.  | 244 |
| Table 5 Ratios in volume oxygen to nitrogen.   | 247 |
| Table 6 Ratios in volume of four oxides of nitrogen recognized by Gay-Lussac in 1809 (*) Modern formulas.  | 248 |
| Table 7 Correspondences between the millimetre scale and capacities in the Bunsen's eudiometric tube.      | 272 |
| Table 8 Experimental results of the determination of the vital air content of a sample of atmospheric air. | 316 |
| Table 9 Calculations of the vital air content of a sample of atmospheric air.                              | 317 |
| Table 10 Experimental results of the determination of the purity of the nitrous air used as a reagent.     | 317 |
| Table 11 Calculations of the purity of the nitrous air used as a reagent.                                  | 317 |



# 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 Cànida, 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.<sup>1</sup> In order to compensate for these

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<sup>1</sup> 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 spectroscopy (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.<sup>2</sup> 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.<sup>3</sup> 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.<sup>4</sup> Anderson placed the works of the previous twenty years into various categories: general, instruments of particular 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

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

<sup>2</sup> Roberts, 1991, p. 200.

<sup>3</sup> van Helden & Hankins, 1994, pp. 2-3; Bensaude-Vincent, 2000, p. 189; Taub, 2009, pp. 339-340.

<sup>4</sup> 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.<sup>5</sup> 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*,<sup>6</sup> 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*,<sup>7</sup> *Eudiometrie, 1772-180*,<sup>8</sup> *Measuring Gases and Measuring Goodness*<sup>9</sup> and *Priestley's Quest for Airs and Ideas*.<sup>10</sup>

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.<sup>11</sup> 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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<sup>5</sup> 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 Incomplete 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.

<sup>6</sup> Partington, 1961-1970, Vol.3

<sup>7</sup> Benedict, 1912, pp. 3-68.

<sup>8</sup> Watermann, 1968.

<sup>9</sup> Levere, 2000.

<sup>10</sup> Boantza, 2013a, pp. 145-170.

<sup>11</sup> 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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# Bibliography

## Abbreviations

- LM Lavoisier, A.L. 1805, *Mémoires de chimie*, Paris: unpublished, 2 vols.; 2004, *Mémoires de physique et de chimie*, Bristol: Thoemmes Continuum, 2 vols.

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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# Index

## A

abridged procedure, 72, 104,  
108, 112, 116, 299  
abridged version, 90, 104, 155  
absorbents, 215, 275, 287, 289  
Académie des Sciences, 42, 63,  
131, 137, 172, 186, 285  
accuracy, xxviii, 47, 60, 74, 85,  
92, 95, 101, 105, 111, 116, 128,  
152, 167, 176, 188, 205, 222,  
231, 241, 253, 262, 272, 282,  
288, 296, 301  
Achard, 119, 132, 142, 159, 181,  
199, 300, 303, 318  
Adams, 74, 110  
aerial acid, 48, 145  
aerial medicine, 20  
affinity, 147, 183  
affordability, 88, 301  
agricultural chemistry, 201  
air measure, 27, 69, 74, 79, 112,  
117, 298  
algebraic approach, 275, 294  
algebraization, 275, 277  
alkaline sulphides, 103, 142, 145,  
152, 157, 182, 188, 199, 212,  
218, 243, 301  
Ampichel, 105  
analytical power, 245, 253  
Anforni, 134  
animal respiration, 3, 98, 115,  
167, 171, 191, 196, 213, 278,  
285, 296, 303, 304, 308  
Animal respiration, 198  
apprenticeship, 118, 295  
artificial illumination, 259, 296,  
306  
artisans, xxiii, 66  
authority, 65, 110, 298

## B

balloon ascent, 242  
Banks, 81, 114  
Beccaria, 37  
Beddoes, 214, 219  
Bérard, 238, 247, 256  
Bergman, 10, 100  
Berthollet, 63, 95, 154, 155, 163,  
179, 182, 184, 188, 198, 202,  
210, 221, 230, 242, 246, 249,  
255, 294, 301, 309  
Biot, 159, 163, 242  
Black, 219, 227  
blast furnace, 268, 290  
Boerhaave, xxvi, 234  
Bonaparte, 181, 201  
Bonpland, 213  
Boyle, 2, 91, 125  
Brugnatelli, 191  
bubbles, 46, 52, 59, 80, 81, 94,  
110, 176, 274, 294  
Bunsen, 267, 278, 284, 286, 295,  
297, 300, 306, 308

## C

cabinet, xxvi, xxviii, xxx, 73, 114,  
313  
calcination, xxiv, 91, 97, 138,  
145, 169, 170, 306, 308  
calcium sulphide, 145, 158, 160,  
164, 218, 221, 228, 235, 243,  
253, 258, 297, 301, 302  
calibration, 60, 62, 79, 293  
caloric, 174, 183  
calorimeter, 98, 171, 307  
Campi, 39, 48  
carbon dioxide, 15, 135, 137,  
159, 162, 196, 223, 226, 255,  
303, 307

carbon monoxide, 39, 255, 287, 290  
 carbonic acid gas, 136, 194, 226, 255, 257, 258, 265, 276, 281, 283, 287, 294  
 carburetted hydrogen, 255, 262, 275  
 Carburetted hydrogen, 277  
 cast iron, 267, 275, 296, 306  
 Castelli, 40, 42  
 Cavallo, xx, 60, 77, 85  
 Cavendish, 8, 35, 49, 90, 91, 94, 96, 117, 124, 157, 159, 202, 216, 239  
 Chaptal, 202, 242  
 charcoal, 63, 98, 99, 171, 177, 178, 200, 255, 257, 268  
 Chaussier, 137, 140, 143, 165, 301  
 cheapness, 83, 87, 88  
 chemical apparatus, xviii, xxvii, 227, 232  
 chemical composition, xxvi, 204, 269, 296, 304, 306  
 chemical device, xviii, xxviii, 226  
 chemical industry, xx, 296, 304  
 chemical instruments, xviii, xxvi, xxviii  
 chemical laboratory, 139, 291  
 chemical revolution, 306, 308  
 chemicals, 76, 121, 205, 290  
 chemiluminescence, 173, 185, 190, 196, 199, 304  
 chemistry of airs, 37  
 Clément, 255  
 Clindworth, 105, 110  
 coal distillation, 260, 296  
 combining proportions, 237, 238, 245, 252, 304  
 combining ratio, 24  
 combining volumes, 245, 247, 249, 253, 265, 267  
 composition of atmospheric air, 151, 165, 181, 205, 246, 267  
 composition of water, 65, 172, 233, 242, 253, 299, 307, 308  
 contraction in volume, 8, 9, 12, 19, 22, 28, 47, 50, 54, 91, 94, 98, 101, 102, 105, 108, 122,

182, 198, 207, 208, 240, 298, 302, 315, 318  
 Coquillion, 290  
 corrupted-air, 145, 147, 148  
 Count Firmian, 20, 38, 57  
 Cruickshank, 255  
 Cullen, 29, 70  
 Cuthbertson, 63  
 cyanogen, 266, 267, 296

## D

D'Arcet, 55  
 Dalton, 229, 233, 241, 249, 252, 256, 294, 299, 302, 305  
 data processing, 85  
 Davy, 214, 218, 225, 228, 231, 237, 238, 246, 248, 302  
 dephlogisticated air, 5, 18, 28, 36, 47, 49, 56, 66, 74, 80, 88, 96, 103, 104, 106, 115, 142, 171, 245  
 dephlogistication, 21, 81  
 Desormes, 255  
 didactic instruments, 309  
 diminution in volume, 8, 11, 30, 35, 42, 43, 50, 64, 74, 89, 122, 128, 140, 175, 181, 207, 218, 226, 239, 256, 265  
 disease, 1, 22, 30, 107, 120, 158, 214, 246, 304  
 dosing, 28, 117, 298  
 Doyère, 287  
 Dumas, 267, 278

## E

École Normale, 147, 180  
 economic context, 296, 306  
 economic development, 290, 296  
 elasticity, 2, 3, 9  
 electric machine, xxvii, 58  
 electric pistol, 40, 41, 43, 49, 65, 142  
 electric spark, 39, 41, 49, 51, 55, 58, 256, 262, 270, 283  
 electrical instruments, xxix  
 electrophorus, xxix, 38, 41, 44, 47, 51, 58

endpoint, 18, 34, 60, 66, 84, 94,  
 111, 117, 123, 181, 188, 199,  
 216, 226, 298, 310  
 equations, 275, 277, 284, 294  
 equipment, xxiii, xxviii, xxix, 69,  
 119, 165, 222, 240, 267, 273,  
 290, 293, 295, 301, 306  
 eudiometrical apparatus, 112,  
 261, 279, 280  
 eudiometrical device, xxiii, 32,  
 75, 90, 92, 95, 111, 122, 130,  
 164, 188, 217, 220, 226, 249,  
 294, 297, 309, 318  
 Eudiometrical device, 187, 311  
 eudiometrical instrument, 14,  
 216, 218  
 eudiometrical procedure, 16, 59,  
 71, 80, 89, 92, 104, 116, 124,  
 148, 160, 174, 186, 211, 234,  
 243  
 eudiometrical reagent, 216, 224,  
 230, 253, 301  
 eudiometrical stations, 204, 230  
 eudiometrical tube, 16, 60, 72,  
 85, 95, 101, 105, 112, 116, 120,  
 140, 177, 195, 213, 231, 241,  
 256, 257, 289, 298, 303, 308  
 eudiometrist, 96, 116, 125, 239,  
 253, 298, 304  
 eudiometry, xix, 5, 22, 34, 118,  
 119, 143, 164, 173, 182, 195,  
 201, 220, 228, 234, 246, 253,  
 267, 293, 300, 304  
 Eudiometry, 211  
 execution time, 73, 116, 182, 299  
 exhalation, 1, 13  
 experimental demonstration, xx  
 experimental design, 30, 154,  
 164, 172, 179, 198, 236  
 experimental philosophy, xxiv, 7,  
 84, 87, 185, 235  
 experimental physics, xxiii, xxix,  
 xxx, 12, 38, 89, 113, 185  
 experimental procedure, xvii, 12,  
 87, 116, 226, 231, 243, 256,  
 275, 293, 298, 302  
 Experimental procedure, 298  
 experimental protocol, 96, 285  
 experimental skills, 94, 172  
 explosion tube, 293, 300, 304

## F

factitious air, 91  
 fast combustion, 172, 199, 236,  
 300, 303, 309, 310  
 final point, 69, 117  
 fire-air, 145, 147, 148  
 firedamp, 290  
 fixed air, 10, 17, 21, 29, 75, 97,  
 107, 125, 133, 145, 151, 168,  
 171, 198, 303, 308  
 Fontana, xxx, 17, 21, 22, 26, 35,  
 60, 69, 70, 84, 86, 92, 99, 105,  
 110, 113, 115, 118, 123, 128,  
 178, 227, 298, 313  
 Fontana-Ingenshousz, 70, 74, 79,  
 85, 91, 95, 101, 104, 108, 115,  
 118, 130, 141, 190, 213, 307  
 Fortin, 63, 141  
 Fourcroy, xxvii, xxviii, xxix, 152,  
 163, 174, 177, 186, 201, 211,  
 242, 245  
 Frankland, 288, 289, 296  
 Franklin, 10, 37, 70

## G

galvanism, xxx, 204, 205  
 Garnet, 235  
 gas analysis, xx, 268, 286, 291,  
 293, 296, 300, 306  
 gas burette, 292, 300  
 gas lighting, xx, 260, 279, 306  
 gas mixture analyser, 66, 224,  
 231, 297, 305  
 gas mixtures, 226, 253, 255, 268,  
 275, 291, 304  
 gasometer, xxx, 63, 114, 224, 307  
 gasometry, 245, 267, 278, 286,  
 287, 306  
 Gattoni, 37  
 Gay-Lussac, 163, 202, 230, 241,  
 245, 247, 248, 249, 251, 257,  
 264, 266, 293, 299, 305, 308  
 Gérardin, 34, 35, 314  
 gestural knowledge, xvii, 300  
 gestures, 294  
 Giddy, 214, 217

Giobert, 123, 134, 136, 137, 143,  
154, 164, 191, 197, 211, 300,  
303, 309  
glassware, xxix, 119, 194, 200  
globe, 61, 112, 318, 320  
globe-shaped, 66  
Gmelin, 267  
goodness of air, 1, 12, 23, 30, 35,  
109, 293  
Göttling, 182, 190, 197, 205, 207,  
230, 303  
Gough, 234  
graduation, 17, 21, 60, 133, 270,  
284, 293, 315  
gravimetric test, 92, 95  
ground glass, 36, 122, 295, 300,  
315  
Guyton de Morveau, 62, 65, 66,  
121, 137, 147, 153, 179, 197,  
208, 242

## H

Hales, 3, 8, 35, 91, 130, 150, 307  
Hauch, 113, 318  
Hempel, 291, 296, 300, 306  
Henderson, 222  
Henry, 214, 217, 227, 228, 235,  
241, 252, 256, 293, 302  
Hippocratic tradition, 1  
Hope, 214, 218, 219, 221, 228,  
231, 241, 302, 305  
human respiration, 171, 172,  
231, 290, 305  
Humboldt, 132, 163, 190, 197,  
201, 205, 206, 211, 212, 228,  
231, 236, 242, 245, 246, 252,  
257, 299, 305, 307  
hydrocarbons, 39, 241, 255, 268  
hydrogen, 39, 43, 63, 135, 152,  
196, 213, 240, 244, 245, 246,  
253, 255, 257, 265, 269, 275,  
277, 283, 292, 303, 307  
hygienist tradition, 1

## I

iconography, 23, 35, 298  
industrial gasses, 290  
inflammability, 41, 259, 267

inflammable air, 30, 39, 41, 43,  
48, 52, 54, 61, 65, 70, 78, 128,  
142, 157, 170, 199, 298  
inflammable air test, 37, 50, 56,  
66, 157, 303  
Ingenhousz, 70, 76, 80, 88, 96,  
99, 103, 106, 111, 118, 119,  
142, 212, 226, 239, 298, 304  
instrument designer, 172  
instrument maker, 31, 63, 66,  
120, 121, 223, 288, 301  
inverted retort, 139, 141, 153,  
164, 301  
iron filings, 16, 96, 103, 113, 128,  
145, 148, 149, 152, 157, 161,  
181, 188, 199, 297, 301  
iron sulphate, 30, 205, 206, 210,  
218, 228, 231, 243, 253, 297,  
301

## K

*Kaliapparat*, 266  
Kirchhoff, 269  
Kolbe, 268, 269, 288, 294

## L

Landriani, 5, 12, 13, 16, 18, 20,  
22, 35, 47, 55, 69, 117, 125,  
298  
Laplace, 49, 55, 98, 170, 179, 201,  
242, 303, 307  
Lavoisier, xxvii, 29, 49, 62, 66, 97,  
98, 99, 101, 102, 114, 133, 134,  
138, 148, 151, 152, 168, 173,  
175, 177, 179, 182, 190, 197,  
206, 214, 239, 252, 303, 306,  
307, 316  
leakage, 36, 224, 231, 295, 298,  
300  
Liebig, 266, 268, 278, 288  
light emission, 197  
Lord Shelburn, 9, 69

## M

Macquer, xxvi, xxviii, 56

Magellan, xx, 27, 31, 33, 38, 60, 78, 83, 86, 110, 116, 125, 128, 298  
 magnifying glass, 116, 138, 168, 173, 298  
 Malacarne, 134  
 manufacturing, xxix, 259, 290  
 Marcet, 289  
 Marggraf, 124, 126  
 marsh air, 39, 65  
 marsh gas, 256, 290  
 Martí, 155, 156, 157, 159, 162, 163, 218, 221, 235, 243, 253, 259, 298, 302  
 Martin, 74, 110, 120  
 material constraints, 200  
 mathematical approach, 300  
 Mayow, 2, 35  
 McLeod, 289  
 mean value, 83, 85, 150, 284  
 Mechanical instruments, xxvi  
 Megnier, 105, 110  
 mephitic air, 5, 98, 101, 102, 158, 165  
 meteorology, 21, 77, 156, 236  
 methane, 39, 256, 275, 284, 296  
 miasma, 1, 34, 173  
 mice, 2, 3, 5, 7, 297  
 mines, 191, 202, 203, 208, 230, 268, 290  
 mining, 119, 203, 204, 230  
 modular conception, 66, 299  
 Monge, 55, 66, 152  
 mophete, 63, 170  
 Moscati, 13  
 Musschenbroek, 37

## N

natural philosophy, xxiv, 37, 55, 113, 234  
 Newton, 3, 37  
 Newtonianisme, xxiv  
 Nicholson, 214  
 nitre, 3, 11, 99, 107, 150  
 nitric acid, 8, 10, 16, 44, 100, 205, 216, 237, 238, 239, 247, 250, 265  
 nitric oxide, 8, 216, 217

nitrous acid, 10, 48, 49, 100, 215, 238, 239, 248, 252, 302  
 nitrous air, 1, 7, 10, 12, 16, 21, 25, 27, 34, 44, 52, 56, 65, 69, 73, 77, 85, 90, 92, 94, 97, 100, 101, 103, 106, 108, 113, 118, 120, 130, 132, 140, 145, 165, 173, 178, 188, 195, 226, 253, 298, 304, 308  
 nitrous gas, 103, 153, 182, 188, 197, 201, 205, 214, 225, 231, 236, 238, 239, 247, 251, 297, 305, 308  
 Nollet, xxx, 37

## O

olefiant gas, 256, 257, 258, 259  
 open mode, 262, 293  
 operational skills, 88, 109  
 optical instruments, xxiv, xxx  
 Orsat, 290, 291  
 oxides of nitrogen, 215, 231, 234, 237, 238, 247, 248, 253, 296, 305  
 oxygen-centred chemistry, 115, 143, 302, 303, 307

## P

parallax, 60, 84, 116, 272, 282, 294, 298  
 Parker, 32  
 Parrot, 188, 189, 190, 199, 211, 321  
 Pelletier, 185, 186  
 Pepys, 214, 219, 223, 225, 226, 228, 231, 305  
 philosophical instruments, xxiv, xxvii, 31  
 phlogistication, 21, 47, 50, 125, 128, 130  
 phlogiston-centred chemistry, 302  
 phosphorous, 119, 125, 128, 130, 139, 154, 164, 167, 172, 173, 178, 179, 190, 196, 207, 216, 230, 236, 243, 297, 303, 308, 309  
 photosynthesis, 116, 304



physiology, xx, xxx, 88, 115, 134,  
141, 156, 172, 198, 212, 230,  
296, 304

plant nutrition, 212

plant respiration, 103, 116, 191,  
197, 223, 305

platinum wires, 264, 270, 274,  
280, 287, 293, 308

Playfair, 268, 269, 288

Pneumatic Institution, 214, 219,  
231

pneumatic trough, xxvi, 105,  
112, 198, 214, 275

point of saturation, 18, 34, 99,  
101, 117, 238, 240, 252, 298

polyvalent eudiometer, 224

portability, 45, 62, 66, 119, 126,  
135, 176, 197, 204, 299, 303

portable eudiometer, 45, 66, 119,  
122, 167, 197, 297

Portable eudiometer, 142

portioning machine, 294

potassium sulphide, 137, 140,  
152, 153, 165, 188, 218, 242,  
258, 297, 301

precision, 16, 75, 89, 91, 182, 284,  
290, 291, 307

predictive value, 294, 300

Priestley, 5, 6, 7, 9, 10, 13, 27, 35,  
42, 44, 51, 58, 65, 70, 75, 83,  
91, 99, 106, 114, 120, 128, 150,  
157, 206, 214, 238, 298, 307

Pringle, 70, 75, 81, 106, 120, 227

proportions of combination,  
180, 233, 234, 252, 253, 302,  
305

prototype, 42, 43, 54, 59, 65, 66,  
165, 298

Proust, 180, 215

prussic acid, 262, 264, 265, 296

purification, 70, 79, 81, 278

purity, 2, 12, 21, 29, 47, 54, 78,  
92, 101, 107, 115, 122, 157,  
199, 206, 226, 241, 299

## Q

quantification, xx, xxiv, xxvii, 7,  
21, 23, 72, 297

*queynomètre*, 5

## R

reacting ratio, 18

reagent, xvii, xxv, 18, 36, 117,  
119, 214, 224, 287, 289, 292,  
295, 300, 317

Reboul, 125, 131, 132, 142, 181,  
197, 204, 213, 300, 303

reciprocal saturation, 100, 101,  
123

reduction in volume, 42, 54, 61,  
69, 90, 98, 127, 140, 240, 252,  
302

Reghter, 110

Regnault, 267, 278, 279, 283, 285,  
287, 289, 295, 300, 304, 305

Reiset, 267, 278, 279, 284, 285,  
305

reliability, 76, 106, 112, 118, 128,  
194, 236, 298, 301

replication, xvii, 6, 24, 33, 109,  
118, 240

resemblance, 16, 130, 187, 197,  
231, 298, 301

respirability, 2, 46, 50, 66, 67, 98,  
137, 142, 304, 315

respirable air, 52, 72, 85, 94, 98,  
107, 113, 171, 176, 177, 239,  
313

restoration, 106

Royal Danish Academy, 62, 114

Royal Society, 29, 71, 80, 90, 104,  
120, 219, 224, 260

rubber, 224, 226, 229, 231, 275,  
281, 295, 296, 300

Russell, 289

## S

salubrity, xvii, 5, 7, 16, 22, 26, 34,  
45, 56, 70, 76, 97, 99, 115, 120,  
128, 142, 153, 162, 173, 180,  
195, 204, 218, 304

Saruggia, 17

Saussure, 43, 92, 120, 121, 125,  
142, 199, 212, 246, 257, 294,  
305

Savérien, 4

Scheele, 70, 101, 128, 145, 147,  
150, 152, 153, 164, 181, 210,  
221  
Schiavetto, 129  
Séguin, xxx, 167, 172, 174, 191,  
199, 211, 222, 245, 301, 304  
Senebier, 47, 54, 62, 88, 103, 111,  
116  
sensitivity, 47, 66, 289, 299  
shaking, 49, 86, 94, 96, 112, 117,  
160, 161, 207, 216, 237, 239,  
248, 252, 299  
Sigaud de la Fond, xxx, 36  
Sikes, 105, 110  
simplicity, 14, 30, 65, 83, 87, 88,  
112, 164, 222, 252, 299, 300  
size, 24, 94, 104, 207, 230, 237,  
238, 249, 252, 266, 299  
slow combustion, 173, 179, 184,  
188, 196, 199, 210, 216, 230,  
261, 293, 301, 307, 309  
smallpox, 70  
Société d'Arcueil, 159, 179, 242,  
247  
soil fertility, 212, 231  
source of inspiration, 12, 35, 137  
source of water, 94, 95, 105, 117  
sources of error, 72, 213, 222,  
236, 250, 269, 293, 300, 305  
Spallanzani, 38, 135, 191, 192,  
196, 197, 300, 304, 309  
standardization, 71, 112, 116,  
118  
stations, 120, 142, 304  
statistical analysis, 76, 96, 118  
stopcock, 19, 241, 289, 295, 300  
strength of nitrous air, 80  
sulphate of iron, 215, 225  
sunlight, 74, 79, 88, 116, 150,  
212, 273  
survey, 284, 286, 296, 304  
Survey, 268  
Sydenham, 1

## T

tactic knowledge, 71, 76, 78, 87,  
94, 118, 200, 294, 301  
Thenard, 242, 266

theoretical framework, 98, 127,  
133, 143, 167, 198, 302  
Thomas, 289  
Thomson, 238  
Timiryazev, 287  
training, 37, 88, 94, 104, 114, 118,  
202, 204, 234, 242, 288, 295,  
298  
transfer of experimental designs,  
165

## U

uncertainty, 7, 56, 84, 86, 94,  
104, 109, 118, 148, 157, 163,  
223, 243  
updating, 110, 191, 197

## V

vacuum, xxiv, 152, 161, 220, 222,  
262, 263, 282, 293  
van Breda, 105, 117, 159  
van Marum, 62, 65, 66, 114  
van Troostwijk, 62  
Vauquelin, 195, 202, 205, 207,  
211, 230, 242, 245  
vegetation, 1, 39, 124, 130, 142,  
171, 202, 212, 304  
Venel, xxiv, xxvi, xxviii  
vital air, 5, 7, 63, 98, 101, 102,  
115, 132, 137, 141, 147, 153,  
157, 167, 173, 178, 243, 245,  
307  
vitiating air, 16, 50  
Volta, xxx, 20, 30, 37, 43, 48, 53,  
55, 56, 62, 77, 91, 113, 118,  
123, 130, 141, 163, 179, 182,  
188, 200, 211, 233, 244, 245,  
253, 255, 262, 269, 286, 298,  
299, 305, 308  
volumetric approach, 242, 249,  
266, 267, 296, 297

## W

Waltire, 42  
Ward, 288  
Whöler, 268  
wholesomeness, 21, 30

Williamson, 289

Wollaston, 238

workshop, xxiii, 119, 142, 148,  
288

## **Y**

Young, 141