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Clocks and Timekeeping in Lavoisier's Experiments on Animal Respiration

The Chemical Revolution, Its Material Culture and Taken-for-Granted Knowledge

Lavoisier's Experiments on Animal Respiration

Around 1777/78, the French nobleman and chemist Antoine Lavoisier (1743–1794) started reflecting on the mechanism of animal respiration and transpiration. The results of long years of experimentation, carried forward with the help of his collaborator Armand Séguin, were only published after 1790. The two *premiers mémoires*, published in the annual collection of the *Académie des sciences* of 1789 (out in 1793) and 1790 (out in 1797), and the two *seconds mémoires*, published in the *Annales de chimie* in 1814 but presented at the *Académie* in 1791 and 1792, are decisive steps towards an interpretation in modern chemical terms of these biological processes.[1] As for the study of respiration, Lavoisier puts into question Joseph Priestley's theory according to which "the respiration of animals has the property of phlogisticating air"[2] – whereby Priestley means that, in the course of respiration, oxygen (*dephlogisticated air*) is turned into nitrogen (*phlogisticated air*). Lavoisier overturns this hypothesis, first by establishing a parallel between respiration and combustion. Observing that not all the inspired oxygen is turned into carbon dioxide, Lavoisier posits that all animal bodies must already contain carbon and hydrogen. Respiration, therefore, is the process by which oxygen combines

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1 Antoine-Laurent Lavoisier/Armand Séguin: Premier mémoire sur la respiration des animaux, in: Mémoires de l'Académie des Sciences, 1789 (out in 1793), pp. 566–584; Premier mémoire sur la transpiration des animaux, in: Mémoires de l'Académie des Sciences, 1790 (out in 1797), pp. 601–612; Second mémoire sur la transpiration, in: Annales de chimie 90, 1814, pp. 5–28; Second mémoire sur la respiration, in: Annales de chimie 91, 1814, pp. 318–334.

2 Antoine-Laurent Lavoisier: Expériences sur la respiration des animaux et sur les changements qui arrivent à l'air en passant par leur poumon, in: Dumas, Jean-Baptiste/Grimaux, Édouard/Fouqué, Ferdinand (eds.): Œuvres de Lavoisier, 6 vol., Paris 1862–1893, vol. 2, Paris 1862, p. 175.

1 After Marie-Anne Pierrette Paulze-Lavoisier, Lavoisier in his laboratory: Experiments on respiration of a man at rest, in: Édouard Grimaux: *Lavoisier, 1743–1794. D'après sa correspondance, ses manuscrits, ses papiers de famille et d'autres documents inédits,* Paris 1888, pl. 5

partly with carbon, yielding (in modern terms) CO_2, and partly with hydrogen, yielding H_2O.[3]

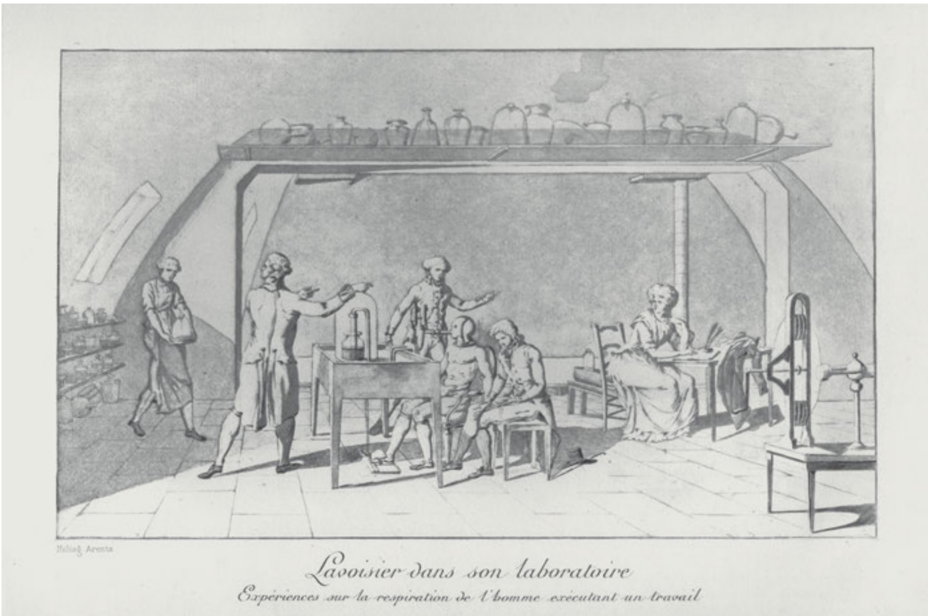
> "Respiration is nothing else than a slow combustion of carbon and hydrogen, which resembles closely the combustion taking place in a lamp or in a burning candle. In this respect, breathing animals are combustible bodies which burn and wear out. In respiration, as in combustion, it is the air of the atmosphere that provides the oxygen and the caloric."[4]

A key part of Lavoisier's chemical methodology consists of quantifying phenomena by measuring the elements – in this case, the quantity of the gases in inspired and expired air – using specific tools (balance, gasometer). In the study of respiration, quantification is also achieved through the application of the law of the conservation of the quantity of elements, which Lavoisier proves to be as relevant to the mechanism of respiration as to any other chemical process.[5]

3 I have not gone into detail on the workings of transpiration. See Beretta, Marco: Imaging the Experiments on Respiration and Transpiration of Lavoisier and Séguin. Two Unknown Drawings by Madame Lavoisier, in: Nuncius 27, 2012, pp. 163–191.

4 Antoine-Laurent de Lavoisier/Armand Séguin: Premier mémoire sur la respiration des animaux, in: Œuvres de Lavoisier 1862 (see footnote 2), p. 691.

5 For further details on Lavoisier's biochemistry, see Holmes, Frederic: Lavoisier and the Chemistry of Life. An Exploration of Scientific Creativity, Madison, Wisc. 1985.

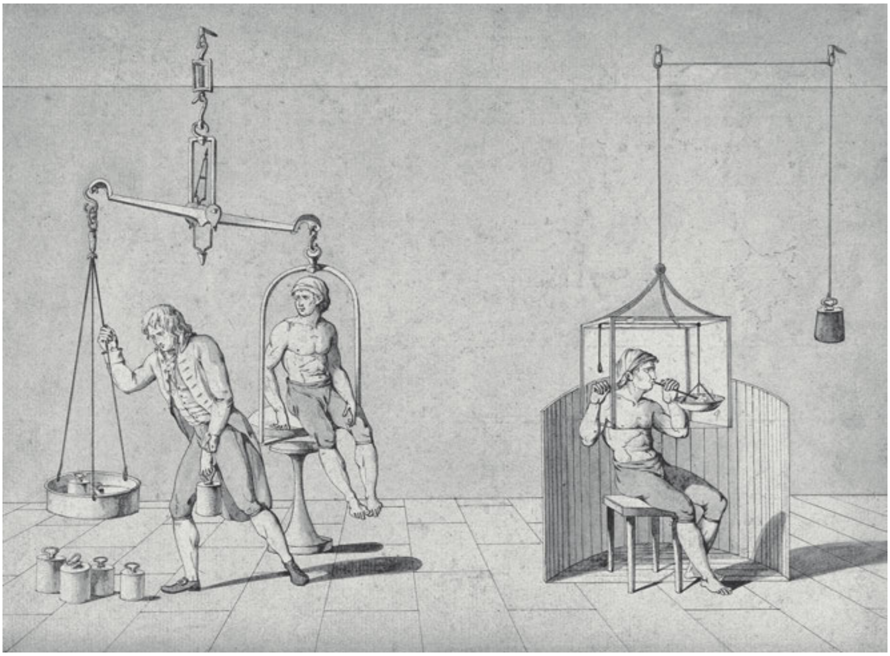


2 Cf. fig. 1, pl. 4: Experiments on respiration of a man carrying out a task

Alongside Lavoisier's efforts to grasp the chemical and biochemical details of respiration and transpiration, scholars have much focused on the complexity and novelty of the experimental system that he developed with Séguin. The engravings made after Marie Anne Paulze's (Lavoisier's wife) drawings have been variously analysed to emphasize the originality of the experimental setting, and of the instruments employed.[6] The idea of isolating the subject of an experiment from the surrounding environment (Séguin himself) and of letting him breath through a copper mask connected to a device from which to control the quality and quantity of inspired and expired air (figs. 1–2), as well as the peculiar tools constructed to weigh the breathing subject (fig. 3), are just some examples of Lavoisier's and Séguin's creativity in experimentation. Their originality in the material culture of chemistry was made possible by Lavoisier's vast network of instrument makers, who collaborated with him towards the practical realization of revolutionary scientific tools.[7]

6 Prinz, Johann Peter: Die experimentelle Methode der ersten Gasstoffwechseluntersuchungen nach A.L. Lavoisier und A. Séguin 1790, Baden-Baden 1993.

7 Beretta, Marco: Between the Workshop and the Laboratory. Lavoisier's Network of Instrument Makers, in: Osiris 29, 2014, pp. 197–214; Golinski, Jan: 'The Nicety of Experiment'. Precision of Measurement and Precision of Reasoning in Late Eighteenth-Century Chemistry, in: Wise, M. Norton (ed.): The Values of Precision, Princeton 1995, pp. 72–91; Holmes, Frederic: The Evolution of Lavoisier's



3–4 Marie-Anne Pierrette Paulze-Lavoisier, Lavoisier performing a respiration experiment: A man with his head in a glass container, c. 1790, London, Wellcome Library

The famous drawings and engravings representing the study of respiration, however, do show something more than they are usually thought to.[8] In fig. 1 and fig. 2, in which Séguin, the subject of the experiment, sits and breathes through a mask, as well as in fig. 4 (portraying a further experiment), Lavoisier stands and dictates his observations, which his wife, at the desk, transcribes. There are a few other experimental assistants, one of whom calls for attention. A man, probably the Scottish physician Hugh Gillan, measures Séguin's pulse by means of a pocket watch.[9] Neither the metric of the heartbeat nor the practice of taking the pulse are discussed explicitly in Lavoisier's texts, nor does one find, in any modern commentaries on Lavoisier's experimental apparatus, mention of a pocket watch, or of any other timekeeper.

Yet the measurement of time (beats per minute) and the use of a watch seem to have been relevant within the experimental apparatus that Lavoisier and his collaborators devised to study animal respiration. First, in all representations of their experiments on respiration, one finds the physician measuring the subject's pulse with a pocket watch. Second, in Lavoisier's and Séguin's texts elaborating on the experiments, the quantification of pulse rate enters into some equations (not explicitly mathematized, though) and general laws. As the *Premier mémoire sur la respiration* reads:

> "In all these experiments, the temperature of the blood is constantly the same, at least to a few fractions of degrees. But the number of pulsations of arteries and the number of inspirations change significantly. In this respect, we came to establish two laws of utmost importance. The first is that the augmentation of the number of pulsations is directly proportional to the sum of the weights elevated to a determinate height […].[10] The second is that the quantity of the vital air which is consumed is, all things being equal, and if the subject breathes only when strictly necessary, […] directly proportional to the product of inspirations and pulsations."[11]

Of course, the reading of the pulse, or of time in general, and the use of a watch are not distinctive features of Lavoisier's physiological inquiry, let alone a sign of its modernity and originality. This is most likely why this temporal aspect of their experiments has been overlooked in most historiographical accounts.

A first analysis of the place of clocks and timekeepers in Lavoisier's study of animal respiration serves to cast light on several hidden aspects of his chemical practice, if not of early modern experimental practices in general. I will indeed take Lavoisier's work as a particularly enlightening case study, and as a starting point for discussing epistemo-

Chemical Apparatus, in: id./Levere, Trevor (eds.): Instruments and Experimentation in the History of Chemistry, Cambridge, Mass. 2000, pp. 137–152.

8 In drawing more information from the pictures than they are usually believed to show, I follow the example of Steven Shapin's famous analysis of the 'invisible technicians'. See Shapin, Steven: The Invisible Technician, in: American Scientist 77/6, 1989, pp. 554–563.

9 The identification of Hugh Gillan has been made through the intense correspondence he had with Lavoisier and his wife. See the "Lavoisier Manuscripts and Graphics Collection, *c.* 1750–1834" (collection no. 4712), Division of Rare and Manuscript Collections, Cornell University Library.

10 The elevation of weights is a reference to the experience of the subject under strain (fig. 3).

11 Lavoisier/Séguin 1862 (see footnote 4), p. 696.

logical questions concerning the nature of early modern science, from both a material and an intellectual point of view. First, I will discuss the many facets of material culture in early modern experimental practice, a practice that existed somewhere in-between the professional and the everyday. I will then proceed to show the complexity of the structures of early modern scientific knowledge, as a meeting point between explicit arguments and tacit assumptions, invention and appropriation of concepts, upheaval of and respect for tradition.

Quotidian and Scientific Objects

The nature of scientific objects, and their role in laboratory practice, has been examined from various perspectives. An insightful discussion is offered by Hans-Jörg Rheinberger in *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (1997), where he formulates a distinction between 'technical things', which constitute the steady and unquestioned apparatuses of scientific research, and 'epistemic things', which are rather subject to processes of continuous reflection and intellectual inquiry.[12] Similarly, in their works on the history of mechanics, Jürgen Renn, Domenico Bertoloni Meli, and others consider the status of so-called 'challenging objects', namely objects that stimulate theoretical reflections through the challenges posed by their use.[13] Lorraine Daston, who insists on the basic distinction between quotidian and scientific objects, adds compelling elements to the discussion. Common objects, as she argues in the preface to *Biographies of Scientific Objects* (2000), are self-evident and need no particular mode of approach in order to be apprehended and used; scientific objects, on the contrary, are by no means immediate, but require an articulated intellectual framework in order to be created, understood and employed.[14] In this paper, I deal with the nature of scientific objects from a perspective different from those mentioned above. I aim to rephrase the distinction between objects of common use and technical or scientific objects,[15] by showing that a 'grey area' exists between these two categories and casts doubts on the reliability of such a distinction. As a matter of fact, the history of early

12 Rheinberger, Hans-Jörg: Toward a History of Epistemic Things. Synthesizing Proteins in the Test Tube, Palo Alto, Calif. 1997.

13 Damerow, Peter/Renn, Jürgen: Scientific Revolution, History and Sociology of, in: Smelser, Neil J. (ed.): International Encyclopedia of the Social and Behavioral Sciences, 26 vol., Oxford 2001, vol. 20, Oxford 2001, pp. 13749–13752; Büttner, Jochen/Damerow, Peter/Renn, Jürgen et al.: The Challenging Images of Artillery. Practical Knowledge at the Roots of the Scientific Revolution, in: Lefèvre, Wolfgang/Renn, Jürgen/Schoepflin, Urs (eds.): The Power of Images in Early Modern Science, Basel et al. 2003, pp. 3–27; Meli, Domenico Bertoloni: Thinking with Objects. The Transformation of Mechanics in the Seventeenth Century, Baltimore 2006.

14 Daston, Lorraine: The Coming Into Being of Scientific Objects, in: ead. (ed.): Biographies of Scientific Objects, Chicago/London 2000, pp. 1–14.

15 In so doing, I implicitly criticize Daston's distinction between quotidian and scientific objects.

modern chemistry – and especially Lavoisier's experiments on respiration – provides many clear instances of the hybridization of quotidian and scientific objects.

In approaching the study of the crossover between quotidian objects and scientific objects, one should distinguish between two different scenarios displaying different levels of complexity. The first level is that of common objects that are used in scientific practice for specific purposes, often as substitutes for proper scientific instruments. Such objects do not thereby become instruments; they merely function as instruments in specific contexts. One finds interesting discussions of the role of common objects in scientific practice in the early modern literature on elementary chemistry for the use of students. A good instance of this is the widely circulated *Epitome of Chemistry*, published by the English chemist William Henry in 1801, a few years after Lavoisier's death (1794). While addressing the preliminary question of the 'chemical apparatus' for practitioners, Henry informs the reader that his text will provide an overview of the chemical tools that are used in the laboratory: "In the course of this work, various […] articles of apparatus will be enumerated, in detailing the purposes to which they are adapted, and the principles on which they are constructed".[16] In order for students to carry out the experiments described in the book, "and even for the prosecution of new and important inquiries", however, few specific instruments are needed:

> "For such purposes, […] very simple means are sufficient; and some of the most interesting chemical facts may be exhibited with the aid merely of Florence flasks, of common vials, and of wine glasses. In converting these to the purposes of apparatus, a considerable saving of expense will accrue to the experimentalist; and he will avoid the encumbrance of various instruments, the value of which consists in show, rather than in real utility."[17]

Henry claims that chemical experiments do not require the use of any highly technical apparatuses, but rather can be carried out with the help of ordinary objects, converted for the occasion to scientific objects. Henry also insists on the resource management aspect of the reuse or recycling of common objects for scientific purposes: the chemical practitioner should pay close attention to the utility of the tools he uses, so that his practice complies with the principles of 'oeconomy'. By the term 'oeconomy', as distinct from 'economy', early modern theorists mean "a body of advice and examples relating to the prudent management of people and things".[18]

The second scenario brings the discussion to a higher level of complexity, and is more tightly connected to the case study of Lavoisier's experiments on respiration.

16 William Henry: An Epitome of Chemistry [1802], New York 1808, p. 12. Simon Werrett provides an in-depth discussion of recycling and reusing in early modern chemistry in his paper: Household Oeconomy and Chemical Inquiry, in: Roberts, Lissa/Werrett, Simon (eds.): Compound Histories. Materials, Governance and Production, 1760–1840, Leiden/Boston 2017, pp. 35–56.

17 Henry 1808 (see footnote 16), pp. 12–13.

18 Werrett 2017 (see footnote 16), p. 38. On the notion of 'oeconomy', see also Schabas, Margaret/De Marchi, Neil (eds.): Oeconomies in the Age of Newton. Annual supplement to: History of Political Economy 35, 2003; Roberts, Lissa (ed.): Practicing Oeconomy in the Late Eighteenth Century, Special issue of: History and Technology 30, 2014.

In 1879, the chemistry professor Pierre Truchot compiled a catalogue of Lavoisier's laboratory tools (*Les instruments de Lavoisier. Relation d'une visite à la Carnière où se trouvent réunis les appareils ayant servi à Lavoisier*). At the end of the catalogue, Truchot includes the following note:

> "I will not describe a certain number of objects which have a more or less close relationship with scientific inquiries, such as, for instance, a golden watch with the decimal divisions of time, sundials, etc."[19]

Truchot has doubts about how to catalogue Lavoisier's pocket watch: it may have some relationship to the scientific activities carried out in the laboratory, but, as he believes, no intrinsic one. Truchot's uncertainty is caused by his discovery, among the scientific tools of the laboratory, of a luxury item, an object conceived for personal use in everyday life. In the early modern period, valuable pocket watches were indeed fairly common among the members of the Parisian upper class (to which Lavoisier belonged), and the price of gold ones could range from a hundred and forty to over three hundred livres.[20]

As the illustrations of the experiments on respiration show, however, the pocket watch (probably not Lavoisier's, but Gillan's) played some role in the experimental process developed by Lavoisier and Séguin, as it served to measure the pulse rate of the subject. My claim here is that the use of a clock in a scientific experiment, as in Lavoisier's and Séguin's experiments on respiration, represents a scenario different from that represented by the use in a scientific context of any of the ordinary objects mentioned in Henry's text (flasks, vials, wine glasses). This difference lies in the very nature of the object in question.

As of the 17th century, the measuring of time and the mechanism of the clock were objects of scientific inquiry.[21] In parallel, the techniques of clockmaking improved significantly in this period, and many technological complications were progressively

19 Pierre Truchot: Les instruments de Lavoisier. Relation d'une visite à la Carnière où se trouvent réunis les appareils ayant servi à Lavoisier, Paris 1879, p. 31. The indication of the "decimal divisions of time" indicates that the pocket watch found by Truchot in Lavoisier's laboratory was crafted after 1792, when the time system was reformed on a decimal basis. On this reform, see Vera, Hector: Decimal Time. Misadventures of a Revolutionary Idea, 1793–2008, in: KronoScope 9/1–2, 2009, pp. 29–48.

20 On the price range of gold watches in the 18th century, see Dequidt, Marie-Agnès: La qualité de l'horlogerie commune à Paris, à la fin du XVIIIe siècle. Justesse et autres critères, in: Histoire & mesure 27/2, 2012, pp. 137–164, pp. 143–144. On the high prices of gold watches elsewhere, see (for England) Styles, John: The Dress of the People. Everyday Fashion in Eighteenth-Century England, New Haven 2007, pp. 98–100.

21 There is a particularly rich bibliography on Christiaan Huygens's contributions. See Yoder, Joella G.: Unrolling Time. Christiaan Huygens and the Mathematization of Nature, Cambridge 1988; Mahoney, Michael S.: Huygens and the Pendulum. From Device to Mathematical Relation, in: Breger, Herbert/Grosholz, Emily (eds.): The Growth of Mathematical Knowledge, Dordrecht 2000, pp. 17–39; Howard, Nicole: Marketing Longitude. Clocks, Kings, Courtiers and Christiaan Huygens, in: Book History 1, 2008, pp. 59–88.

implemented on such devices.[22] One noteworthy example is the work of the English craftsman Samuel Watson, who, at the beginning of the 18th century, built a pocket watch endowed with a lever to stop the mechanism, and with a button to open the case of the watch with only one hand. This very watch was conceived and produced in collaboration with the physician John Floyer, to assist in the practice of measuring the pulse.[23] A similar kind of pocket watch, with probably the same mechanical features and used for the same purpose as Watson's, is shown being used by Gillan in the engravings of Lavoisier's experiments. As the design of Watson's watch demonstrates, clocks were, by virtue of their technological sophistication, a central element of early modern scientific practice, and were scientific objects themselves. In the 18th century, however, mechanical timekeepers became popular even beyond the scientific elites and the upper social classes, diffusing also among the members of the middle class. Clocks and watches were no longer only luxury items, but came to circulate widely as they grew more affordable and more portable in size. Scholarship has much insisted on the deep influence of this diffusion of timekeepers on the development of modern society, for both the internalization of time awareness and the regulation of social interactions on a shared timeline.[24] In this sense, one might rightly state that clocks and watches, in the 18th century, became objects of common use. The large diffusion of timepieces also contributed to their becoming fashionable accessories, employed not only to measure the duration of everyday life activities but also to display the social status of their owners.[25]

As I have already stressed, in Lavoisier's experiments of the late 18th century, the pocket watch was used by Gillan to measure the pulse rate, with important consequences for the accuracy of the experimental results. One way to interpret this would be to claim that the common object, the pocket watch, plays the role of an instrument in this particular scientific context. Yet the clock, as I showed, is not a common object *tout court*, but rather has an intermediate status between a common and a scientific object.[26] One might say that a mechanical clock is an object in which a set of heterogeneous opera-

22 Cardinal, Catherine: La montre des origines au XIXe siècle, Fribourg 1985; Dohrn-van Rossum, Gerhard: History of the Hour: Clocks and Modern Temporal Orders [1992], Chicago/London 1996.

23 A good analysis of this object and its epistemological meaning is provided in Bernasconi, Gianenrico: Pour une archéologie des pratiques. mesure du temps, corps et prestations (XVIIIe-XXe siècle), in: Socio-anthropologie 40, 2019, pp. 247–262. For further details on Floyer, see below (section 3).

24 Dequidt, Marie-Agnès: Horlogers des Lumières. Temps et société à Paris au XVIIIe siècle, Paris 2014; Glennie, Paul/Thrift, Nigel: Shaping the Day. A History of Timekeeping in England and Wales, 1300–1800, Oxford/New York 2009.

25 On the large diffusion of pocket watches in the late 18th century, see Gerrit Verhoeven's essay in this same volume, "Time Technologies. Londoners and Their Timepieces (1775–1825)". Verhoeven argues that the diffusion of timepieces did not contribute – at least not immediately – to foster a fine-grained sense of time among their users. On the possession of timepieces as a sign of social distinction, see also Styles 2007 (see footnote 20), pp. 97–107.

26 In Jürgen Renn's terminology, we might call the clock a 'challenging object' for modern scientists (Galileo, Huygens).

tions, both technical and quotidian, is inscribed.[27] In semiotic terms, the clock has a 'functional dimension' that places it neither among the purely scientific objects (because it can be – and mostly is – used for everyday purposes, often without any measuring function but only as a status symbol), nor among the merely quotidian ones (because it allows for specific technical and scientific operations).[28] Timekeepers thus defy the rigid distinction between common and scientific objects.

Taken-for-Granted Knowledge

From this discussion of material culture, I will now turn to an analysis of the theoretical function of timekeeping in Lavoisier's experiments on animal respiration. The question is what role the measurement of time (viz. pulse rate) played in the chemical understanding of the phenomenon of respiration. I will tackle this question from an epistemological perspective, investigating what type of knowledge this specific measurement of time can be seen as an instance of, and what role it played in the construction of Lavoisier's biochemical theories. I aim to show that, although not explicitly discussed, timekeeping in fact played an important role as 'taken-for-granted knowledge' in the apprehension of the mechanism of respiration.[29] I will then suggest criteria for identifying and defining 'taken-for-granted knowledge', arguing that the notion could also be extended to case studies other than Lavoisier's.

Lavoisier's interpretation of respiration is exemplary of his innovative approach to chemical and biochemical phenomena. Particularly, Lavoisier's theory, as I showed earlier, was revolutionary in its quantification of chemical and biochemical findings. Recent scholarship, however, has suggested that the novelty of Lavoisier's discoveries be reconsidered, since they built upon many discoveries from previous decades (e.g. the isolation of oxygen) and thus were not entirely original.[30] This point is, I think, trivial.[31] It is far more productive, I argue, to investigate the way in which even the most revolutionary

27 Among the operations that are halfway between scientific and everyday practices is also the problem of measuring time to establish distances and longitudes for navigation.

28 Deni, Michela: Oggetti in azione. Semiotica degli oggetti: dalla teoria all'analisi, Milan 2002, pp. 81–82.

29 I deliberately leave aside the debates surrounding tacit and explicit knowledge, which are only partly relevant to my concerns. 'Taken-for-granted knowledge', as I will define it, is tacitly assumed as valid, but its tacit nature is neither the only nor the most important of its characteristics. On tacit and explicit knowledge, see Collins, Harry: Tacit and Explicit Knowledge, Chicago/London 2010.

30 See, for instance, Gough, Jerry B.: Lavoisier and the Fulfilment of the Stahlian Revolution, in: Osiris 4, 1988, pp. 15–33; Basu, Prajit K.: Similarities and Dissimilarities between Joseph Priestley's and Antoine Lavoisier's Chemical Beliefs, in: Studies in History and Philosophy of Science Part A 23/3, 1992, pp. 445–469.

31 I take up Thomas S. Kuhn's point that a discovery is revolutionary only when framed within a new explanatory framework (namely, a new paradigm). Otherwise, the discovery is not revolutionary, but just a plausible or good answer to a certain problem. See Kuhn, Thomas S.: The Structure of Scientific Revolutions, Chicago 1962.

scientific theories are the product of heterogeneous sources and traditions of knowledge, which are tacitly or unconsciously used to build new forms of knowledge or new experimental systems. For example, the reading of the pulse in Lavoisier's experiments on respiration demonstrates the use of an established medical practice, from a field other than chemistry, in the context of a chemical experiment to build up a new theory.

The reading of the pulse is an old technique that was widely practiced throughout the Middle Ages and the modern period. It was only in the early 18th century, however, that the English physician John Floyer introduced the practice of counting "the pulse rate as we measure it today", being the "first physician to use a pulse watch that would run for sixty seconds to count the pulse".[32] A disciple of William Harvey and a proponent of the centrality of the discovery of blood circulation for modern medicine, Floyer is the author of the treatise *The Physicians Pulse-watch, or an Essay to Explain the Old Art of Feeling the Pulse, and to Improve it by the Help of a Pulse-Watch* (1707–1710). Floyer's medical theory rests on the claim that disorders in the circulation of blood cause a majority of the existing diseases, and that such disorders can be detected by measuring the pulse and can be healed according to a pulse-based diagnosis. As he states in his treatise,

> The physician's business is to regulate the circulation, and to keep it in a moderate degree, suppose once in three minutes; if it run oftener or slower, our mechanism is out of order; but it is not necessary for us to understand the motions of the particles in the blood, not the texture of the viscera and organs; it is enough that I know by a hot regimen and hot tastes I can raise deficient pulses, and by a cold regimen and medicines of a cool taste, I can depress and sink the number of exceeding pulses. By this method all fine hypotheses will be excluded from practice, and a more certain and sensible foundation will be laid for it.[33]

Although Floyer's reduction of medicine to the art of taking the pulse would not find favour in the subsequent development of medicine, the practice of measuring the pulse through the use of technical devices would become increasingly widespread, along with 'pulse-watches' allowing for an accurate reading. In Lavoisier's experiments on respiration, theoretical and practical knowledge concerning the measurement of the pulse is present as a constitutive element of the experimental apparatus. It is a knowledge necessary for the establishment of the theory, but whose existence Lavoisier does not deem it necessary to acknowledge. In Lavoisier's biochemical theory, the reading of the pulse thus plays the role of taken-for-granted knowledge.

32 Ghasemzadeh, Nima/Zafari, A. Maziar: A Brief Journey into the History of the Arterial Pulse, in: Cardiology Research and Practice, 2011, pp. 1–14, p. 5. See also Townsend, Gary L.: Sir John Floyer (1649–1734) and His Study of Pulse and Respiration, in: Journal of the History of Medicine and Allied Sciences 22/3, 1967, pp. 286–316; Kümmel, Werner Friedrich: Der Puls und das Problem der Zeitmessung in der Geschichte der Medizin, in: Medizinhistorisches Journal 9/1, 1974, pp. 1–22.

33 John Floyer: The Physicians Pulse-watch, or an Essay to Explain the Old Art of Feeling the Pulse, and to Improve it by the Help of a Pulse-Watch, London 1707, unnumbered page.

The epistemological question I now want to raise is as follows: what does it mean for knowledge to be 'taken-for-granted' in a scientific theory? Are there any applicable criteria that might help to identify and define such knowledge?

(a) Taken-for-granted knowledge is not explicitly discussed. This, of course, does not necessarily imply that this knowledge is hidden, or invisible, in the texts or documents at stake. It simply implies that the discussion of other forms of knowledge is preferred to any discussion of it, thereby preserving the taken-for-granted standing of this knowledge.

(b) Taken-for-granted knowledge is not contested, but rather is assumed to be valid. The validity assumption is implicit, and usually no positive argument is given to prove it. Taken-for-granted knowledge is indeed knowledge upon which a theory relies, and cannot therefore be called into question without undermining the very basis of the theory.

(c) Taken-for-granted knowledge is largely drawn from a field of study other than that in which it is taken for granted towards the formulation of a theory. This can either be another field of scientific inquiry, or a more quotidian practice. As relevant cases of taken-for-granted knowledge, one might call to mind the place of advanced mathematics in astronomy during early modern times, or the role that observational techniques play in astronomical practice. One might also consider that early modern medical practice, especially when it came to the production of remedies (i.e. pharmacy), relied upon received, and thereby taken-for-granted, chemical knowledge.

The three criteria I outline here leave us with an open problem. The category of knowledge that counts as taken-for-granted in a scientific theory can broaden dramatically if one includes all notions and gestures belonging to the sphere of the quotidian. The design of Lavoisier's experiments on respiration, for instance, involves the practice of measuring the pulse as taken-for-granted knowledge, but also, say, the knowledge of how to weigh an object with a balance, or to filter liquid through a strainer.[34] Were this informal knowledge incorporated into the category of the taken-for-granted, the category would become too large to be used productively in an epistemological analysis of the structure of scientific knowledge. I shall therefore introduce a fourth criterion, which restricts the category of taken-for-granted knowledge to certain forms of knowledge only.

(d) For implicitly assumed knowledge to count as taken-for-granted knowledge, it, first, must contribute positively to the building of the new theory and, second, must play a relevant scientific role therein. What does it mean to 'contribute positively' and

34 A relevant role, however, might be played by less trivial kinds of notions and gestures, which exist in-between the quotidian and the scientific spheres. This is the case, for instance, for the knowledge and the bodily practice entailed in the elaboration and performance of recipes as remedies, or for the chemical and medical experimentations that take place at home. On these practices, see (among the others) Spary, Emma: Feeding France. New Sciences of Food, 1760–1815, Cambridge 2014; Guerrini, Anita: The Ghastly Kitchen, in: History of Science 54, 2016, pp. 71–97; Leong, Elaine: Recipes and Everyday Knowledge. Medicine, Science, and the Household in Early Modern England, Chicago 2018.

to 'play a relevant scientific role'? Many forms of knowledge and many gestures upon which scientific theories rely do not serve to qualify those theories in any particular way; therefore such knowledge and gestures do not 'contribute positively' to the establishment of those theories, in that they do not supply any otherwise lacking scientific element to them.[35] As for the 'relevant scientific role', I mean that the taken-for-granted knowledge must be relevant to the scientific basis of the theory to which it contributes. In other words, taken-for-granted knowledge must be pertinent to the subject at stake.[36]

These epistemological views, stemming from an analysis of Lavoisier's case study, could arguably be extended to other historical cases, and used to interpret the role of taken-for-granted knowledge in scientific theories across the early modern period.[37]

Conclusion

In this paper, I looked at Lavoisier's and Séguin's well-known experiments on animal respiration, emphasizing the role of clocks and timekeeping in the development of their experimental system, and in deciphering the results. After summarizing the contents of Lavoisier's theory of respiration, I focused on the use of a mechanical clock in his experiments, questioning the classical distinction between common objects and scientific objects. My goal was to demonstrate that this distinction is not as clear-cut as has been suggested in current scholarly formulations. The counterexample I provided to the object-instrument distinction was that of the mechanical clock, as used in scientific experiments such as Lavoisier's. I then examined the epistemological status of the measurement of the pulse, and therefore of timekeeping, in Lavoisier's theory of respiration, arguing that it should be interpreted as an instance of 'taken-for-granted knowledge'. Taken-for-granted knowledge, I hold, is knowledge that is necessary for the building of a theory, but whose presence is not necessarily acknowledged by the historical actors involved. Based on this definition, I formulated some epistemological criteria for identifying and studying taken-for-granted knowledge.

The intended contribution of my work is twofold. In the field of Lavoisier studies, I mean to bring attention to some aspects of material and intellectual culture as mediated by scientific practices, aspects that have to date been considered marginal. Such an analy-

35 In the case of Lavoisier's experiments on respiration, the ability to weigh an object with a balance is not a qualifying scientific aspect of the practice, whereas the reading of the pulse is, as the latter enters into the laws and equations elaborated on the basis of the experiments.

36 According to my definition, therefore, forms of knowledge such as the ability to walk or to write would not count as taken-for-granted knowledge in Lavoisier's chemical experiments. These are of course skills necessary for carrying out any experimental work, but can be left aside in an epistemological consideration of relevant taken-for-granted knowledge.

37 I am not giving other arguments for the exemplarity of these criteria than their generality. Earlier on in the paragraph, however, I had referred to the role of mathematics in astronomical theory, and chemistry in medical practice, as possible instances of taken-for-granted knowledge.

sis can, I think, better account for the complexity of Lavoisier's 'chemical revolution', which includes many heterogeneous elements that at first glance are hard to detect. Scholars, indeed, have variously complained about the lack of a "more comprehensive analysis of Lavoisier and the Chemical Revolution", and about the underdevelopment of interest in contextual factors. This historiographical situation has led to a call for a "fourth phase of Lavoisier scholarship"[38] that moves beyond the previous focus on Lavoisier's methodology, his achievements and discoveries in the laboratory and the professional figure of the chemist.[39] With respect to the epistemology of early modern science more broadly, my approach revises a widely accepted distinction, and elaborates criteria for the analysis of overlooked forms of knowledge. These criteria, I have argued here, can benefit the study of early modern scientific productions by offering a new framework through which to examine much-studied theories.

38 Donovan, Arthur: Lavoisier and the Origins of Modern Chemistry, in: Osiris 4, 1988, pp. 214–231, p. 219.

39 For a detailed reconstruction of the 'four phases' referenced here, see Donovan 1988 (see footnote 38), pp. 217–219.