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Pneumatic Chemistry Viewed from Pavia

One striking feature of eighteenth-century chemistry was the intense activity of translations. In mid-century most of the translations went from Northern Europe to Southern Europe. In his 1959 study of "Some French Antecedents of the Chemical Revolution", Henry Guerlac described the 1750s as a "decade of translations" which brought new mining technologies, new analytical techniques and new concepts to France from Germany and Sweden, and thus stimulated French chemistry.[1] Towards the end of the century, after the reform of chemical language, the movement turned the other way around, since most translations went from France to other European languages.[2]

Because nowadays translations are supposed to be accurate and faithful to the original, we tend to view them as simple vehicles of diffusion. Consequently, historians of science are mainly concerned with them when they address the traditional topic of the reception of scientific theories. For instance, it is said that Lavoisier's doctrine was spread around Europe by the numerous translations of his nomenclature and by the translation of French textbooks. It is generally assumed that what is translated is a ready-made doctrine which is not affected by its circulation except for minor and unavoidable alterations of the original meaning.

This presentist view of translations is totally irrelevant when applied to the eighteenth century. Translations were much more flexible than today. Reliance on the original was by no means a priority. On the contrary, the translators were active interpreters and became co-authors of the books, co-founders of the views expressed in them. Most eighteenth-century translations were considered as improvements on the original text.[3] For instance, Paul-Henri d'Holbach's translation of Stahl's *Treatise on Sulfur* gave a more systematic presentation of Stahl's views than the author and contributed to the success of phlogiston chemistry in France.[4] When in 1757, Jacques-François Demachy translated into French Juncker's German translation of Becher and Stahl, this cascade of

[1] GUERLAC (1959).
[2] In the last decade of the eighteenth century more than 50 translations were prompted by the reform of chemical language. See ABBRI and BERETTA (1995).
[3] GUERLAC (1959).
[4] BERETTA (1996).

translations was clearly presented as a continuous process of improvement.[5] Sometimes the translation could be intended to depreciate the original rather than to improve on it. For instance, Madame Lavoisier's translation of Kirwan's *Essay on Phlogiston* (1787) was an excuse to raise criticisms of the phlogiston theory developed in that volume, through the footnotes of the translation.

Whatever their function, the footnotes, comments, cuts and additions to translations were common practice. Let us call this kind of grafts on foreign publications "second-hand writings". This literary genre presupposed and reinforced interaction between European chemists, and therefore they can provide an invaluable observatory on the life of the European chemical community at the time of the chemical revolution.

Macquer's *Dictionnaire de chymie* did not escape the general rule. The second edition, published in 1778, comprised four octavo volumes. The German translation by D. Johann Gottfried Leonhardi amounted to seven volumes, whereas the Italian translation by Giovanni-Antonio Scopoli grew up to ten octavo volumes.[6] Volta's notes and additions to Scopoli's translation were written in 1783, i.e. five years after Macquer's publication.[7]

Why did Scopoli (1723-1788), a professor of chemistry and botany at the University of Pavia since 1777, feel it necessary to ask his colleague Volta to provide notes and additions on a number of articles?[8] Did he seek to update Macquer's views on the various kinds of air? Or was he trying to "acclimatize" Macquer's views for an Italian audience? We have no evidence about the functions assigned to his commentators or about Scopoli's motives for choosing Volta. However, since Volta had been active on the front-stage in the study of inflammable air over the past five years, this intense research activity was a plausible reason for Scopoli to appoint him in his editorial enterprise of Macquer's *Dictionnaire*.

How many articles was Volta asked to comment on? Since he mentioned them in a letter, dated 28 October 1783, to Jean Hyacinthe de Magellan, we know for sure that he wrote short notes on the articles "Aria", "Aria Fissa", "Aria Deflogisticata", "Aria Nitrosa" and a more expanded one on "Aria Infiammabile".[9] To these notes published in the first volume, he added an appendix on the various kinds of airs. Later on, he also contributed full articles on "Calore", "Eudiometro", "Vapore" and a note to the article "Volatilità". These notes and additions properly belong to the

[5] DEMACHY (1757).

[6] MACQUER (1784-85). Scopoli later turned to be an opponent to Lavoisier's antiphlogistonist chemistry and to the new language. See ABBRI (1991).

[7] Thanks to a footnote in MACQUER (1778), pp. 583-4, we know that Macquer wrote the article "Gaz Inflammable" in October 1776.

[8] Volta's contributions to the Italian edition of Macquer's *Dictionnaire* are collected in *VO* (see Abbreviations), VI, pp. 349-436 and *VO*, VII, pp. 5-105. The editors also included in volume VII a note on "Phlogiston", on the assumption that it was a note of Macquer's *Dictionnaire*. However there is no evidence for this attribution.

[9] *VO*, VI, pp. 319-20.

genre of "second-hand writings" for Volta did not sign them. They appeared as Scopoli's writings in the publication. And we shall see that Volta got the best out of this special status that could have been perceived as a major constraint.

This paper will only consider the articles on airs, because they shed light on the process of emergence and stabilisation of a new research area – the science of airs – which developed so quickly in the 1770s that it became one major focus of chemical investigation and the ferment of reorganization of the entire chemical theory in the 1780s.

Although the emergence of a research area is often the prelude to a new discipline or sub-discipline, it is important to catch its identity in the nascent state. To us, it is obvious that the identification of various kinds of airs belonged to chemistry. However, the word "pneumatic chemistry" was used neither by Macquer nor by Volta. The latter, after all, was a professor of experimental physics in Pavia, although he conducted experimental investigation into the properties of airs for many years.

Therefore, I am not going to consider the emergence of pneumatic chemistry as a sub-discipline of chemistry. A field of research can be broadly characterized by its territory, as well as by the identity of its actors. Through a comparison between Macquer's articles on airs and Volta's comments on them, I will characterize the emerging science of airs from three different perspectives: its actors, its genealogy, and finally through the questions opened for debate.

1. The Actors

For both Macquer and Volta a science had emerged during their lifetime, whose object was first coined as "factitious airs", as opposed to common atmospheric air. "Factitious airs" proliferated so much between 1766, when the first edition of Macquer's *Dictionnaire* came out, and 1778 that Macquer inserted additions on them – which amounted to more than 100 pages – in the second edition.[10]

An Increasing Population of Airs

Inflammable air (our hydrogen) had been isolated and characterized by Henry Cavendish in 1766. In Uppsala, Carl-William Scheele had identified about fifteen new acids, including the gas now called chlorine, which he considered as the acid of dephlogisticated sea salt. All these factitious airs were characterized in terms of the phlogiston theory. In 1774, Scheele isolated a new air capable of absorbing the phlogiston from phlogisticated bodies. He called it *Feuerluft*, "fire air" and demonstrated that its union with phlogiston left a corrupt, vitiated air in the container, that he named *Verdorbeneluft*. In parallel with Scheele, Joseph Priestley had identified the same air produced by reducing a calx of mercury, supposedly rich in phlogiston, and called it "dephlogisticated air" (our oxygen). He had also isolated

[10] MACQUER (1778), I, pp. 536-643.

"phlogisticated air" (our nitrogen) and characterized many kinds of airs including the gases that we now call hydrochloric acid, ammonia and sulfur dioxide, hydrogen sulfide, hydrogen phosphate and ethylene. Scientists were thus facing a huge collection of airs that Priestley described in the successive editions of his *Experiments and Observations on Different Kinds of Air*.[11] Volta, among many others, had spent much time and effort to understand the nature of the various kinds of air, working in close contact with Marsilio Landriani and Joseph Priestley.[12] As Ferdinando Abbri noticed, since the publication of his correspondence with Priestley in 1778-79, he appeared as an important figure in the field.[13]

Actor or Reporter?

When I first read Volta's notes on Macquer's articles, I felt a kind of indignation. Most additions and comments deal with Volta's own contributions to the study of airs. "Il Signor Volta did this and that". "This has been established with certainty by il Signor Volta". The dominant impression is that Volta used the columns of the Italian translation of Macquer's *Dictionnaire* for purposes of self-promotion. He took the opportunity of this anonymous report to push himself onto the front stage. Since the author's identity was hidden, he could pretend to write an objective report of the recent developments on airs. He went so far as feigning that Scopoli himself was the narrator, when he wrote: "These experiments have not yet been published by him, but he was kind enough to communicate them and to perform most of them for me". In another note he wrote "these experiments have been performed in our laboratory".[14]

Volta was not exceedingly modest in his self-portrait. He first presented himself as a skilled instrument maker, who designed the inflammable air pistol and was able to establish solid facts with it. In the notes on inflammable air, he portrayed himself as an outstanding experimental philosopher, who was able to conduct a systematic campaign of experiments to obtain inflammable air by dissolving various metals in various acids.

It is clear that rather than trying to objectively report on the recent developments, Volta wrote these notes as an actor eager to publicize his contributions and opinions on the nature of the recently discovered gases. Actor or reporter? Volta played on the ambiguity of his position. Volta simply took the opportunity offered by Scopoli to insert his own work, and the work of his close collaborators, in a more general framework.

However, Volta's attitude is not very different from the narrator's position adopted by Macquer. Although his contributions to pneumatic science were in fact very modest, Macquer mentioned them in his *Dictionnaire* with modesty

[11] PRIESTLEY (1772); ID. (1774), (1775), 1777); ID. (1779-86).
[12] Volta's campaign of experiments in 1777 is finely described in Frederic L. Holmes's paper in this volume.
[13] See ABBRI (1984), pp. 200-14.
[14] VOLTA (1783), pp. 377, 384.

and in a neutral tone. Like Volta, he played on the dual position of actor and observer. He positioned himself as a narrator, using the first person, "je", and did not hesitate to give his own opinion. He also adopted the attitude of a spectator who marvelled at the spectacular aspects of this new science, extensively using qualificatives such as "fertile", "surprising",[15] "curious".[16] Without looking naive, he expressed his personal opinion as a mature chemist facing a young, booming discipline. Neither for Macquer nor for his commentator Volta was objectivity to be sought in a dictionary. Their attitude seems to indicate that the writer had to adopt the position of a participating witness to the story told.

National Biases

The bias induced by the dual position of actor and reporter can be made visible by a quantitative survey of the quotations. Although the method of the citation index is anachronistic and partly misleading,[17] it can be illuminating if we use it only for the purpose of comparison between Volta and Macquer. When comparing the names quoted by Macquer and Volta concerning inflammable air and dephlogisticated air, we get two very different views of pneumatic chemistry. In Volta's view, the new science of gases developed around two metropolises based in the United Kingdom and the North of Italy. In fact, it appeared above all an Italian science, with 48 mentions of Italian chemists, 32 of British chemists and 17 of French chemists. The other nations were far behind: 3 for Germany, 7 for Sweden, 6 for the Netherlands and 3 for Switzerland. If we consider now the individuals quoted, it is clear that the prevalence of Italy and Britain was due to the domination of two leading figures. The Italian reader would get the conviction that Priestley and Volta were the two main protagonists of this great adventure (figures 1, 2).

Volta's emphasis on local Italian contributions can be seen as a way to counterbalance Macquer's own national prejudices. For Macquer, pneumatic chemistry was a French science whose centre of gravity was the Paris Academy of Sciences. In the introduction to the article "Gaz", Macquer listed the main contributors to the development of this new area of research:[18] Priestley, Hales, van Helmont, Meyer, Le Comte de Saluces (Turin), Cavendish, Crans, de Smeth, Touelle, Bucquet, Lavoisier, le duc d'Ayen, le duc de Chaulnes, de Lassone, Fontana, Berthollet. Among the 16 scientists mentioned, 7 were French.

[15] MACQUER (1778), I, p. 583.
[16] *Ibid.*, pp. 589, 591.
[17] Misleading because it gives equal weight to a long exposition of experiments conducted by a scientist and to a brief elusive mention of somebody.
[18] MACQUER (1778), I, p. 539.

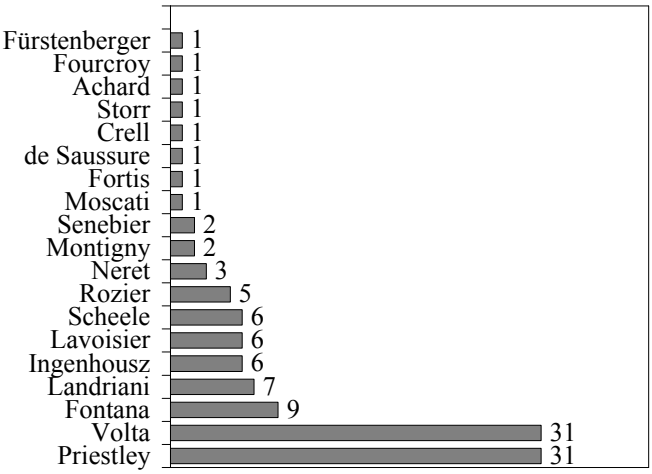

Figure 1 The authors quoted by Volta in his notes to Macquer's articles "Gaz Déphlogistiqué" and "Gaz Inflammable".

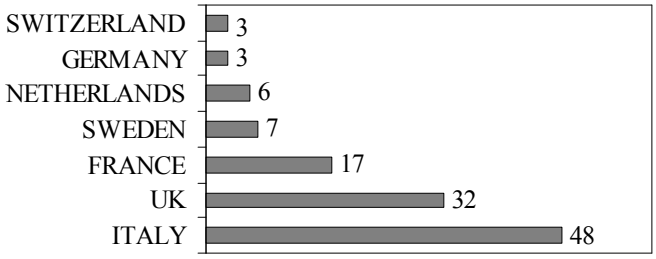

Figure 2 The geographical distribution of the authors quoted in Volta's notes to Macquer's articles "Gaz Déphlogistiqué" and "Gaz Inflammable".

In the details of his exposition Macquer did not give up his Parisian perspective. He delivered a narrow local view of the emerging science. Hence the contrasting geographical distribution that is obtained from an account of the citations in Macquer's articles "Gaz Déphlogistiqué" and "Gaz Inflammable":[19] 32 quotations from French

[19] In the article "Gaz Déphlogistiqué", I counted 2 citations of Boerhaave, 6 of Priestley and 17 of French chemists: Cadet 6, Baumé 6, Lavoisier 4 and Bayen 1. The disproportion in favour of French science was mainly due to a long report on a controversy between Cadet and Baumé. In the article "Gaz Inflammable", Priestley 11, Hales 2, Cavendish 1, de Lassone 6, Montigny 2, Lavoisier 2, Rouelle 2, de Chaulnes 1, Sigaud de la Fond 1, "je" (Macquer) 1, Stahl 1 and Meyer 1. After Priestley the hero is de Lassone because he kindly communicated his results before publication.

pneumatic scientists, 20 from English – mostly Priestley – 2 from Dutch and 2 from German scientists (figures 3, 4). By thus ignoring the work of Scheele and Landriani, Macquer provided a very narrow and partial perspective on pneumatic research.

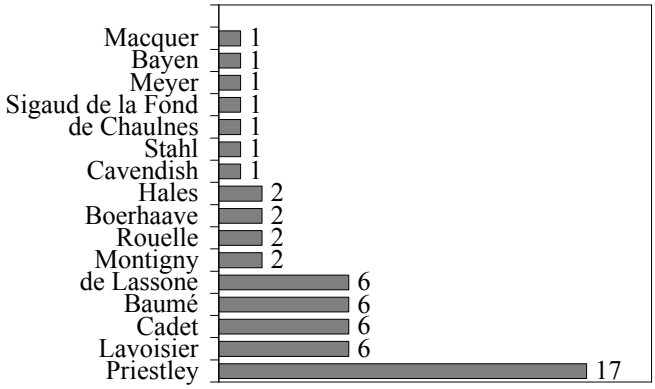

Figure 3 The authors quoted by Macquer in the articles "Gaz Déphlogistiqué" and "Gaz Inflammable" of his *Dictionnaire*.

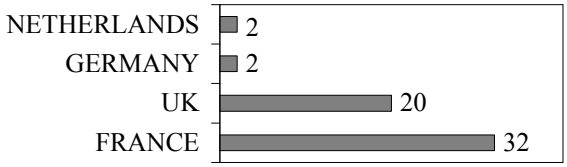

Figure 4 The geographical distribution of the authors quoted in Macquer's articles "Gaz Déphlogistiqué" and "Gaz Inflammable".

2. The Genealogy of Pneumatic Science

The constitution of a new field of research is often characterized by the designation of a founding father. Pneumatic science did not escape this general rule. Despite their disagreements about the geography of pneumatic science, Macquer and Volta agreed on its history. They both recognized Priestley as the founder of the science of airs. In this respect, our comparative analysis confirms the view developed by Ferdinando Abbri that, in the early 1780s, Priestley dominated the science of his time. By this time, Lavoisier was but one minor actor among many others. The controversies between Priestley and Lavoisier had not created the kind of

polarisation of the field of pneumatic science that historians of the chemical revolution used to describe.

However, Macquer's and Volta's perception of the role and contribution of Priestley differed. For Macquer, Priestley emerged as the leader in a collecting tradition dating back to Boyle, van Helmont and Hales. In the preliminary pages on "Gaz", he described Hales's apparatus for collecting gases but he claimed that Priestley was the main inventor.[20] Priestley is praised for recasting the significance of previous observations. In the case of "nitrous air", Macquer even suggested that his power of invention derived from his ignorance of chemistry:

> Il me semble même que cette découverte ne pouvait, en quelque sorte, être faite par un chimiste; j'avoue du moins en mon particulier, que, voyant que toutes les fois que l'acide nitreux agissait sur un corps combustible, il le dissipait par la continuation de la chaleur, jusqu'à la dernière portion, en vapeurs rouges, ayant tous les caractères de l'acide nitreux, & singulièrement la miscibilité avec l'eau, il ne me serait probablement jamais venu à l'idée de faire passer ces vapeurs à travers de l'eau pour les recevoir dans un récipient, bien persuadé qu'elles se seraient unies à l'eau & ne seraient point parvenues en état de fluide aériforme jusque dans le récipient. C'était cependant ce qu'il fallait faire; c'est ce qu'a fait M. Priestley, qui ne s'était point jusqu'alors occupé de chimie; & c'est à cette expérience qu'il a dû l'importante découverte du gaz dont il s'agit: tant il est vrai que, quoiqu'en général les connaissances conduisent à d'autres connaissances, il arrive pourtant qu'elles peuvent nous faire manquer des découvertes, quand on fait trop de fond sur les conséquences qui semblent en résulter![21]

Too much knowledge or expertise can prevent great discoveries.[22] For Volta, by contrast, Priestley is the initiator of a brand new science. Volta wanted to pay tribute to the founding father in keeping the name given by Priestley to one of the airs, although he considered it inadequate. For "we are in debt [to Priestley] for almost the entire doctrine of airs. He made more discoveries and shed more light on these matters by himself than all the Physicists and Chemists together, before and after him".[23]

The two contrasted portraits of Priestley reveal two divergent concepts of science itself. For Volta, pneumatic science was a kind of creation *ex nihilo*. He did not mention scientists prior to Priestley. He ignored Hales, Black and Cavendish. Volta adopted the now familiar historiographic scheme of the founding hero who created a new space of knowledge and opened up the way to a cohort of followers. Moreover, for Volta, the new science was mainly conceived of as a collection of discoveries:

[20] MACQUER (1778), I, pp. 539-41.
[21] *Ibid.*, p. 589.
[22] It is interesting to know that a similar remark was made one century later by Jacob Volhard to account for Lavoisier's success. Lavoisier is depicted as an amateur chemist, a dilettante, compared to the maestro Carl Wilhelm Scheele (VOLHARD (1872), p. 62).
[23] VOLTA (1783a), p. 369.

> Dr. Priestley has nearly created a new science of all factitious airs. He distinguishes *fixed air* properly so-called, *nitrous air*, *inflammable air*, *phlogisticated air*, *dephlogisticated air*, *acid airs* and *alcaline air*. MM. Scheele and Bergman have added *hepatic air*.[24]

3. The Issues at Stake in Pneumatic Science

From a comparison between Macquer's articles on gases and Volta's comments on them what image can we draw of the evolution of pneumatic studies?

In this booming field of research, there was no consensus on the denomination of what was under investigation. In 1778, Macquer gathered all his additions on airs in the second volume under the entry "Gaz". Scopoli, on the contrary, transferred all these articles to the first volume under the entry "Arie". Macquer's choice reflects his concern with nomenclature. He was trying to find a generic name for all aerial fluids. Air is only one of them, or more precisely one component of all of them:

> Comme parmi ces substances si différentes les unes des autres il y en a qui sont véritablement de l'air, plus ou moins mêlé de matières hétérogènes, tandis qu'il y en a d'autres qui, malgré quelques propriétés communes avec l'air, en diffèrent néanmoins si essentiellement par d'autres propriétés constantes, qu'on peut affirmer qu'elles ne sont point de l'air, que ce sont des composés différents de l'élément que nous nommons air, il m'a paru beaucoup plus exact & plus avantageux de comprendre toutes ces substances aériformes, sans en excepter l'air lui-même, sous le nom commun de gaz, qui est celui que Vanhelmont, & d'autres chimistes antérieurs à Hales, avaient donné en général aux substances volatiles expansibles, qu'on ne pouvait retenir dans les appareils ordinaires, des distillations & autres opérations chimiques.[25]

Macquer considered for a while the French word "esprit". He finally rejected it because it was still used for a number of substances having nothing in common with air. In his view, "gaz" being a "barbaric name with no reference either in our language or, I think, in any other one", might better "exactly mean whatever one wants it to mean". Despite his admiration for Priestley, Macquer openly criticized his choice of the name "nitrous air":

> Ce célèbre physicien avoue lui-même que ce nom d'air ne convient pas au gaz nitreux, & dit que c'est faute d'en avoir trouvé un autre qu'il a adopté celui-là. Un nom différent de celui d'air, celui de gaz par exemple, par lequel on peut désigner en un seul mot tout fluide élastique aériforme, aurait évité ces inconvénients de nomenclature, dont l'inexactitude répand nécessairement de la confusion et de l'obscurité; & c'est, comme je l'ai dit, ce qui m'a déterminé à m'en servir, malgré la difficulté qu'il y aura peut-être à le faire passer, à cause de ces noms d'air donnés d'abord inconsidérément par MM. Hales, Black, Macbride, Priestley lui-même, & qui semblent avoir été adoptés et consacrés par le plus grand nombre des physiciens qui

[24] VOLTA (1783b), p. 333.
[25] MACQUER (1778), I, article "Gaz", p. 536.

> ont fait & font encore tous les jours quantité d'expériences curieuses & importantes, depuis ces premiers inventeurs.[26]

Whereas the pioneers did not bother about the use of the term "air" for a variety of substances which had nothing to do with common air, Macquer sought to create more adequate denominations for new substances. In this respect, he appeared much more concerned with the reform of language than Lavoisier, who did not bother about using the term "air". Macquer clearly distanced himself from the "logic of inventors", whose main concern was the characterization of individual substances. His suggestion of an adequate generic name, embracing all species of aeriform substances without reference to common air, was undoubtedly an attempt at providing the conceptual basis of a new science.

Does it mean that Macquer's *Dictionnaire* could be seen as a kind of turning point in a process of disciplinary formation? Was it the moment when the collection of individual contributions were reorganized and subsumed under a more general approach?

Clearly no. Macquer's attempt at defining a generic concept of gas was too limited and too ambiguous to change the perspective among the gas collectors. Volta and Scopoli adopted the logic of inventors and deliberately kept the term "air". In so doing, Volta wanted to follow Priestley, as he mentioned about the phrase "phlogisticated air". He acknowledged that this term was not correct since fixed air also contained phlogiston but he adopted it "to avoid confusion in the nomenclature with new vocabulary and moreover because this name was given by Priestley".[27] Beyond respect for Priestley, this linguistic choice reflected a conservative attitude towards nomenclature. For Volta, the science of airs was above all a culture with a language of its own created by its practioners. Customs prevailed over rationality.

If Macquer and Volta disagreed on a generic name, did they agree on the denomination of the various kinds of airs?[28] Most of the names given to the airs were stable and uniform: "dephlogisticated air", "inflammable air" and "nitrous air" were generally adopted. "Fixed air" (our carbon dioxide), however, was a matter of debate. Bergman used the term "aerial acid". From the proceedings of the Paris Academy of Sciences we know that a debate took place in 1766 but no clear decision was made concerning the best name. Macquer adopted the phrase "gaz méphitique" though he considered it still inadequate:

> Aucune des dénominations, sans en excepter celle que j'ai adoptée, ne convient parfaitement au gaz dont il s'agit; celle d'air fixe, moins que tout autre, parce que ce n'est point de l'air, & qu'il n'est pas plus fixe que l'air lui-même. On verra que ce gaz est acide; & comme il est sous forme d'air, & même naturellement mêlé en assez grande

[26] MACQUER (1778), I, p. 588.
[27] VOLTA (1783b), p. 369.
[28] Macquer considered the following gases: dephlogisticated air, mephitic or fixed gas, inflammable gas, nitrous gas, and vitriolic, marine, acetic acid gases; the volatile alkali gas and spathic acid gas.

> quantité à l'air commun de l'atmosphère, le nom d'acide aérien lui conviendrait beaucoup mieux; mais presque tous les acides pouvant se présenter sous la forme d'air, & plusieurs même étant susceptibles de conserver cette forme dans leurs mélanges avec l'air commun, le nom d'acides aériens leur convient à cet égard aussi bien qu'à celui dont il s'agit; & c'est un inconvénient. Il en est de même de la dénomination de gaz méphitique, tous les gaz connus jusqu'à présent, excepté l'air commun, sont méphitiques, c'est-à-dire, malfaisants, meurtriers, incapables d'entretenir la respiration des animaux & la combustion des corps solides; ainsi à cet égard le nom de gaz méphitique ne peut servir à mieux distinguer ce gaz, que celui d'acide aérien, & par cette raison j'aurais volontiers adopté ce dernier; mais une considération m'en a empêché, c'est qu'il peut signifier acide de l'air, et qu'il n'exprime point assez que cet acide est dans l'état de gaz.[29]

Volta did not care about these linguistic issues and adopted the more common name "fixed air". This air, which deserved 19 pages in Macquer's *Dictionnaire*, was no longer a matter of interest for him. He just added a short note on the conversion of dephlogisticated air into fixed air.

By contrast, to the ten pages that Macquer devoted to dephlogisticated air Volta added many more pages. His comments were first intended to update and enlarge Macquer's references. Since Macquer based his article only on Priestley and Lavoisier, Volta described Scheele's work on *Feuerluft* as well as other experiments performed by himself and Achard from Berlin. Macquer thought that dephlogisticated air could only be obtained by the reduction of metallic calxes and reported a local controversy between Baumé and Cadet about the conditions for reducing the *précipité per se*. Volta wrote a 13 page addendum at the end of Macquer's article on current debates. There was first a controversy opposing Priestley, who claimed that dephlogisticated air was formed of nitrous acid and an earth (of variable nature), to Landriani and Moscati, who had found that dephlogisticated air could be produced not only by the action of nitrous acid on metals but also by several acids. Whereas in 1777 Volta sided with Priestley – as emphasized in Holmes's paper – in 1783 he resolutely sided with the views developed by his Italian colleagues. While he distanced himself from Priestley, Volta came nearer to the French chemists, and yet did not incline towards Lavoisier's theoretical views. He built up his own theoretical views on dephlogisticated air, in discussing Fontana's and Lavoisier's divergent opinions. Fontana suggested that dephlogisticated air was nitrous air which had deposited its phlogiston in the base. Lavoisier assumed that nitrous dephlogisticated air and nitrous air were combined in nitrous acid. In both cases, to prepare dephlogisticated air from nitrous acid, a base was required but their opinion about its action differed. For Fontana, the base acted as an intermediary (as a kind of receptor of phlogiston), whereas for Lavoisier the base separated dephlogisticated air from nitrous air:

> I would believe with Mr Fourcroy's *Leçons de chimie* etc. that dephlogisticated air is contained in any acid, but, in my view, as fixed air, which needs but to lose its phlogiston

[29] MACQUER (1778), I, pp. 556-7.

> to be transformed into dephlogisticated air, as has been demonstrated above by many proofs. Our hypothesis greatly differs, as we see, from Lavoisier's theory which we shall better examine elsewhere, discovering that it does not agree with several like phenomena; but it differs less from Fontana's theory, who is all for phlogisticating the nitrous acid, while we are for phlogisticating fixed air. Mine has the advantage that … [the presence] of fixed air can be supposed in any acid.[30]

Volta's hypothesis on dephlogisticated air does not mean that he was getting out of Priestley's sphere of influence. In fact, he was following Priestley when he added an article on phlogisticated air that did not exist in Macquer's *Dictionnaire*. Volta renewed his allegiance to Priestley in adopting the name that Priestley gave to this air and assumed that it made up 3/4 of the total quantity of atmospheric air. However a number of uncertainties remained about its identity. Was it different from fixed air or was it a "supersaturated" fixed air, as Priestley assumed? Volta often used the term "transmutation" of one air into the other. He also raised an interesting debate which echoed – without mentioning him – Lavoisier's criticisms of the expression "fixed air" in 1775. Lavoisier had argued that this substance was not released from a solid in which it was fixed, but was produced by the combustion of the eminently respirable portion of the air with charcoal.[31] Was phlogisticated air released from the substances used as sources or produced during the reaction? "Edotto" or "prodotto"? There was no reason to believe that phlogisticated air was already in the substance since it did not easily combine with a substance, whereas fixed air easily recombined with the calx or the alcaline salt from which it was obtained:

> I think therefore that only fixed air is combined with those bodies from which it can be obtained as such, in which case it is an extract [*Edotto*], or as dephlogisticated or phlogisticated [air], in which case it is a product [*Prodotto*], or finally as part of one kind [dephlogisticated air] and part of the other [phlogisticated air], according to circumstances. This fixed air is in a middle state and close to the two extremes [dephlogistication and phlogistication], so that one step forward or backward takes it to one or to the other: it is a true Proteus.[32]

This passage points out to a major feature of the discussions on the nature of the new gases during this decade. "Edotto" or "prodotto"?, the old question, which prompted Boyle's scepticism about the results of analysis and the possible "creatures of fire", was not resolved. Scientists were still heavily dependent on the sources and modes of preparation of aerial substances, and still wondered whether the source determined their composition or not.

This is especially clear in the debates concerning the identity of inflammable air. Macquer raised and discussed at length the question: Is there one species of inflammable gas embracing all individual inflammable aerial substances collected from different sources? Is it the same air that is obtained by dissolution of metals in

[30] VOLTA (1783a), p. 364.
[31] LAVOISIER (1864-93), II, p. 128.
[32] VOLTA (1783a), pp. 372-3.

acids or by decomposition of supercompounds?[33] Macquer adopted a pragmatic solution. He would consider this gas which seems the simplest and the purest either as the unique inflammable gas, or as the prototype or standard to which others should be compared. The model inflammable gas that he elected was the one obtained by dissolution of iron in vitriolic acid. Finally, Macquer concluded that "inflammable air is a constant substance, always the same, of a determined nature, and there is only one species of it".[34] However Macquer conceded that his hypothesis called for further investigations.

Reading Volta's notes on this article, it seems that Macquer's article had opened up a research program for Volta. Since he had collected and identified an inflammable air extracted from marshes, Volta spent a lot of time on this issue. And he finally came to the conclusion that there was not a unique species of inflammable air. After reporting the experiments he performed with the air pistol in 1777, he admitted that metallic inflammable air differed in its composition and properties from marsh inflammable air as well as from all inflammable airs obtained from other vegetable or animal sources. "The idea of a simple and identical inflammable air was beautiful and plausible, but the facts tell the contrary".[35]

Like Priestley, Volta was willing to present himself as open-minded. He did not hesitate to acknowledge past convictions that facts obliged him to abandon. He thus mentioned his past error on the composition of inflammable air. When he started his work on airs, he assumed that inflammable air consisted of an aerial acid (which he called *solfo aero*) intimately combined with phlogiston. He thus could claim that he had identified a unique inflammable air which was contained in all inflammable substances. In 1783, he declared "this idea of an acid, or another saline aerial principle, as the basis of phlogiston in inflammable air has been almost abandoned by Volta himself".[36]

Despite the considerable efforts that Volta spent on the study of inflammable air – all efforts complacently advertised in his notes – Volta did not come to any firm conclusion concerning its composition and identity. On the contrary, his work led him to more and more radical doubts.

Finally, the comparison between Macquer and Volta also hints at the objectives of pneumatic research. For both of them, cognitive aims prevailed over applications. However, in the article on inflammable air, both of them were so interested in the use of hydrogen as an explosive that they overlooked the formation of water, which would become Lavoisier's main achievement. In the article on dephlogisticated air, whereas Macquer was only interested in understanding the process of calcination, Volta showed great concern for its

[33] MACQUER (1778), I, pp. 578-86.
[34] *Ibid.*, p. 586. Macquer mainly based his opinion on Priestley's experiment which allowed him to obtain inflammable gas directly without the mediation of any acids: "The acids that serve to produce or to release it do not enter into its composition".
[35] VOLTA (1783), p. 399.
[36] *Ibid.*, p. 390.

medical applications.[37] He also mentioned that dephlogisticated air could be used to reinforce combustion and described the chemists' furnace devised by Ingenhousz. In contrast with Macquer's perspective focused on operations performed in the laboratory, Volta developed a natural perspective on dephlogisticated air. He referred to Ingenhousz and quoted de Saussure's *Voyage dans les Alpes*. His opinion was that: "The instrument adopted by Nature to produce dephlogisticated air [...] and maintain in the Atmosphere the dose necessary for animal life, is not the distillation of bodies [...] but *Vegetation*".[38] It means that in these few pages of "second-hand writing", Volta was able to involve and express all his experience, his knowledge, his culture, his intellectual adventures. He transformed commentary into a personal genre of literature.

4. Conclusion

Volta's notes and additions to the Italian edition of Macquer's *Dictionnaire de chymie* help emphasize the creative function of translations, which has been too often overlooked by historians of science. They testify to the effervescence raised all over Europe by the study of airs in the 1780s and to the great instability of this emerging research area.

Looking at Volta's notes, it is clear that by 1783 the debates on the nature of these airs were still going on. Although a kind of tacit agreement had emerged on standard laboratory methods of tackling the problem with the adoption of a number of standard chemical tests such as the burning candle, the respiration of mice, etc. which were performed in all laboratories over Europe, there was no agreement on any crucial experiments that could close the controversies.

From Volta's picture of this booming field of research, it seems that it belonged neither to physics nor to chemistry. Rather it mobilized all possible resources: chemical experiments, physiological tests, and electricity in particular. By 1783, a European Community had emerged, whose unchallenged leader was Priestley. This informal community was cemented through specific practices and controversies. The most striking feature revealed by this comparison is that the state of affairs in the study of gases was by no means more systematic in 1783 than in 1778. Whereas Macquer timidly tried to outline the basic concepts of a pneumatic science, Volta described a kind of natural history of airs. His main interest was to characterize and identify each variety of air. All the debates reported in his notes concerned the identity of individual gases isolated.

Not only did he not believe that a generic entity of gases existed, he also doubted that there were constant species of air. Since the identity of species could only be inferred from the study of individual gases, there was still a possibility that all gases were individually different. Volta's approach to airs deeply contrasted with

[37] VOLTA (1783a), pp. 367-8.
[38] *Ibid.*, p. 367.

Lavoisier's investigation during the same years. One major contrast is that Volta raised no question about the nature of airs in general. There is no effort to come to a definition of a permanent aerial fluid, which means that strictly speaking a pneumatic science did not exist.

However, Volta's approach to the various kinds of air points to key issues for chemistry. His comments show how difficult it was to agree on criteria to define the identity of chemical substances, to ascertain the existence and constancy of chemical species. In my view, one major interest in Volta's comments on Macquer is to demonstrate that such basic epistemological issues were not settled in the 1780s. It is also interesting to notice that Lavoisier managed to overcome such doubts by applying the standard chemical mode of proof dating back to Stahl and even further to the Spagyrist tradition, i.e. to determine the composition of a substance by decomposing and recomposing it.

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