# ROBERT BOYLE, BACONIAN SCIENCE, AND THE RISE OF CHEMISTRY IN THE SEVENTEENTH CENTURY

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**Abstract.** This paper aims to achieve a better understanding of Robert Boyle as one of the main figures in seventeenth century chemistry. Focusing on his correspondence, we try to analyse the following complex and still not sufficiently understood contexts: a) Boyle is well known for his conduct of "Baconian science," but it is incorrect to call him a pure mechanist or a cold-blooded experimentalist. In many respects, Boyle is a Baconian, but it has to be clarified what this means and why it matters with respect to the rise of chemistry as an early modern science. b) The role of modern chemistry – if we let it begin in the seventeenth century – can better be understood when we analyse its metaphysical presuppositions, which are closely related to mechanism and supernaturalism. c) Boyle pointed out one basic feature of chemistry as a science, i.e., the necessity of focusing on practical, e.g., technical aspects of experiment design. Furthermore, Boyle provides us with an example of how we can understand the various relations between actors such as scientists, craftsmen, and technicians.

**Keywords:** Boyle, developments in chemistry in the seventeenth century, alchemy, Baconian programme, mechanism, supernaturalism

Robert Boyle (1627-1691) is one of the most fascinating, important, and dazzling figures of early modern science. Though he attracts scholarly attention in the fields of the history of science, especially the philosophy of chemistry and the philosophy of physics, literary studies, and the sociology of science, his impact on many topics is still underrated. In this paper, I shall throw light on the interdependence of the following aspects of Boyle's works, particularly by taking his prolific correspondence into account.[1] The first section deals with the questions of how and to what extent Boyle conducts a "Baconian programme." Although this term is often used, it has to be fixed in section 1. This is still important, as simply equating Bacon with experimental science and with early modern science does not show the whole picture, as we will see. Furthermore, I will sketch a theoretical setting of what is called "Baconian science" (section 1). Thus, even if Boyle was a Baconian – which is partly true – his adherence to mechanism, i.e., Newtonian mechanical philosophy[2] (physics), does not rule out supernaturalism. This would mean "boiling down Boyle's

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philosophy." His rich philosophical reflections[3] reconcile supernaturalism and mechanism rather than asserting a contradictory relation (section 2). Finally, I will highlight how chemistry, as an entirely practical science, is and should be organised based on Boyle's rather unsystematic view on the relevance of craftsmen, technicians, artisans, and their specific roles in experimental settings (section 3).

## 1 How does Boyle conduct the "Baconian programme"?

In this section, I will first outline why Bacon's influence on Boyle was important for the rise of chemistry in the seventeenth century (section 1.1). Secondly, I will focus on some general meanings of what I call the "Baconian programme" (section 1.2). Thirdly, I will argue that while Boyle conducted the Baconian programme,[4] he did not follow Bacon in every particular. On the contrary, Boyle contradicted Bacon (section 1.3). Why is this important? I think that Boyle's role in the development of early modern chemistry could be better explained if we can keep in mind some limitations of the Baconian programme.

### 1.1 Why does Bacon's influence on Boyle's achievements in chemistry matter?

The broader context, which cannot be elaborated within the scope of this essay, is the rise of chemistry from an art or auxiliary science to a mature and accepted science. One widely accepted thesis is that Boyle was one major thinker and practitioner of chemistry on its long path to becoming a respected, systematic discipline. In Bacon's view, chemistry was an art. In his *Preparative toward a Natural and Experimental History*, Bacon writes:[5]

> Again, among the particular arts those are to be preferred which exhibit, alter, and prepare natural bodies and materials of things, such as agriculture, cookery, chemistry, dyeing, the manufacture of glass, enamel, sugar, gunpowder, artificial fires, paper, and the like. Those which consist principally in the subtle motion of the hands or instruments are of less use, such as weaving, carpentry, architecture, manufacture of mills, clocks, and the like, although these too are by no means to be neglected, both because many things occur in them which relate to the alterations of natural bodies, and because they give accurate information concerning local motion, which is a thing of great importance in very many respects.

From this view to Boyle's theoretical localisation of chemistry, we can find the following shift: whereas Bacon integrates chemistry in the list of human activities closely related to craftsmanship, Boyle recognises the enormous relevance of "subtle motion of the hands or instruments" for developing reliable, significant, systematic, and reproducible chemical experiments (see section 3). I do not assume that Bacon contradicts Boyle with respect to these basic requirements of chemical instruments, but Boyle pays much more attention to experiment design, concrete descriptions, and prescriptions of experiments than Bacon does.

One further aspect closely related to this point is a different notion of "natural history." I will spend a little more time on this issue in the next section. For the purpose of underlining Bacon's relevance to Boyle's achievements in chemistry, it is enough to point out the distinction between "experimental philosophy" versus "speculative philosophy." As Anstey and Hunter[6] have convincingly argued, the following shift of meaning of these terms is of great importance for English natural philosophy, and therefore of relevance to the development of chemistry:

Bacon used the distinction between "experimental" (or "practical" as Boyle uses the term) and "speculative" as a term in the scholastic tradition. But by the 1660s, these terms had taken on a specific connotation that was rather new: "Speculative" basically means referring to first principles and hypotheses while simultaneously neglecting observation.

> 'Experimental philosophy' by contrast emphasised the primacy of experiment and observation and decried the use of hypotheses and speculation. Thus, when Boyle claimed that the first preliminary discourse [of his *Design of Natural History*, TS] would show the advantages of compiling natural histories to both the speculative and the practical, he was claiming that both approaches to nature can only benefit by deploying the Bacon-inspired method which he is advocating. (Hunter, Anstey, 2008, 98)

I will now take a closer look at what is called "Baconian science." Many research papers have recently been published on this rather complex issue, which is of great interest since the Baconian legacy is omnipresent.

**1.2 What is "Baconian science"? Conceptualizing "art", "science" and "natural histories"**

My aim is to clarify concepts that are interrelated, but more or less distinct. The broader context is the rise of one science, i.e., chemistry, in the second half of the seventeenth century. First, "science" is not a Baconian term, but nevertheless it is a central term in the context of the early modern scientific revolution. Science aims to understand certain features of nature or, in modern terms, of "natural systems." One important element of Bacon's philosophical background of his programme has been pointed out by Peter Dear[7], who explains that Bacon tried to overcome the separation of the two categories of "art" and "nature." Art was

> only a matter of setting up situations in which nature will produce a desired result – so that art is the human exploitation of nature rather than an activity outside of nature. […] For Bacon, by contrast [to Aristotle, TS] human purposes were paramount: his natural philosophy aimed at creating knowledge of how to achieve human ends. An independently existing realm of natural purposes thus became a strictly irrelevant category […].

Though this seems a rather odd notion, it is one of the Baconian core elements of his research programme. Let me summarise other views of what might be called Baconian:

*Firstly*, we have to distinguish between Bacon's own insights and the various ascriptions by later authors, including Locke, Boyle, Descartes, Hobbes, Gassendi, Newton, etc. Just as Darwin was no Darwinian, Bacon was no Baconian, but rather became a Baconian. To quote Guido Giglioni,[8] Boyle, for example, was "interested in creating a new style of doing research on nature focused on natural appearances of matter (phenomena) and dismissed both the desires of matter and the passions of men as belonging to the inscrutable province of knowledge. […] Boyle tried to limit his [Bacon's, TS] endeavour strictly to the field of natural philosophy." There is no question that "Boyle adopted a more diluted version of Baconian philosophy, both metaphysically and politically". To keep this in mind might obviate the simple view that Boyle – or any other intellectual – adopted Bacon's philosophical, methodological, or scientific theses.

*Secondly*, in order to understand the post-Baconian legacy, I shall briefly describe Bacon's notion and use of the term "natural history." Recent research has portrayed Bacon as being enormously influential with respect to his concept and vision of "natural history" (see e.g. Anstey;[9] Manzo;[10] Jalobeanu[11]). In the context of this paper, i.e., with respect to Boyle's contributions to chemistry, I shall summarise the importance of Bacon's concept of "natural history" – according to Anstey (2002, 71f.) – which Boyle regarded as essential to natural philosophy, "for in this way only, can the foundation of a true and active philosophy be established" (Anstey, 2002, 71, footnote 27). Natural histories – though they are histories and not scientific tractates – are vast collections of objects and their properties, materials, descriptions of technical inventions, etc. Indeed, natural histories gain importance because of their programmatic nature. To produce natural histories means engaging in a collective enterprise, and requires a significant expenditure of time and labour. The scope of a natural history is a) the collection and description of natural objects and species, b) "aberrations of natural objects" (Anstey, 2002, 72), and c) the manipulation of nature by "art and human ministry" (Anstey, 2002, 72, footnote 31). It is almost impossible to define "natural histories" because of the "elusive character of early modern histories" (Corneanu, Giglioni, and Jalobeanu, 2012, 4). Various tensions in natural histories might be regarded as conceptual weaknesses, but they are intrinsic and – in my view – unavoidable. Natural histories aim at the "accumulation of knowledge" and to produce practical effects. They have to cope with their empirical approach and the simultaneous need for hypothesizing. These and other tensions can be highlighted as follows: "Bacon's *Sylva Sylvarum* (1627) represents the culmination of a philosophical crisis that affected the aforementioned tensions and contrasts became true oppositions: between reality and appearance, sense and intellect, word and image, self-introspection and collective participation." (Corneanu, Giglioni, and Jalobeanu, 2012, 5)

*Thirdly* – as Jalobeanu[12] recently pointed out – we find four different idols with more or less distorted views of "Baconian scholarship" (Jalobeanu, 2013, 5ff.). Jalobeanu is certainly right that we should be careful not to see any of the following paradigms of Baconian scholarship as absolutes. Nevertheless, I will try to partly defend Thomas S. Kuhn's understanding of Boyle as a Baconian. I will briefly outline the four idols: 1) the first idol can be put in the formula "Bacon disliked mathematics." Kuhn is one adherent to this idol "that has many features of a

Baconian *idola tribus*" (Jalobeanu, 2013, 9); 2) the second idol reduces Bacon to a speculative thinker who never carried out experiments but "only mimicked the language of experimental practice to support his purely speculative system." Because this idol – amongst other things – assumes a "hidden agenda", it has many features of the Baconian *idola specus* (Jalobeanu, 2013, 8); 3) the third idol is based on the assumption that Bacon rejected mathematics as a "language of nature." The point of this idol (the Baconian *idola fori*) is that if Bacon rejects both mathematics as a "language of nature" and "'mechanicism' as a trademark of modernity" (Jalobeanu, 2013, 10), he can be pigeonholed in a pre-modern (hermetic, natural magic, Paracelsian, etc.) tradition; 4) Finally, the idol of theatre, applied to Baconian scholarship, rests on the view that "Bacon rejected the physic-mathematics and mechanics of Galileo (and his precursors) in order to promote a purely qualitative physics […]" (Jalobeanu, 2013, 11). Again, Kuhn is one of the followers of this idol. I will partly defend Kuhn's view in section 1.3.

*Fourthly*, I point out another burden of interpreting Bacon, who was no naïve inductionist. He did not rule out hypotheses from methodology. This view is defended, *inter alia*, by Karl Popper, van Leuwen, and Barbara Shapiro (see Manzo, 2009, 127). Bacon did not outline a science "whose primary aim is hypothetical knowledge per se. In fact, he criticises the traditional natural histories because their goal was to 'conjecture and hypothesize' instead of to look into nature for the discovery of the truth. Notwithstanding, on the other hand, Bacon thinks that it is necessary to use temporary hypotheses to achieve the best certainty possible as the final result of the induction." (Manzo, 2009, 128) I will now show – within this framework - how Boyle interpreted, adopted, and rejected a "Baconian programme."

**1.3 Boyle as a Baconian? Views between adoption and rejection**

Of course, the argument that Boyle conducted Baconian science depends on what we understand by a programme originated and intensely demanded by Bacon.[13] Thomas Kuhn elaborated one famous attempt of how we can understand the multifaceted term "Baconian sciences." Although we also have to consider new and fresh approaches, it is still worth thinking of Kuhn's concept. According to Kuhn, Baconian science can be grasped as

> a new cluster of research areas that owed their status as sciences to the seventeenth century's characteristic insistence upon experimentation and upon the compilation of natural histories, including histories of the crafts. To this second group belongs particularly the study of heat, of electricity, of magnetism, and of chemistry.[14]

Elements of Baconian science include the openness to and the implementation of quantification, measurements, design, and constructions of appropriate instruments, reproducibility, a growing scientific community of men working in laboratories, new techniques, and methods to make the invisible visible and a broad, at least Europe-wide communication of ideas.[15]

Now, that is certainly not the whole story. But even if Kuhn's characterisation of "Baconian science" is misleading – keeping Jalobeanu's criticism in mind (see section 1.2) – Kuhn's approach is still inspiring as regards understanding "Baconian science" with respect to Boyle's achievements in seventeenth century chemistry.

At first glance, Boyle's activities were "inspired by the Baconian imperative to collect data that was central to society's rationale."[16] Additionally, we might argue, as Burns did, that "[I]n short, he was an exponent of the Baconian or modern inductive scientific method."[17] His *New Experiments and Observations Touching Cold*[18] give us many examples of research in a Baconian tradition, e.g., "Bodies capable of Freezing others", "Bodies disposed [or indisposed] to be Frozen" or "the degrees of Cold in several bodies".

With respect to Boyle's correspondence, I would like to provide a more detailed overview of what Boyle and his correspondents thought about Bacon: in which respects did Boyle follow Bacon? Bacon accuses alchemists[19] (like chemistry, alchemy was not a clearly defined category) in his *Novum Organum*[20] of using the wrong method in their experimental work.[21] "Bacon urged them to progress 'from Vulcan to Minerva,' namely, from fire analysis to analysis by reason, in order to discover the nature of bodies they manipulated […] Robert Boyle's main allegation to chemists was that they failed to provide philosophical interpretation of their experiments."[22]

As mentioned above, Boyle's writings show a clear tendency towards Baconian science. Bacon plays a specific role in this correspondence as a guide on methodology. This can be seen both in letters to and from Boyle: "[...] I misse *The Continuation of Lord Bacons Sylva Sylvarum*, or *Promiscuous Experiments*, mentioned in your *Physiologicall Essayes* pag. 14 15 & 16 [...]"[23] (letter from Coxe to Boyle).

In a letter from Boyle to Oldenburg dated 13 June 1666[24] (see also Anstey, Hunter, 2008, 83-126), Boyle outlines a rather modern methodological view of science. (The term "science" is much younger and first occurred in the nineteenth century. Thus, Boyle does not use this term, but I translate many of the intellectual enterprises he mentions as "science"). He argues that the opinions of men conducting science can change, i.e. that positions might be fallible, and implicitly refers to the character of those who act as scientists. The trustworthiness of the scientist is a topic that is discussed elsewhere.[25] Another claim that Boyle makes is the occasion to "make tryal of the Experiments he relates."[26]

Another common "Baconian topos" is Boyle's and his correspondents' notion of "usefulness." Although the relevance of "usefulness" is not always explicitly mentioned, it is a common background assumption. In a letter from Beale to Boyle dated 13 July 1666, Boyle is praised as a disciple of Bacon:

> And nowe the Methode [for carrying out various physical experiments, TS] which I doe softly, & tenderly propose, is as followeth.
> 1 *Usefullness* may be first, or laste, or both, It may be first, because in all practicall Tractates, The end should give the first encouragements & directions; And herein you have particularised, explicated, approprionated, & exemplifyied those fayre encouragements, & affectionate directions, which my Lord Bacon had in a wide & spacious generality Essayed, or conjecturally proposed […].[27]

Several more letters show a certain sympathy for Bacon's programme that was shared by a growing community of correspondents,[28] although this does not mean that Boyle was interested in every particular of Bacon's projects. It is worth noting that Boyle was more often described by others, rather than by himself, as a true Baconian.

Another important aspect of Bacon's programme concerns the nature of knowledge. In a letter from Behm to Boyle dated 2 October 1668,[29] the author summarises very clearly why Boyle is the ideal Baconian scientist: a "solid foundation of chemistry" depends on investigating the real differences between things – by accomplishing "chemical analysis and various experiments one can discover the powers and the compositions of things; rather than by following the usual method, which is to rely solely on perceived diversity in colour, smell, or shape, and such-like differences, which do not reveal internal qualities." I will refer to these internal qualities in section 2, where I discuss Boyle's intermediate position between Newtonian mechanism and supernaturalism.

As another line of argumentation, I assume that Boyle – though he contradicts Bacon in many ways – shares the latter's view on the enormous relevance of technical skills and of the *utility of science* in many respects, especially as regards facilitating human life, e.g., through improved medical treatment, nutrition, and husbandry.[30]

To quote Oster,[31] "utility clouded the general principles of scientific investigation." It is far from clear if and how the idea of being a "noble searcher of Nature"[32] can be reconciled with the usefulness of science and scientific knowledge. I will now focus on "utility." What Boyle had in mind since 1644 can also be described as useful knowledge in trade, manufacturing, and related areas. It is striking how often "usefulness" is addressed in many ways. When we analyse different modes of utility, we should always keep in mind the rhetorical and metaphorical notions of utility as a mere act of courtesy that literally involves etiquette techniques. The relevance of this form of courtesy for the development of early modern science has been investigated by Biagioli.[33] An anonymous letter to the Reverend Dr Bentley on a controversy between him and Boyle provides one example of this kind of usefulness: "Seeing they (the writings are so useful to the World as well as to my self, that there might be a just proportion between the Benefit and the Acknowledgement [...]."[34]

Let us now take a closer look at different modes of utility. In one sense, Boyle used the term "utility" in the same way as colleagues such as Hartlib and Evelyn: in his correspondence we find a vast selection of examples "of the usefulness of natural philosophy to all aspects of human life, from agriculture to industry and transport. It exemplifies Boyle's passion for collecting information about trade practices and the like […]."[35] Letters from Boyle to Hartlib "included discussions about artificial means of hatching chickens and inventions of Johann Sibertus Küffler and Cornelius Drebbel such as an unusually strong and bright scarlet dye, an improved design for industrial furnaces, and even the prototype of a submarine."[36] Usefulness is also ascribed to better manufacturing conditions, e.g., "improvement of silke" that enables "many poore Women and Children to worke." (Letter from Boyle to Hartlib, January 1659)[37]

This shared use of the term "utility" has to be separated from a specifically Boylean utility, that is, an ethically loaded view of medical and pharmacological subjects. John Ward gives us a very illustrative report about his stay in Boyle's house. Boyle himself, in his correspondence, speaks of related topics that are described by Ward. Boyle's "plain diet and godly lifestile, and the continuing problems which Boyle had with his sight are underlined by his daily dose of eyebright – the plant euphrasy was widely used at the time as a treatment for diseases of the eyes."[38] In his correspondence, the descriptions of chemical properties and pharmacological aspects of chemical substances are combined with an ethical attitude, e.g., the duty to improve our knowledge about plants and chemical substances, and the usefulness of doing so, especially in the correspondence during 1666-7. To give just one example, I quote from a letter of 14 June 1665[39] from Boyle to Oldenburg, in which Boyle mentions a book that he had not the leisure to read but was directed by Henry Stubbe to

> take notice of one passage, which I confesse I think worthy of the Experiment of the Society, & of which I am like if God permit to make tryall, when I arrive at Oxford, He [Stubbe] says then, That the Plant he calls Rata Capraria (in Italy wont to be named Galega) is wonderfull Efficiacy against the bitings & stings of venemous creatures.

After describing the application of this plant in an animal experiment, he praises the brilliant physicians who ingeniously reduce suffering. Although this is not a physical or chemical experiment, he writes that it will be of great interest to the Royal Society because of the relevance of this useful medicine to the "fatall Plague." Although the emphasis on "beneficence" and "usefulness" is a common topos even among critics of early modern chemistry, it is worth mentioning that Boyle used these more practical features as a tool of political and scientific propaganda. He tried to persuade quite influential members of the scientific community that chemistry should be respected as a science rather than as an art or "auxiliary science."[40]

Without doubt, Boyle adopted some of Bacon's programmatic views on the relevance of natural histories and natural philosophy. Anstey (2002, 74f. and 78-80) described Boyle's *Spring of the Air* as a Baconian project. Anstey and Hunter (2008, 83-126) analysed Boyle's *Designe about Natural History* as being very much influenced by Bacon. Leaving several other Baconian elements in Boyle's thinking and research aside, I will now turn to the non-Baconian facets and even anti-Baconian elements of Boyle's writings.

*Firstly*, according to Anstey and Hunter (2008, 124f.), there is one striking difference regarding Bacon's conception of natural history compared to Boyle's history of particular qualities. Bacon definitely shared a view of a more speculative natural history in his *Abecedarium,* whereas Boyle argued "for the superiority of the corpuscular philosophy in so far as it can explain the qualities of bodies by appealing to the [...] mechanical affection of shape, size, motion and texture." (Anstey and Hunter, 2008, 124f.) To avoid misunderstanding Boyle as a straightforward adherent of mechanism, we point to Boyle's reticence as regards to designating and determining shape, size, motion, and texture as qualities since Boyle was aware that the qualities have to be "fitting objects of experimental investigation" (Anstey and Hunter 2008, 125f.). I will return to Boyle's views on mechanism in section 2.

*Secondly*, Boyle's thoughts and scientific motivations are clearly governed by a deeply religious worldview, and by his aspiration to harmonise the religious and supernatural features of the world with scientific findings. Again, his correspondence sheds light on this rich field of thinking about Boyle, as we will see in section 2. For the moment, it is sufficient to point out that contrary to Bacon, Boyle does not simply contradict alchemical claims and inventions (see below). Reading Bacon's *New Organon*[41] leaves the enduring impression that Bacon tries to separate religious and scientific methods, results, etc.

*Thirdly*, Boyle's view on errors and failures was very different from Bacon's: to avoid any misunderstanding, I am not downplaying Bacon's discussions of ideals as a systematic source of errors, but rather Bacon's comparatively optimistic view on negotiating errors and failures. Boyle seems to believe that many seemingly accidental or unavoidable errors are insuperable obstacles on the way to progress and the growth of scientific knowledge. He distinguishes the "seemingly erratic behaviour of magnetic needles"[42] from the problems that physicians have to face, especially "contingencies as the same disease may be brought about by different causes and proceed differently due to the patient's individual constitution."[43] Boyle was also one of the first writers to point out contingencies in mathematics with respect to their dependence on the exactness of observation and measurements by instruments. Boyle's notion of the relevance of erratic and unsuccessful experiments is striking.[44] Boyle is – unlike Bacon – full of confidence that the reader, especially scientists and intellectuals, will understand the parameters of the success of experiments, such as a lack of skills, poor and insufficient instruments, impure materials, the wrong materials, and the variation of natural objects.

*Fourthly,* Boyle was both aware of his relevance and rank in the community of scientists, researchers, and intellectuals, and was very cautious, not to say reluctant, with respect to publishing or even communicating his results. In a letter from Boyle to Oldenburg dated 26 October 1667[45], Boyle writes:

> CARE will be taken for the future, that the letters I send you be dated. But, in any case at any time it should be forgotten, you may be pleased in great part to supply the omission, by endorsing on the letter, when you received it; for by that it will appear, that, at least, it was written as early, as the time mentioned in the endorsement […] IF I can conveniently […] I may, in my next, impart to you an experiment, as odd as most I have met with, and which will, perhaps, set speculative wits awork, as much as another […] I have also lately put into practice another thing, about which I must earnestly desire your secrecy. For, though long since, perhaps, some years, I was so hopeful of a success, that I set down, and have now by me, a long catalogue of experiments, that I think, never have been made, (nor, perhaps, designed) that may be tried by help of this invention; yet, for want of tools, and because the nature of the experiments requires time, I have not been able as yet to perform them.

*Fifthly*, according to Muriel West – her paper from 1961 is still of great importance – Boyle contradicts Bacon. In Boyle's report on his experiments on respiration he "pays Bacon rather dubious respect when he says that as true disciple of the 'great Verulam' he sets forth his 'doubts', a tribute that seems even more dubious when one observes that he presently says he prefers, with the 'acute Sr. Austin', to confess cautious ignorance rather than profess false knowledge."[46]

The next section is another element of the discussion on a Baconian legacy and its influence on Boyle's metaphysical background, here especially the relation of mechanism and supernaturalism.

## 2 Boyling down philosophy? Mechanism *and* supernaturalism as paradigms for chemistry

There are ongoing debates as to whether the rise of chemistry as a science was inevitably bound to mechanism. Historically, this would be a shortcoming. First of all, Boyle was definitely no pure or strict mechanist "who grounded Chemistry solely upon the mechanical philosophy."[47] But we may have the impression of neglecting and actually boiling down philosophical aspects when we study Boyle's correspondence. Shapin and Schaffer point out that Boyle "offered the matter of fact as the foundation of proper knowledge."[48] The matter of fact in experimental situations is inseparably bound to experimental situations. It is obvious that more and more scientists have asserted the fact generating force of observation. There is a large study by Gross, Reidy, and Harmon, which analysed over 100 scientific articles of seventeenth century scientists, considering especially stylistic features. One result is: "(O)bservation is by far the favourite means of establishing new facts in our 100-article sample. About half this sample presents observational facts exclusively, or observational facts buttressed by some theoretical discussion."[49] For this essay, it is important to notice that the *Philosophical Transaction* was included in this study, and that Oldenburg promoted research that was based on observations. Gross et al. (2000, 375) suggest that the philosophy behind this view is that "theories come and go and are constantly being revised and expanded."

If we take this hypothesis seriously, we may argue that philosophical reflections, like metaphysical views of mechanism or supernaturalism, are *ex post facto* considerations. Chemistry can be organized and experiments can properly designed and carried out *without* philosophy. But at least for many of the seventeenth century scientists, this would be a shortcoming.

My argument in this section is that Boyle's view on chemical aspects cannot be separated from his claim that mechanism and supernaturalism can be reconciled, and from his views on alchemical aspects. More than this, the development of chemistry from Boyle through the whole eighteenth century can better be reconstructed if we do not exclude religious impetus like supernaturalism. In a letter from Boyle to Stubbe, 9 March 1666,[50] the former clearly states that, even if mechanism is true, supernatural phaenomena cannot be ruled out:[51]

> And to this soe much more might be added to the same purpose, […] that thô I have given some Proofe of my being afraid to propose Paradoxes, if I

> think them Truths: yet I shall clearly professe to you that as much I ascribe to the Corpuscularian Philosophie (both in <my> […] other Tracts and professedly in a new one that this week comes out in favor of it) […] I am far from believing that any Mechanicall of Phisicall hypothesis will make out those supernaturall Phænomena without having recourse to the Miraculous Interposition of God [...].

It is not the whole story that Boyle was an extremely religious person, being engaged with theological issues, promoting better translations of the Bible, etc.[52] There are definitely chemical and philosophical reasons why he cannot be regarded as a unambiguous mechanist. Clericuzio has recently argued that in the appendix to the second edition of the *Sceptical Chymist,* bearing the title of *Producibleness of Chemical Principles* (1680),

> Boyle's position was less strict, showing that he did not rule out the existence of homogeneous chemical substances. In the section devoted to mercury, he did not deny that mercury was a homogeneous substance, though he pointed out that nobody had extracted it […]. In a manuscript contained in the Royal Society Boyle Papers we find a more positive statement about mercury, where Boyle asserts that the corpuscles of mercury are primary concretions as well as the primary ingredients of some mixed bodies (Royal Society, Boyle Papers, xvii, fol. 154v).[53]

Moreover, Clericuzio and Chang have argued that, in Boyle's point of view, the properties of chemical corpuscles cannot be reduced to mechanical properties.[54] Clericuzio points to the endowment of the so-called "spiritus" (the spirit of the world) with hidden qualities, i.e. entirely celestial forces. That does not exclude that the effects of those spiritus are of corporeal nature (see Boyle's *Suspicions about some hidden qualities in the air* (1674).[55]

I would like to give another example where Boyle defends both mechanism and supernaturalism:[56] In his *Usefulness of Naturals Philosophy,* Boyle had attempted an intermediate position in the controversy between Galenic and chemical physicians which had dominated European medicine since the time of Paracelsus a century earlier.[57] In his correspondence of 1663, he discusses various medical experiments, and partly defends Galenic methods. Later, Boyle shifted more and more towards Anti-Galenic medicine.

Now, let us begin with the analysis of Boyle's mechanism: In *The grounds for an Excellence of the Corpuscular or Mechanical Philosophy*,[58] Boyle defends and limits mechanism. This short piece is opened and closed in form of a letter. I summarize Boyle's view:

1. Boyle is "far from endorsing the view of the Epicureans that atoms, meeting together by chance in an infinitive vacuum, are able unaided to produce the world and its phenomena."
2. Boyle writes: "All I'm defending is a philosophy that (1) deals only with

purely corporeal things [i.e. deals only with bodies, and has nothing to say about minds]; and (2) distinguishes (a) the ultimate origins of things from (b) the subsequent course of nature, and teaches concerning (a) that God not only gave motion to matter but also at the outset guided the various motions of its parts in such a way that he contrived them into the world he planned for them to compose–a world supplied with seminal principles [see Glossary] and structures or models of living creatures–and established the rules of motion and the order amongst bodies that we ordinarily call 'the laws of nature'. And having said this about (a), the corpuscular philosophy may be allowed to teach regarding (b) that once the universe had been constructed by God, and with the laws of motion being settled and then upheld by his unceasing concourse [i.e. his unceasingly allowing, consenting to, going along with, them] and his general providence, the phenomena of the world thus constituted are physically produced by the mechanical states of the parts of matter, and the effects they have on one another according to mechanical laws."

3. Mechanical principles and explanations are intelligible and clear.
4. There cannot be fewer principles than matter and motion.
5. We cannot conceive any principle more basic than matter and motion.
6. These principles are also simple and fruitful.
7. "Any ingredient that has a real existence in nature can be derived–either immediately or through a series of decompositions–from universal matter and its mechanical states and qualities."

Additionally, I will quote Clericuzio (2010, 342) to underline the thesis, that Boyle cannot be regarded as a strict reductionist.

> Boyle's explanations of chemical change are the kind of subordinate causes that Boyle referred to in this passage as intermediate theories. Thus, it is apparent that Boyle allowed chemistry a specific role in the study of nature. As recent studies have pointed out, in his chemical investigations, Boyle did not adopt a strict reductionist approach, having recourse to compound corpuscles, namely corpuscles endowed with chemical, not mechanical, properties (…).

Even if the summary (see above, 1 to7) might sound as if Boyle was a kind of mechanistic hardliner, he clearly says that matter is endowed by God's activity and plan, and that God usually works with much finer materials than we do. Because motion and matter are endowed by God this supernaturalistic view fits well to mechanistic consequences. In his *Origin in Forms and Qualities* (1666/67),[59] Boyle argues against a strict mechanism and he continues his critique of mechanism in *Cosmic Qualities*. In his correspondence of 1671 and 1672, we find some passages which allow a more supernaturalistic view to be ascribed to Boyle. I restrict myself to citing just one passage of the above-mentioned *Cosmic Qualities*. Boyle writes:

> [T]hat which I chiefly in this discourse (the interaction of matter] consider, is the impressions that a body may receive, or the power it may acquire from

> those vulgarly unknown or at least unheeded Agents by which it is affected, not only upon the account of its own peculiar texture or disposition, by virtue of the general fabric of the world.[60]

Another striking argument against the oversimplification that Boyle primarily shared a mechanist view concerns his commitments to alchemy. This point is not to be underestimated. Interestingly, he invoked it in connection with another preoccupation which emerged at almost the same time, namely with witchcraft, the subject of a correspondence between him and Joseph Glanvill, the divine, which occurred in the later part of 1677 and early in 1678. In these letters, Boyle again emphasized the value of authenticated accounts of actual instances, citing the reliable testimony that he had received from credible witnesses about J.W. Seiler's transmutation of base metal into gold at the imperial court to illustrate that so called "supernatural phenomena" could be empirically verified.[61]

If there was reliable proof of such phenomena, then it was not rationally defensible to deny them. Indeed, though Boyle clearly had various motives in his pursuit of alchemy, including a desire to penetrate the secrets of nature and to provide "extraordinary and noble medicines,"[62] his engagement with alchemy complements his chemical investigations rather than contradicts them.

I cannot explore the argument that chemistry was for a long time successful and flourished, because of some assumption that now seem to be superfluous, like hidden qualities, a use of principles that mixes up modern scientific categories. I only would like to mention the success and heuristical force of the Phlogiston Theory.[63] Moreover, though in some respects Boyle tries to overcome alchemy, he and many of his contemporaries commented positively on alchemical issues. In a letter from Pierre to Boyle, 13/23 December 1677,[64] Pierre describes a process that is related to Boyle's "animation of mercury," a process linked to the preparation of the Philosopher's Stone. Boyle writes:

> I Think that you have come across something good in animating your common mercury with regulus, but on another occasion I have seen that, having made it pass through an earthen retort, and having joined it with some crystals of lune […; silver, TS] & and having purified it with six distillations, it united very well with heat in the mixture with calx of gold or silver, but, Sir, this is not yet the correct method.

Boyle was also elected to a secret alchemical society. Thus, he was known in alchemical circles and did partly agree that alchemical procedures were useful and relevant.[65] Keeping this theoretical background in mind, I will take a closer look at Boyle's views on the practical aspects of experiments and of the organization of research.

### 3 Organizing chemistry: craftsmen, technicians and science

It is both quite obvious – but not well understood – that the manifold interactions of the above-mentioned actors had consequences on the character of chemistry as a practical and theoretical discipline, and for its development as an independent science in the seventeenth century. It is worth mentioning that many philosophers and scientists at this time denied chemistry the status of a discipline of its own right, and merely thought that it was an auxiliary science, e.g. for medicine or natural philosophy, i.e., more or less physics.[66] Another common position regarded chemistry as a rather unsystematic invention carried out by "unlearned empirics."[67] No wonder that it took more than 100 years to establish chemistry as a widely accepted independent discipline.[68] Among the many facts of the rise of chemistry, I think that these aspects are especially worth further analysis: a) How did Boyle understand the practical issues of chemistry, such as inventing experimental setting, carrying out experiments, the role of laboratories, etc.? (Section 3.1) b) Why it is important to analyse the collaboration of craftsmen, technicians, artisans, and scientists as actors, each of them with specific roles? (section 3.2) c) Is there any new model for the production and evaluation of knowledge because of the entirely practical component of chemistry? (Section 3.2) Each of these questions deserves more attention than I can pay here.

### 3.1 Boyle on the practical issues of chemistry

Boyle is one of the most important figures in seventeenth century chemistry inventing, proposing, and reflecting on most deeply practical elements of chemistry. Many other authors have pointed this out. Our aim is to argue in favour of Boyle's view of why practical considerations are indispensable for the systematization[69] and soundness of chemical inventions. First, I again consider Boyle's correspondence as a rich source of insights. In a letter from Boyle to Oldenburg, 13 June 1666,[70] Boyle sketches the plan to invent

> *Chymical Utensils*, Furnaces, Crucibles, Retorts, Glassbells, Cupells &c. Together with directions how to perform such manual Operations, as testing of Metals, weighing bodies in Water, hermetical sealings & c. as must *either* be often imply'd in the History *or* imploy'd about Experiments of great moment. Care being yet taken that as for such Chymical and other Operations or Practices as are already intelligibly enough describ'd in Books, or of which the Reader may easily enough produce himself living Instructors, men be refer'd to those helples, if it be not thought convenient to have a Book or directory compiled to contain at large such Instructions.

This sounds as if Boyle thinks that chemical "operations" and "practices" have already been sufficiently described in books, or that at least skilled men could carry out the procedures. Contrary to this view, Boyle often defends his insistence on different aspects of experiments, such as their reproducibility, the exactness of their description, especially in terms of quantification of substances, the improved use of instruments, such as thermometers, pumps, and various apparatus, and the fallibility of experimental outcomes.[71] He stresses the interdependence of the practical side of experiments as extended and improved sensory perception and their theoretical interpretation. I summarise the major feature of experiments,[72] their epistemological and methodological functions, and exemplify these features by reverting again to Boyle's correspondence.

*Firstly*, experiments create "matters of fact" that have to be distinguished from causal and other ultimate explanations. Experiments are an appropriate instrument to test hypotheses, i.e., to convert a "notion" into a "fact" which has a higher epistemological status.[73] Some hypotheses are transformed into facts by virtue of sufficient evidence. I will discuss the notion of evidence in more detail in section 3.2.

*Secondly*, experiments, as mentioned above, extend the realm of empirical results. Boyle writes on the difference of observation, which is ordinary sensory perception, and experimental experience. He stresses the importance of searching for underlying principles of pure perceptional data, i.e., of interpretation of our experimental results. Thus, experiments help to understand and clarify philosophical assumptions, and vice versa. It is worth noting that some conflicts between the Cartesian, mechanical philosophy, and adherents of "universal spirit" are also part of intense correspondence, e.g., in a letter from Hartlib to Boyle, 10/20 March 1660.[74]

*Thirdly*, in his experimental research program, experiments of course play the central role. They generate new facts and knowledge, and Boyle has several strict methodological rules for designing and carrying out experiments: a) repetition and variation of experiments (see e.g. a letter from Oldenburg to Boyle, 3 December 1667,[75] b) a bulk of experiments (see e.g. a letter from Conradt to Boyle, 28 April 1672,[76] where he proposes 100 experiments), and c) experiments need witnesses for their credibility and trustworthiness (see e.g. the letter from Boyle to Hartlib, 13 October 1659).[77] I cannot explore more general methodological considerations which frame experimental settings,[78] and refer again to Boyle's correspondence where chemical, astronomical, mechanical, and various other experiments and their setting are described.[79]

### 3.2 Craftsmen, technicians and scientists and the production of knowledge

This final section aims to throw light on the relation of Boyle's views on the role on different actors in the experimental settings on the one hand, and their relevance for the production of knowledge on the other.

Though Boyle was a kind of hero in the early stage of the Royal Society, he was more than "a noble researcher of nature," as Oldenburg puts it.[80] Relationships between the scholar and scientist Boyle on the one hand, and the craftsman Boyle, on the other, have been asserted quite often in widely received studies.[81] They have been "delicately negotiated by Boyle, as knowledge gleaned from mechanics involved the incursion of gentlemen into rather foreign territory, both literally and metaphorically."[82] Just like his contemporaries (see e.g. a letter from Coxe to Boyle, late March 1666[83]), Boyle himself uses the *topos* of a "skillful chemist." This does not imply a special interest or any appraisal of those who actually carry out the experiments. But in Boyle's correspondence, the practical abilities in the context of the work in laboratories play a certain role. In a letter from Avery to Boyle, 1 May 1684,[84] Avery writes of his own son, "a person of good repute, and a practicioner in physic, and an assiduous labourer at the chemical fire." As I have sketched above, Boyle was engaged with issues that were entirely in the domain of craftsmanship, e.g., the design of instruments. In a letter to Evelyn, 23 May 1657,[85] he stresses that only "skillfull Enquiries into the secrets" of nature will be successful. But what was the role of craftsmen (and the artisans)? The authority of the experiment – and this is one common argument in Boyle's letters – has to be expanded and consolidated by witnesses. Even if craftsmen had no academic or any scientific education they were important witnesses. This aspect is still under-appreciated from our point of view. The role of observation in chemistry differs very much from e.g., Newton's famous dictum about his physical experiments. In a letter, published in the *Philosophical Transactions* (1676) Newton writes: "For if any of those [experiments; TS] be demonstrative, they will need no assistants, nor leave room for further disputing about what they demonstrate."[86] For the sake of the argument, I assert that Newton is right. Even if he is right, chemical experiments need assistants. (And they need theories on how to interpret their results which undermines partly the parlance of "demonstrative").

Above, I have argued that Boyle's correspondence comprises lots of experimental settings, partly including the experimental design. It is obvious that Boyle sometimes mentions aspects of craftsmanship and technical details. Unfortunately, many actors are not mentioned. I would like to explore one thesis about the relation between craftsman, technician, and chemistry with respect to Boyle's role as a scientist.

First, there is an invisible technician, as Shapin puts it.[87] They are invisible insofar as we do not know much about them. But they are, on the other hand, the most visible and dominant persons if we think of the practice of really carrying out experiments.

There are two paradigmatic figures for Boyle and his contemporaries:

> Descartes' retirement to his stove-heated room and his immersion in self-reflection were systematically rejected. This method is perhaps 'allowable in matters of Contemplation, and in a Gentleman, whose chief aim was his own delight,' but it will not serve as the basis for 'practical and universal Inquiry.' The unsociability of Cartesian method was the basis of its philosophical illegitimacy. [88]

Practical inquiry is not possible without technicians and craftsmen. The role of craftsmen and technicians is immense because of the extremely costly experiments and of the need for new apparatus and new ceramic or metal materials. But why should Boyle, the aristocrat, condescend to handle chemicals, furnaces, and pumps? It is because in Boyle's self-ascription as a "drudge" or an "under-builder" in the search of God's truth in nature, he gives a quite simple answer. This was his performance of nobility and Christian piety.[89] Though it is rhetoric that presented Boyle as a craftsman or technician, it is more than pure rhetoric. Boyle had much respect and the clear view on the efforts of the men (we think that no women worked for him), he calls his collaborators "lusty and dexterous" assistants.[90] He also reported in his correspondence about his conversations with technicians on various details that are of great interest for the success of experiments. Denis Papin is one of the very few technicians known by us by name. We know that Papin constructed and designed experiments, and that Boyle explicitly holds the view that some experiments only were successful because of Papin's knowledge and skills.[91] Papin (1647-1712) invented a steam digester, i.e., a precursor of the pressure cooker, and helped Boyle immensely in carrying out experiments.[92]

It is one of Boyle's merits to have organized chemistry in a quite modern way by promoting a view on knowledge and experimental research encompassing the work and skills of artisans, craftsmen and technicians. One of the most striking features of early modern chemistry is the public character of knowledge. In the words of Eamon:[93]

> In his earliest published work and in his correspondence Robert Boyle made one of the strongest statements against secrecy in science, and at the same time placed himself squarely within the Hartlib tradition. The work, printed in a collection of tracts edited by Hartlib, was an *Epistolical D&course . . . inviting all true lovers of Vertue and Mankind, to a free and generous Communication of their Secrets and Receits in Physick* […].[94] Boyle chastised the 'secretists' who withheld their rare recipes from the public, charging that their only motive for concealment was vanity and avarice. 'Those secrets that were intended for our use, are not at all profaned by being made to reach their end,' Boyle wrote; God 'intended them for the good of all Mankind, and to make that Almoner to whom he trusted them, not the grace but the steward of his graces'. Besides, revelation of secrets would lead to public examination of them, and hence would serve another purpose: to sift the grain from the chaff, for 'tis very unlikely, there should be then more false receipts believed, when there are more true ones extant to confute them'.

It is not self-evident to think of a scientific or an extended non-scientific public. One extremely important point is of experimental replicability as one element of knowledge and as a rather modern feature. To give just one example: the Florentines (Academia del Cimento in Italy) announced that they had verified Boyle's results without needing Boyle's machine, i.e., the air-pump. This would be impossible or at least extremely unlikely if the results and the exact description of the experiment would not have been communicated to a growing community of interested researchers, scholars, etc.

At the same time, when the concept of openness in science gains in importance, the *topos* of solitude of science as one *topos* of knowledge production deserves our closer attention. Shapin brings together the rhetoric of solitude with an "individualistic views of society and empiricists portrayals of scientific knowledge."[95] This is of great importance because it affects e.g., Boyle's view on his role as a scientist. Throughout his life, Boyle portrayed himself as a solitary and his philosophical work as taking place in seclusion from the civic world (an early source is a letter to Tallents, 20 February 1647).[96] And this portrayal, while less familiar to historians, was equally influential among Boyle's contemporaries.[97] So we find a dialectical relation between the openness of a scientific community and the solitary researcher. At the beginning of early modern science, we find explicitly two main paradigms for scientists: *first*, the genius, the lonely searcher for truth, directly in contact with the sources of knowledge, which is contrasted to any social epistemology and Study of the Sociology of Science. *Second*, we think of the scientist as a collaborating member of a scientific community.

**4 Conclusion**

Throughout his life, Boyle portrayed himself as a solitary. To understand Boyle's role in the rise of chemistry, we need both, the *topos* and model of the solitary researcher and philosopher, and the scientist arguing in favour of an open scientific community. As I have sketched above (section 3), Boyle pays very much attention and practical aspects of chemical experiments. The rise of chemistry from an "art" or an "auxiliary science" depended very much on exact experimental design and on the growing importance of different actors, such as artisans, technicians and craftsmen. It is beyond the scope of this paper to point out the complementary facets of chemistry, i.e. chemistry as theory and as practice.

Furthermore, Boyle's correspondence is one rich source not only for analysing the social dimensions of his chemical thinking, but also for rethinking his complex intermediate position between mechanism (and mechanicism) and supernaturalism (section 2). Boyle's research programme, especially with respect to the design and setting of chemical experiments, can be labelled as "mechanistically." But Boyle is nevertheless, with respect to the metaphysical grounding of chemistry, an adherent of supernaturalism.

Finally, regarding Boyle's role in the context of Bacon's legacy, we defend an account that stresses several differences between a "Baconian programme" and Boyle's own adoption and rejection of Bacon (section 1). With respect to Bacon's conception of natural history compared to Boyle's history of particular qualities, we have pointed out that Bacon definitely shared a view of a more speculative natural history than Boyle did.

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The grammar and spelling have been left in the original 17th century English, except in cases where the editors Michael Hunter and Antonio Clericuzio translated letters written in Latin and French.

[2] Boyle was 15 years older than Newton and was one of his correspondents, especially in the 1680s.

[3] One *locus classicus* for Boyle's entirely philosophical conceptions is *The Sceptical Chemist* (see Hunter, M., Davis, E.B. (eds.), *The Works of Robert Boyle* (London: Pickering & Chatto, 1999-2000), 14 volumes), vol. 2, 205ff. For the purpose of the sceptical chemist in Boyle's own view, see Hunter, M., *Boyle: between God and science* (New Haven, US; London: Yale University Press, 2010), 324, endnote 50. Hunter stresses that Boyle intended to convince artists to reflect philosophically on their only seemingly sound principles. For Boyle's articles in the *Philosophical transactions* see e.g. Hunter, M., (2010), 152-155; 157, 171, 179, 186, 188f., 218, 246, 281.

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[14] Kuhn, T.S., (1961): 186.
[15] For a more detailed concept see e.g. Shapin, S. "Science and Prejudice in Historical Perspective" (1998/99): 51-61 (Translation of "Vorurteilsfreie Wissenschaft und Gute Gesellschaft: Zur Geschichte eines Vorurteils", *Transit: Europäische Revue* xvi), [Online] Available via http://www.fas.harvard.edu/~hsdept/bios/docs/shapin-Science_and_Prejudice_1998-1999.pdf, cited 12.3.2013; especially 4ff.; Boyle also mentions correspondents outside Europe, e.g. in Bombay, in a letter from Boyle to Oldenburg, 19 March 1665; see Hunter, M., Clericuzio, A., Principe, L.M. (2001c), 117 and footnote b.
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[27] Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 188.
[28] Oldenburg to Boyle (in Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 369f., footnote e); translation of a letter from de Sluise, a Belgian mathematician, to Oldenburg, written in Latin: "I have no words to express the pleasure it gave to me to learn the Royal society's design from your letter; every learned man must applaud it, and promote it by joint labours. For I think that the extension of natural knowledge (which the illustrious Bacon desired and earnestly strove after) will in the future be immensely promoted by its virtue." Another example is a letter from Cudworth to Boyle, 16 October 1684: "The writers of hypotheses, in Natural Philosophy will be confuting one another, a long time, before the world will agree, if

ever it doe. But your pieces of Natural History are unconfutable. And will afford the best Grounds to build hypotheses upon. You have much outdone Sir Francis Bacon, in your Natural experiments, & you have not insinuated any thing, as he is thought to have done, tending to Irreligion […]" (Hunter, M., Clericuzio, A., Principe, L.M., (2001f), 48).

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[52] Wojcik, J.W., (1997).
[53] Clericuzio, A., (2010): 342.
[54] Büchel, J., *Psychologie der Materie: Vorstellungen und Bildmuster von der Assimilation von Nahrung im 17. und 18. Jahrhundert unter besonderer Berücksichtigung des Paracelsismus* (Würzburg: Königshausen & Neumann, 2005), 108, especially footnotes 257 and 258. Clericuzio, A., "The internal laboratory. The chemical reinterpretation of medical spirits in England (1650-1680)", in P. Rattansi, A. Clericuzio (1994), 53-58.
[55] Büchel, J., (2005), 108.
[56] Hunter, M., (2010), 160.
[57] Hunter, M., (2010), 160.
[58] Boyle, R., *The grounds for and Excellence of the Corpuscular or Mechanical Philosophy* [Online] Available via www.earlymoderntexts.com/pdf/boylexce.pdf (ed. Bennett, J; first launched March 2010, cited 16.3.2013). Citations in the list: 1) and 2) see p. 1; 3) see p. 2; 4) and 5) see p. 3; 6) and 7) see p. 10.
[59] Boyle, R., *Origins in forms and qualities* 1666/67.
[60] *Cosmical Qualities*, 268.
[61] Hunter, M., (2010), 186.
[62] Hunter, M., (2010), 186.
[63] Phlogiston was regarded as a substance without colour, odour or weight, believed to be given off while burning by all flammable materials.
[64] Hunter, M., Clericuzio, A., Principe, L.M., (2001d), 472, footnote b. For Boyle's occupation with alchemy see *passim* and see Principe, L.M., (1998), 153-79.
[65] Hunter, M., Clericuzio, A., Principe, L.M., (2001d), 471, footnote c: "There is a document in the Boyle papers which certifies Boyle's election to this society (BP 40, fol. 91 (dated 7 Mar. 1678) is entitled "a transcription from the journal-book of the Cabalistic Society of Philosophers in an ecumenical and general meeting at Herigo [...]"
[66] Clericuzio, A., (2010): 332f.: "An influential seventeenth-century physician and philosopher, Daniel Sennert (1572–1637), dealt with the goals of chemistry and with its relationship to medicine in *De chymicorum cum Aristotelicis et Galenicis consensu ac dissensu liber* (1619). Sennert maintained that chemistry was *ars,* not *scientia*, and pointed out that it was not independent of medicine, but was an aid to it. *Chymiatria*, he wrote, is part of medicine and it is the physician's task to prepare and to apply chemical remedies."
[67] Clericuzio, A., (2010): 329.
[68] Meinel, C., (1983): 121-132.
[69] This encompasses the prevailing views of many of his correspondents who encouraged him to publish his results more systematically. See e.g. a letter from Beale to Boyle, 18th April 1666: Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 137-140.
[70] Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 170f.
[71] See e.g. Burns, T.B., (1982), 227: Bacon argued in favour of a "clear break with the obscurity of alchemical expression, the insistence that experiments must be described in plain language, that experiments must be capable of being repeated to yield the same result, and that theory is to be based on a consideration of the known facts, following which new experiments can be designed to throw fresh light on the subject."

[72] The following passages owe much to Wagner, L., *Alchemie und Naturwissenschaft. Über die Entstehung neuer Ideen an der Reibungsfläche zweier Weltbilder. Gezeigt an Paracelsus, Robert Boyle und Isaak Newton* (Würzburg: Königshausen & Neumann, 2011), 132-136 and 145-151.
[73] Sargent, R-M., *The Diffident Naturalist. Robert Boyle and the Philosophy of Experiment (Science and its Conceptual Foundations)* (Chicago; London: University of Chicago Press, 1995), 131.
[74] Hunter, M., Clericuzio, A., Principe, L.M., (2001a), 404.
[75] Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 371, footnote c).
[76] Hunter, M., Clericuzio, A., Principe, L.M., (2001d), 248-261.
[77] Malcolm, N., "The Boyle Correspondence: some Unnoticed Items" [Online] (no date). Available via http://www.bbk.ac.uk/boyle/boyle_whatsnew/Malcolm%20%27Boyle%20-Correspondence%27.pdf, cited 17.3.2013; here 5.
[78] Wagner, L., (2011), 152-157.
[79] Hydrostatical experiments: See e.g., a letter from Boyle to Oldenburg, 19 March 1665, see Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 120; Experiments on gravitation: See e.g. a letter from Hooke to Boyle, 21rst March 1666, see Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 121-124.); Experiments on blood transfusion: See e.g., a letter from Lower to Boyle, 6th July 1666, see Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 182-185 and Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 217-219.
[80] See footnote 32.
[81] Oster, M., (1992); Shapin, S., "Pump and Circumstances: Robert Boyle's Literary Technology", *Social Studies of Science* 14, 4 (1984): 481-520, Shapin, S., Schaffer, S. (1985), Biagioli, M., (1996), Hunter, M., (2010).
[82] Oster, M., (1992): 256.
[83] Hunter, M., Clericuzio, A., Principe, L.M., (2001c), 133.
[84] Hunter, M., Clericuzio, A., Principe, L.M., (2001f), 22.
[85] Hunter, M., Clericuzio, A., Principe, L.M., (2001a), 214.
[86] Hutton, C., Shaw, G., and Pearson, R. (eds.), *Philosophical Transactions of The Royal Society of London, Vol. II (1672-83)* (Blackfriars: C. and R. Baldwin 1809), 342.
[87] Shapin, S., (1989): 564.
[88] Shapin, S., (1990): 201f. The citation within the citation refers to Thomas Sprat's *History of the Royal Society* (1667).
[89] Shapin, S., (1989): 556.
[90] Shapin, S., (1989): 557.
[91] Shapin, S., (1989): 559.
[92] Hunter, M., Clericuzio, A., Principe, L.M., (2001f), 26, footnote a); Shapin, S., (1989): 559.
[93] Eamon, W., (1985): 341.
[94] Eamon, W., (1985): 341 cites Rowbottom, M.C., "The Earliest Published Writing of Robert Boyle", *Annals of Science VI* (1950): 376-387. See also Maddison, R.E.W., "The earliest published writing of Robert Boyle", *Annals of Science* 17, 3 (1961): 165-173.
[95] Shapin, S., (1990): 191.
[96] Hunter, M., Clericuzio, A., Principe, L.M., (2001a), 46.
[97] Shapin, S., (1990): 202.