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Corpuscularism and Experimental Philosophy in Domenico Guglielmini's *Reflections* on Crystals[1]

Forthcoming in *The Idea of Principles in Early Modern Thought: Interdisciplinary Perspectives*, ed. Peter Anstey (New York: Routledge)

Natural-philosophical *novatores* in late seventeenth-century Italy typically endorsed a corpuscularist view of principles. They claimed that natural philosophy should identify the causes or principles of natural phenomena and they identified those principles either with corpuscles, or with motion and matter, which in turn consists of corpuscles. Yet, several Italian *novatores* were also adherents of early modern experimental philosophy, that recent studies have portrayed as being incompatible with corpuscularism. This raises the question of whether early modern philosophers could consistently endorse both a corpuscularist doctrine of principles and the tenets of experimental philosophy. This paper addresses this question by examining Domenico Guglielmini's *Philosophical Reflections derived from the Figures of Salts* (1688).[2] In this treatise on crystallography, Guglielmini puts forward a corpuscularist theory and he defends it in a way that is in line with the methodological prescriptions, epistemological strictures, and preferred argumentative styles of experimental philosophers. The examination of the *Reflections* shows that early modern philosophers could consistently endorse, at the same time, both experimental philosophy and a corpuscularist doctrine of principles.

The paper starts by explaining what I understand by experimental philosophy and corpuscularism. I then show that a corpuscularist doctrine of principles was widely accepted among late seventeenth-century Italian *novatores*, although most practitioners refrained from highlighting it or defending it explicitly. We will then turn to the main corpuscularist claim of the *Reflections* and its methodological preface, that explicitly endorses experimental philosophy. I conclude by discussing how Guglielmini's adherence to experimental philosophy relates to his corpuscularism.

EXPERIMENTAL PHILOSOPHY AND CORPUSCULARISM

The movement of early modern experimental philosophy emerged in England around 1660 amongst fellows of the early Royal Society like Robert Boyle and Robert Hooke. It quickly spread to Italy, where it found a favourable reception among the naturalists and physicians who regarded themselves as Galileans.[3] It even influenced those Jesuits, like Daniello Bartoli and Filippo Buonanni, who were willing to integrate new insights in an eclectic version of Aristotelian-Scholastic *scientia* and to engage with *novatores* on the specific details of their discoveries (e.g., Bartoli 1677: 5–18), rather than rejecting their outlook a priori for its metaphysical and theological implications (Torrini 1979b: 20–27). Among other works, Geminiano Montanari's *Physico-Mathematical Thoughts* (1667) and Francesco Redi's *Experiments on the Generation of Insects* (1996 [1668]) endorse central tenets of experimental philosophy.

Experimental philosophers shared a common rhetoric, based on the praise of experiments and the criticism of hypotheses and speculations. They had common heroes, like Bacon, and common foes, especially Aristotelian and, later, Cartesian natural philosophers. But their most important common trait lies in their views on how we can acquire and expand our knowledge of nature. Experimental philosophers held that, before firmly committing oneself to any substantive claims or theories of the natural world, one should gather extensive empirical information by means of experiments and observations. They assigned the same primary role to experiments and observations (Anstey 2014: 105–106): identifying matters of fact which are the basis for developing and confirming theories on the natural world. Experiences (that is, experiments and observations) reported by others must be critically evaluated and, if possible, their experiments must be replicated. Only once this process of fact gathering and checking is nearing completion, will we be entitled to commit firmly to substantive claims or theories (Hooke 1705a: 18), and only insofar as they are warranted by experiments and observations (Boyle 1999 [1662]: 12; Sprat 1667: 107).

Seventeenth-century experimental philosophers often claimed that empirical information should be organized in experimental natural histories (Oldroyd 1987: 151–152): large structured collections of experiments and observations on any kinds of items (biological kinds, minerals, diseases, states of matter, counties, and arts). These collections should serve as the preliminary step to the construction of "a Solid and Useful Philosophy."[4] Natural philosophical theories should be derived from empirical information through a process called induction (Glanvill 1668: 87; Hooke 1705b: 331; Montanari 1980: 540) or deduction (Newton 1999 [1726]: 943). Yet, seventeenth-century experimental philosophers did not take up Bacon's theory of induction,[5] nor did they develop detailed accounts of how theories can be derived from experiments and observations.[6]

These methodological and epistemological views of seventeenth-century experimental philosophers entail neither the endorsement, nor the rejection of corpuscularism. I understand corpuscularism as a view on explanatory natural-philosophical principles, namely, the view that physical phenomena should be explained in terms of the shape, size, and spatial arrangement of the particles that make up physical bodies, along with the motion of such particles according to the laws of nature.[7] Yet, several recent studies on early modern experimental philosophy distinguish sharply between experimental philosophy and corpuscularism. According to Luciano Boschiero and Marta Cavazza, experimental philosophy was a "purely descriptive" endeavour, "programmatically disinterested" in the "metaphysical causes" of natural phenomena (Cavazza 1998) and independent from "theoretical convictions," "presuppositions and preconceptions" (Boschiero 2007: 1, 9).[8] Corpuscularism did not merely describe phenomena, but sought to explain them in terms of causal processes involving unobserved, metaphysically basic entities. For Stephen Gaukroger, on the other hand, experimental philosophy was not purely descriptive. It provided "non-reductive explanations" that avoid any mention of corpuscles (Gaukroger 2006: 254), "as opposed" to corpuscularist attempts to explain phenomena "in terms of some underlying micro-corpuscular structure" (Gaukroger 2014: 28). According to Alan Chalmers, corpuscularist explanations aimed to identify the "rock-bottom or ultimate causes of material phenomena." The explanations of experimental philosophers singled out non-ultimate, intermediate causes, as "opposed to accounts of the ultimate structure of matter" (Chalmers 2012: 551).

The view that experimental philosophy and corpuscularism were sharply distinct and, possibly, in conflict with each other underlies several studies of the authors who committed themselves to both, like Robert Boyle and several Italian natural philosophers. To what degree Boyle's experimental science depends on his corpuscularism is a matter of controversy,[9] as is the view that Boyle suspended his commitment to corpuscularism when articulating his experimental philosophy (Gaukroger 2014: 19). Yet, it is generally agreed that Boyle's "theoretical reflections on the corpuscular hypothesis" belong to his "speculative theory," as opposed to his experimental philosophy.[10] This divide between experimental philosophy and corpuscularism has been portrayed as being so deep that some Italian natural philosophers allegedly endorsed experimental philosophy to conceal their corpuscularism. According to Luciano Boschiero, the members of the Florentine Accademia del Cimento portrayed themselves as experimental philosophers to hide their allegiances to competing Aristotelian and corpuscularist matter theories.[11] And for Marta Cavazza (1990: 145), Bolognese authors followed the model of English experimental philosophers to downplay their matter-theoretical commitments and preserve the freedom of teaching "in the ideological framework of the Catholic Counter-Reformation." According to Cavazza, it is by presenting themselves as experimental philosophers, rather than corpuscularists, that Bolognese practitioners avoided the charges of atheism raised against Neapolitan *novatores* (Torrini 1979a) and the conflicts that led to the imposition of Aristotelianism as the sole natural philosophy to be taught in Florence (Galluzzi 1974, 1995).

This paper provides a different perspective on the relation between experimental philosophy and corpuscularism by focusing on Domenico Guglielmini's *Philosophical Reflections derived from the Figures of Salts* (1688). In this work, Guglielmini commits himself to experimental philosophy as well as corpuscularism. He does not treat these commitments as opposed or competing with one another. The work is not divided into a speculative disquisition about corpuscles on the one hand, and metaphysically neutral experimental reports on the other. Instead, Guglielmini relies on premises and arguments that conform to the epistemological and methodological strictures of experimental philosophy in order to develop corpuscularist explanations. This work shows that at least one early modern experimental philosopher could and did consistently entertain corpuscularist views.[12] Corpuscularist explanations were not necessarily in contrast with experimental philosophy, nor did they always belong to the realm of speculation.

NATURAL PHILOSOPHICAL PRINCIPLES IN LATE SEVENTEENTH-CENTURY ITALY

Corpuscularism was a widely held view among late seventeenth-century Italian *novatores*. They did not provide any explicit, detailed discussions of principles, however, a survey of their texts reveals a broad agreement on two claims. The first is that natural philosophers should not stop at "experimenting, and narrating," as the proem to the Cimento's *Saggi* states,[13] but they should also search for the causes or principles of natural phenomena.[14] The second claim is that these principles are neither the traditional four elements, nor the Paracelsian *tria prima*, nor water, as Van Helmont had claimed. They are either corpuscles, or motion and matter, which in turn consists of corpuscles.[15] For instance, Giuseppe Valletta states that, for modern philosophers, corpuscles "are the first principles of all material things."[16] Donato Rossetti (1667: 14) claims that the "Democritean principles," that is, "corpuscles and atoms," are necessary to explain natural phenomena. He divides atoms into dark and bright and he calls both types of atoms principles (Rossetti 1671: 1). Rossetti's adversary, Geminiano Montanari, officially denies that we are already able to establish whether corpuscles are "first principles" (Montanari 1980: 547). In his view, we will conclusively identify the first principles only once we have charted all of their effects (540). Yet, it is telling that, having surveyed a variety of opinions on whether the true principles are those of the Presocratics, Democritus' atoms and vacuum, Plato's matter and ideas, or Aristotle's matter, form, and privation, Montanari ignores all those theories except Democritus', and goes on to discuss "corpuscles, that is, atoms."[17]

Perhaps the most instructive example of how widespread the adoption of corpuscularist principles was among Italian *novatores* is provided by Francesco Redi. At first sight, he might appear to provide a nice illustration of the discontinuity between experimental philosophy and corpuscularism. He is often portrayed as the prototype of a "superficial" style of inquiry (Baldini 1980: 427) that focuses on "macroscopic and behavioral features of animal species" (Bernardi 1996 [1668]: 7) and eschews any "hypotheses on the basic structure of phenomena" (Baldini 1980: 450). There is good reason to believe that this approach was motivated, at least in part, by Redi's concern to avoid conflicts with the Aristotelians and the Church. Those conflicts might have endangered not only his privileged position in the Medici court, but also the freedom of teaching and research of Florentine *novatores*. Redi was instrumental in dissuading Rossetti from publishing the *Polista fedele*, a work on the compatibility of corpuscularism with the Catholic faith, whose appearance would have raised the ire of the traditionalists (Gómez López 2011: 231). Yet, in an anonymous text, Redi was quick to declare that "the truly natural principles" of the sensible world are atoms or corpuscles.[18]

Despite these endorsements, corpuscularism was far from being universally accepted, undisputed, or uncontroversial in late seventeenth-century Italy. It was a distinctive view of natural philosophical *novatores*. Traditionalist Aristotelian philosophers and Church authorities rejected it on several grounds. Their most vocal objections were theological, especially those concerning the incompatibility of corpuscularism with the dogma of transubstantiation (see e.g., Borrelli 1995b: 13–50). These objections were the ground for charges of atheism and smear campaigns. In Naples, these were followed by trials. More broadly, traditionalist Aristotelians perceived corpuscularism as subverting the entire edifice of *scientia* (Torrini 1979: 18–20), along with the positions of cultural and political power to which they saw Aristotelianism as being subservient. As the Aristotelian Giovanni Maffei (1995 [1670]: 1327) candidly stated, Aristotelianism was "more useful than any other [doctrine] to the attainment of those ends to which the monarchs of the earth aspire."

Although corpuscularism was a controversial natural philosophical view, the authors who defended it most vocally, Francesco D'Andrea (1995 [1685]) and Giuseppe Valletta (1975 [1691–1697]), were not primarily natural philosophers, but lawyers. If we look at the most significant contributions to natural philosophy and medicine that were published by Italian authors—including Lorenzo Bellini, Domenico Guglielmini, Marcello Malpighi, Alessandro Marchetti, Geminiano Montanari, and Francesco Redi—we can easily identify corpuscularist assumptions underlying specific arguments or entire theories (see e.g., Baldini 1977: 11–12). Yet, none of those authors published any explicit, extended development of a corpuscularist matter theory or a defense of corpuscularist principles.[19]

This might be explained in two ways. In the first place, one might note that, in the light of Galileo's condemnation and given the hostility of Church authorities, the most effective strategy for spreading corpuscularism was not to publish explicit defenses of its principles or replies to the attacks of the Aristotelians. It was to publish descriptions and explanations of specific natural phenomena that presupposed corpuscularist principles, sometimes even mentioned them in passing, but did not emphasize them (Vasoli 1979: 205–206). When the Aristotelians—even the most progressive ones—engaged with the *novatores* on specific empirical questions, unprejudiced readers could often see that the empirical evidence weighted on the side of the *novatores*.[20] These could hope that an increasing acceptance of their explicit empirical results would pave the way for the acceptance of their implicit corpuscularism. In the second place, one might claim that the most prominent natural-philosophical *novatores* did not provide any explicit defense of corpuscularist principles because they were incompatible with the adherence to experimental philosophy that was key to their successes. In what follows, we will see that Guglielmini provides a counterexample to the latter claim.

Before we turn to Guglielmini's views, it is worth acknowledging that not all corpuscularists were adherents of experimental philosophy. Tommaso Cornelio held that natural philosophers should not start by carrying out experiments and observations, but by formulating hypotheses and axioms (Cornelio 1688: 78–81). Rossetti held that, before turning to experiments and observations, natural philosophers should develop a theory of nature as a whole (Rossetti 1669: 11). Giovanni Alfonso Borelli, a key member of the Accademia del Cimento and the author of a seminal work on biomechanics, relied on a priori arguments to show that certain animals cannot move in given ways because they are not sufficiently simple, economical, or conducive to the achievement of natural purposes (Borelli 1680–1681, 1: 266–267). Unlike Cornelio, Rossetti, and Borelli, several corpuscularists openly endorsed experimental philosophy. Among them is Domenico Guglielmini.

GUGLIELMINI'S *PHILOSOPHICAL REFLECTIONS DERIVED FROM THE FIGURES OF SALTS*

Domenico Guglielmini was a Bolognese natural philosopher and physician whose most notable contributions lie in the fields of crystallography (1688, 1719 [1705]) and fluid mechanics (1697; see Maffioli 2002). He presents his *Reflections* as a discourse that was read in Bologna, at a meeting of a "philosophical-experimental academy"[21] in the tradition of the Accademia del Cimento and the Royal Society. Despite their brevity, the *Reflections* are one of the most significant seventeenth-century works on crystals.[22] They reflect his practice with the procedure for obtaining salt crystals,[23] his familiarity with the views of the Aristotelians, Descartes (whom he often criticizes[24]), "the most famous Boyle,"[25] and others on what determines the shape of crystals, and his knowledge of Antoni van Leeuwenhoek's (1687: 119–148) microscopic observations of Cyprus vitriol and tartrate floating in water, published only one year before the *Reflections*.

In 1669, Nicholas Steno had highlighted the difference between the regular figures of crystals and the irregular figures of petrified living things. He proposed that quartz crystals "grow through the deposit of layers parallel to their surfaces" (Gohau 2002: 835). He also spelt out, with more precision than his predecessors, what the uniformity of their shapes amounts to. Their angles have always the same measure, whereas the relative length of their facets can change.[26] With this proposal, Steno anticipated the law of constancy of interfacial angles, that Jean-Baptiste Romé de l'Isle would generalize and confirm in 1783.[27]

Guglielmini's *Reflections* address the issue of what determines the constancy of interfacial angles. Aristotelians could explain it by appealing to substantial forms. Boyle had denied that it is necessary to appeal to substantial forms to account for the figures of "alum, vitriol, and other salts, that are so curiously and geometrically shaped." "[T]hese bodies themselves may receive their shape from the coalition of such singly invisible corpuscles" and from the way in which they "are determin'd to stick together."[28]

Boyle's comments on the figures of the corpuscles of specific crystals were characteristically cautious (Burke 1966: 32), unlike Descartes' and Hooke's. In the *Meteorology*, Descartes had claimed that, "since we observe salt grains to be square, they must be made up of oblong shaped particles arranged side by side, to form a square."[29] As Helen Hattab notes, "[t]his is fairly typical of Cartesian explanations," many of which are "hasty inferences from observed effects to the supposed geometrical properties and arrangements of unobservable material particles."[30] Unlike Descartes, Hooke (1665: 85–86) supposed that the particles of all crystals may be spherical and that the combination of spheres of different sizes determines the variation in the shapes of crystals.

In the *Reflections*, Guglielmini (1688: 18) extends the constancy of interfacial angles from macroscopic crystals to their smallest constituent corpuscles, that is, *minima*. Guglielmini argues that the *minima* of salts have the same interfacial angles as the crystals that they compose. The *minima* of common salt are cubes, those of vitriol rhombohedra, those of nitre hexagonal prisms, and those of alum tetrahedra.[31]

This claim provides the basis for Guglielmini's explanation of why all instances of the same crystal have the same interfacial angles. This is not due to their substantial forms, nor does it depend on which acids can be found in the crystals (1688: 20–21). It is due to the fact that the visible instances of any given salt are combinations of *minima* which are tightly stacked together and which have the same interfacial angles of the salt that they compose. The *Reflections* fall squarely within the tradition of corpuscular philosophy: they argue for a claim concerning corpuscles and they employ it to account for the properties of macroscopic objects.

FOUR METHODS

Guglielmini prefaces his corpuscularist arguments with a discussion of four natural philosophical methods and a clear-cut endorsement of the method of experimental philosophy. He begins by criticizing traditional philosophers. Instead of starting the study of nature by observing specific natural phenomena, they endorse certain general principles and derive propositions on specific phenomena from them. Yet, experience shows that their conclusions are false. This is because they rely on principles whose truth is dubious (3).

Hypothetical philosophers seek to avoid the error of traditional philosophers by starting their inquiries from experience.[32] Having observed certain phenomena:

> they formulate a hypothesis on the constitution and nature of principles, which is suitable to explain [*rendere ragione*] effects that are ordinarily observed. They claim [*pretendono*] that the agreement of the supposed principles with observations is a sufficient demonstrative proof of the hypothesis. (4)

Their assumption is mistaken because alternative hypotheses can explain the same empirical facts equally well. Guglielmini shows this by using the familiar example of alternative astronomical systems. If they are to provide persuasive explanations, philosophers should not rush to devise hypotheses for any given phenomenon. They should first gather extensive observations. Although Guglielmini does not mention any hypothetical philosophers, Descartes' argument on the figure of salt provides a good example of their way of proceeding and experimental philosophers had often contrasted Descartes' premature reliance on hypotheses with their reliance on experience. As a consequence, Guglielmini's readers could hardly fail to read the passage as a criticism of Descartes and his disciples.[33]

Superficial philosophers make a mistake opposite to that of hypothetical philosophers.

They gather a large amount of observations on natural phenomena, but they refrain from identifying their causes. Although their efforts are commendable, they are not authentic natural philosophers, because natural philosophy is a search for the causes of phenomena (6–7). Maurizio Mamiani (1987: 248) holds that superficial philosophy "is certainly the method of natural history, with an old tradition, recently renewed by Boyle." Yet, far from turning his back on causal inquiries, Boyle conceived of experimental natural history as a preliminary to the search for causes. Guglielmini was certainly aware of this. He is more likely to have identified superficial philosophers with ancient and Renaissance natural historians, like Ulisse Aldrovandi, or with the superficial style of natural philosophical inquiry of Francesco Redi and his disciples.

According to Guglielmini (1688: 8), natural philosophers should collect a large number of "replicated and well-regulated" experiments and organize them in a "natural history," that will provide "a solid and necessary foundation" for identifying the "causes" of "nature's operations" (7–8).[34] This method "provided the opportunity for the establishment of many famous academies" (7) in England, Italy, and elsewhere. It is the method of experimental philosophy, as it was described at beginning of this paper. Guglielmini states that it is the method of his exposition in the *Reflections*.[35] This indicates that he views the *Reflections* as a work that conforms to the dictates of experimental philosophy.

EXPERIMENTAL PHILOSOPHY AND CORPUSCULARISM

To see if the *Reflections* really conform to the dictates of experimental philosophy, we should focus on two issues: whether the organization of the work is in line with the methodological precepts of experimental philosophy, as Guglielmini states, and whether its contents conform to the epistemic strictures of this movement. As for the organization of the *Reflections*, they do not contain a proper experimental natural history of salts. However, they do have a two-part structure which broadly conforms to the preferred methodology of experimental philosophers: first, they provide a description of given phenomena, and then they put forward explanations. After the methodological preface (1–9), Guglielmini devotes several pages to the description of the figures of five types of salts (9–17). This is followed by an explanatory section that extends the constancy of interfacial angles to corpuscles, relies on it to account for the figures of salts, and refutes alternative accounts (17–33).

As regards their contents, the *Reflections* will conform to the epistemic strictures of experimental philosophy if they adhere to the prescription that any firm commitment to substantive claims or theories must be justified by experiments and observations. Guglielmini establishes his claim on the figures of corpuscles both positively, by providing three arguments for it, and negatively, by responding to objections that may be raised against his view and refuting alternative accounts of the figures of salts.

The first argument establishes its conclusion by means of an inference from a feature of visible crystals to a feature of the *minima*. Guglielmini invites his readers to observe:

> that all visible crystals of the same salt, whether big or small, have the same figure, so that the arrangement of their parts is independent from the greater or smaller quantity of their matter; indeed, one can observe that the efflorescences of nitre on walls … are arranged in very subtle rows which have the same figure that is displayed by its crystals.

He then infers that:

> the salts that our senses cannot perceive, too, will have the same figure … by applying the same reasoning to the smallest parts, we will know that the ultimate parts of matter, that is, those that no natural agent can divide into smaller particles, have a given figure.[36]

The reasoning that underpins this inference is an analogical reasoning. This raises the question of whether Guglielmini holds that analogical reasoning presupposes a priori principles. Analogical reasoning is a close relative of induction and one of Guglielmini's correspondents, Gottfried Wilhelm Leibniz, held that induction can only be warranted by substantive a priori principles.[37] If Guglielmini held that analogical reasoning presupposes any such principles, his first argument on the *minima* of salts would rely not only on observations and experiments, but also on substantive a priori truths. If so, one might worry that Guglielmini's reliance on a priori truths is in contrast with the professed reliance of experimental philosophy on experiments and observations alone.

In response, it should be noted that there is no evidence for the view that Guglielmini took analogical reasoning to rely on a priori assumptions. As far as I am aware, neither Guglielmini, nor those of his peers who wrote extended methodological discussions, like Giorgio Baglivi and Marcello Malpighi, discuss whether the foundations of analogical reasoning are empirical or non-empirical.

The comments of Giuseppe Antonio Barbari and Giorgio Baglivi on analogical reasoning are telling in this regard. Barbari is a little known author who, like Guglielmini, studied in Bologna under Montanari and who published a treatise on vision. Its preface discusses analogical inferences from the macroscopic domain to the sub-microscopic domain in some detail. Barbari (1678: vii–xi) discusses their degree of reliability, their potential pitfalls, and their psychological basis, which he takes to be innate. Yet, he does not even raise the question of whether analogical inferences presuppose non-empirical assumptions. The same holds for Baglivi, who devotes an entire chapter of *The Practice of Physick* (1696: Bk. I, Ch. 6) to analogical reasoning. He praises its usefulness, sets limits to its employment, and defends the legitimacy of the analogies employed by mechanist philosophers and physicians. Yet, he does not discuss their empirical or non-empirical basis. As far as I know, this issue was not on the table for seventeenth-century Italian *novatores*. Nor is there any reason to believe that Guglielmini took his recourse to analogy to presuppose non-empirical truths.

Guglielmini's employment of analogical reasoning to establish a claim about corpuscles might raise another worry. This is whether Chalmers' objections against Boyle's analogical arguments concerning corpuscles apply to Guglielmini's argument. Chalmers notes that one of Boyle's arguments applies the law of fall to corpuscles and ascribes weight to them. Yet, corpuscles have only fundamental, mechanical qualities or affections. Boyle does not include weight among them, nor does he explain how weight might derive from the properties or collisions of corpuscles (Chalmers 1993: 549). Boyle's other arguments explain features of body by means of analogies between the behavior of the corpuscles that compose them and that of strands of fleece, clocks, or watches. Yet, Boyle fails to account for "the elasticity" of the fleece and "the spring and the rigidity of the gear wheels" in terms of "the shapes, size, motions and arrangement of corpuscles" (550).

Chalmer's objections against Boyle do not apply to Guglielmini. This is because, unlike Boyle's analogical arguments, Guglielmini's argument does not ascribe to corpuscles properties like gravity, weight, rigidity, and elasticity, that he fails to explain in terms of the fundamental properties of corpuscles. The only properties that Guglielmini's argument ascribes to corpuscles are shapes and figures. These were routinely included in early modern lists of basic, primary qualities, including Guglielmini's own list. In his view, shape and size are the only fundamental, intrinsic qualities of all material bodies (Guglielmini 1719a: 466, 468).

While Guglielmini's first argument does not raise concerns, the second argument is more problematic:

> When we separate some salt from water, the parts of salt are ordered in such a way that they form an exquisite figure. What can we imagine that could bring about such figures?

> Nothing else than the inclination of the planes of their smallest parts. Since they all have the same inclinations, as they gradually and orderly join each other, the size will grow, but the figure will not change. (Guglielmini 1688: 18–19)

This argument is problematic because, rather than resembling the argumentative style of experimental philosophers, it recalls the all-too-quick flight of hypothetical philosophers from experience to theories. Guglielmini notes an empirical fact. He sketches a corpuscular story that accounts for it. He claims that the story provides the only explanation for the fact. Instead of pausing to justify on this claim, he takes it as established that the explanation must be accepted.[38]

It is hard to believe that Guglielmini could have given much weight to this argument. This is because he was well aware that his corpuscular story does not provide the only explanation for that empirical fact. Just one page later (20–21), he discusses and then refutes an alternative explanation, according to which the shape of salts is due to "the spirit, or volatile acid that predominates in the salts" (20). In the light of this, the second argument is best seen as a brief rhetorical parenthesis between the first and the third arguments. These carry the real argumentative weight of Guglielmini's view. They aim to establish that his explanation is not the only possible explanation of the facts, but the best and most probable explanation. Like many of his Italian peers, Guglielmini holds that natural philosophical theories can attain only probability, not certainty.[39]

The experiences on which his third argument relies are the microscopic observations reported by Leeuwenhoek in his *Anatomia seu interiora rerum* (1687: 122–126). Guglielmini states that Leeuwenhoek saw the fact mentioned at the beginning of the second argument. Specifically, he saw that particles of vitriol and tartrate floating in water have the same interfacial angles of their macroscopic conglomerates (19). Leeuwenhoek also reported that he saw the particles of salts increasing in size, while maintaining the same figure. This provides further evidence for the scale invariance of the figures of salts on which the first argument relies.

Experimental philosophers stressed the importance of first-person experience and the necessity of verifying the testimony of others whenever possible. In the light of this, it may seem surprising that Guglielmini appeals to Leeuwenhoek's testimony, instead of providing first-person reports of those observations. Guglielmini was skilled in the use of the microscope. He had learned it from his teachers Geminiano Montanari and Marcello Malpighi, both accomplished microscopists.[40] Presumably, he too observed the crystals of tartrate floating in water under a microscope, as Leeuwenhoek had done.

Two remarks help explain Guglielmini's reference to Leeuwenhoek's observations. In the first place, as Steven Shapin (1994) has stressed, experimental philosophers relied on a significant extent on "borrow'd Observation[s]" of "Authors not to be distrusted."[41] Boyle (2000 [1690–1691]) approves the reliance of experimental philosophers on the testimony of "Shepherds, Plowmen, Smiths, Fowlers, *&c.*," who "are conversant with the Works of Nature" (313), and the reliance of "the most rational physicians" on the testimony of their patients and earlier physicians.[42] In the eyes of Guglielmini and his peers, Leeuwenhoek was a trustworthy source of information. Although, occasionally, accomplished experimentalists reacted with caution to some of Leeuwenhoek's observations,[43] by 1688 he had established a strong reputation. He had published no less than twenty-seven articles in the *Philosophical Transactions*,[44] two volumes in Latin, and he had been elected Fellow of the Royal Society. In the light of this, even though Guglielmini probably replicated Leeuwenhoek's observations, noting that Leeuwenhoek had carried them out might have helped lend plausibility to them.

In the second place, Guglielmini's use of Leeuwenhoek's observations to establish a conclusion concerning *minima* was in line with the assumptions and expectations of many *novatores*. Bacon had related the use of the microscope to the vision of *minima* as early as

1620 (2004 [1620]: Part II, § 39). He stated that, "if Democritus had seen" a microscope, "he would perhaps have leaped for joy, thinking a way was now discovered of discerning the atom." In 1664, Henry Power claimed that microscopes allow us to see "the very Atoms and their reputed Indivisibles and least realities of Matter."[45] Newton's *Opticks*, first published in 1704, sixteen years after Guglielmini's *Reflections*, states that microscopes will allow us to see at least the largest particles, perhaps even most of them (Newton 1730: 236–237). Giuseppe Gazola, a promoter of experimental philosophy who, like Guglielmini, studied with Montanari, states in a posthumous discourse that microscopes enable "modern physicians" to see "the figure of the smallest [*menome*] particles that make up compound bodies" (Gazola 1716: 172–173). Guglielmini does not state that the particles seen by Leeuwenhoek are themselves *minima*.[46] However, his appeal to microscopic observations to defend a conclusion about *minima* is in line with the view, widely shared by *novatores*, that there is no radical discontinuity between the *minima* and those corpuscles that can be observed with the microscope.

Guglielmini's reference to Leeuwenhoek's observations is especially interesting because some of them may appear to disprove Guglielmini's views. Guglielmini holds that the *minima* of alum are square pyramids with adjacent bases, so as to form octahedra. In his later, systematic treatise on crystals (1719 [1705]: §xxi), Guglielmini refers to Leeuwenhoek's observations in order to establish this claim. Yet, as the *Reflections* note in passing and his systematic treatise explains (1719 [1705]: §xxiii), Leeuwenhoek describes "the figures of alum as being mostly hexagonal," rather than octahedral. Guglielmini confirms that, "[u]sing the microscope, one can really see them as having a hexagonal, sometimes even pentagonal shape."

Guglielmini explains the apparent hexagonal or pentagonal shape of alum by noting that, in the salts observed with a microscope, "the distance between the opposed sides is minimal" and their "transparency, even if it may be low, cancels completely the effects of distance itself." As a result, what is actually an octahedron can appear as a hexagon or pentagon. Consider two adjacent *minima* of alum, which form an octahedron. If its depth is not perceived, then, depending on the observer's position, it may appear as a square, a rhombus or a hexagon, as can be seen from Figure 1. A single *minimum* of alum, which has the shape of a square pyramid, may appear as a square, a pentagon, or a triangle, as can be seen from Figure 2.

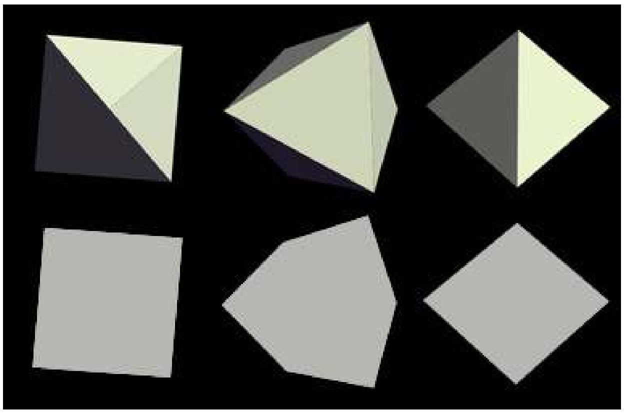

Figure 1: The three figures on the top row are octahedra in different positions. If their depth is not perceived, they may appear like the square, hexagon, and rhombus on the bottom row.

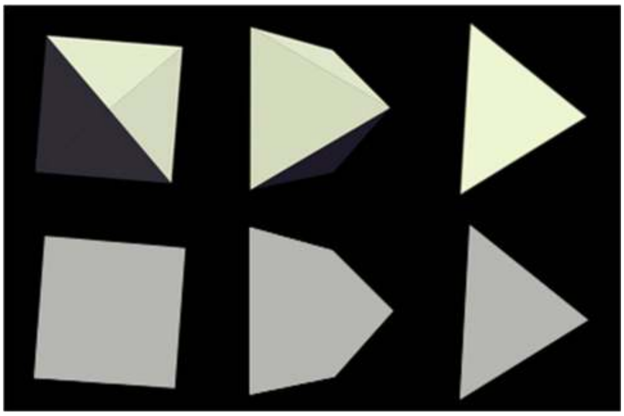

Figure 2: The three figures on the top row are tetrahedra in different positions. If their depth is not perceived, they may appear like the square, pentagon, and triangle on the bottom row.

Guglielmini's explanation of the observations by Leeuwenhoek that appear to disprove his view exemplifies the kind of "genuine empirical support" for corpuscularism that, according to Alan Chalmers, Boyle never provided. Chalmers writes:

> It is conceivable that genuine empirical support for the corpuscular hypothesis could be arrived at by (*a*) appealing to some phenomena to determine something about the shapes, sizes and motions of corpuscles and then (*b*) to employ those characteristics to explain or predict other phenomena, but I am not aware that Boyle achieved any successes of that kind. (Chalmers 1993: 553, letters added)

Guglielmini (*a*) appeals to phenomena concerning the macroscopic crystal of salts to determine the figures of their corpuscles. In particular, he determines that the corpuscles of alum, when combined two by two, have an octahedral figure. Leeuwenhoek observed, to employ Chalmers' words, "other phenomena" (the apparent hexagonal figures of alum) that Guglielmini's theory does not account for. Guglielmini (*b*) explains those phenomena by combining his claim that paired corpuscles of alum have an octahedral figure with the remark that microscopic observations of salts do not reveal their depth.

This pattern of argument conforms to Bacon's recommendation to ascend and then descend "a double scale or ladder:"[47] "to extract … from works and experiments causes and axioms, and in turn from causes and axioms new works and experiments" (Bacon 2004 [1620]: Bk. I, § 117). Guglielmini ascends from phenomena concerning salts to their material cause, which is the figure of their corpuscles, and then descends from those causes to the explanation of Leeuwenhoek's observations.[48]

Having made a positive case for his claim on the figures of corpuscles, Guglielmini replies to objections and criticizes alternative accounts of what determines the figure of given salts.

He thoroughly discusses a series of objections concerning alum. Some of them are empirical, whereas others are a priori. Guglielmini does not hesitate to provide a priori replies to the a priori objections, but he combines them with empirical remarks. Consider, for instance, the following objection. Visible crystals of alum appear to have the shape of an octahedron. Yet, it is hard to see how one could form an octahedron by combining smaller octahedra (Guglielmini 1688: 22–23). This is an a priori, geometrical worry. Guglielmini replies that an octahedron can derive from the combination of two tetrahedra (square pyramids) with adjacent bases. He proposes that the *minima* of alum are not octahedra, but tetrahedra, and that each octahedral crystal of alum is made up of twelve tetrahedra. He explains how they must be arranged to form an octahedron.

This reply may recall Descartes' "hasty inferences" from given *explananda* "to the supposed geometrical properties and arrangements of unobservable material particles" (Hattab 2011: 73). Yet, in contrast to Descartes, Guglielmini rushes to back up his proposal that the crystals of alum are tetrahedral with observations. For instance, he observes that:

> in the crystals formed by solutions of tartrate, mixed with alum, one can see that the figures of alum are composed by other, similar figures, for one can see that the surface of one of the superficial triangles [i.e. tetrahedra] is composed by many other triangles [tetrahedra] of the same nature, even though, sometimes, one of those triangles protrudes a bit on the outside. This happens because the matter of tartrate entered between those parts of alum and, when it hardened, it separated them from one another. (Guglielmini 1688: 23–24)

Guglielmini's recourse to a geometrical model to explain the disposition of salt crystals is consistent with the tenets of experimental philosophy, even if geometrical reasoning may be seen as a form of a priori reasoning. This is because experimental philosophers were not averse to a priori reasoning as such, but to non-empirical justifications of claims on the natural world. Guglielmini establishes the correctness of his geometrical model by means of observations. He then discusses three objections. He answers each of them with arguments based on his experiments and observations (24–30). This way of proceeding is in line with his later claim that “the number and figure” of the angles of salt particles cannot be “contrived in one’s mind or established a priori,” but must be derived “from experiments and observations” (1719 [1705]: §xv).

In sum, Guglielmini’s *Reflections* is a corpuscularist treatise whose methodological preface explicitly endorses experimental philosophy. Guglielmini does not endorse experimental philosophy to conceal or downplay his corpuscularist commitments. He does not portray experimental philosophy as being merely descriptive, uninterested in the causes of phenomena, or independent from theoretical claims on the existence and the properties of corpuscles. On the contrary, the *Reflections* is explicitly devoted to establishing a claim about the figures of the most basic corpuscles and constituents of salts, their *minima*.[49] This claim is not relegated to a speculative section of the work, as distinct from an experimental or natural historical section. On the contrary, the structure of Guglielmini’s corpuscularist treatise conforms to the two-step method that experimental philosophers favoured. With the exception of his second argument, that plays a merely rhetoric role, Guglielmini’s positive arguments on the figures of corpuscles and his replies to objections conform to the *desideratum* of experimental philosophers that any substantive claim on the natural world be based on experiments or observations. Even his response to an a priori, geometrical objection is not limited to a priori considerations, but is backed up by observations. Guglielmini’s *Reflections* shows that corpuscularist theories can be in line with the methodological prescriptions, epistemological strictures, and preferred argumentative styles of experimental philosophers.

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[1] I would like to thank Tom Sorell and the participants in the symposium "Principles in Early Modern Thought" for their helpful comments. This work was supported by the Arts and Humanities Research Council [grant number AH/L014998/1].

[2] References are to the first edition (Guglielmini 1688). The *Reflections* were re-edited, along with a Latin translation, as part of Guglielmini's *Collected Works* (1719c, 1: 65–104).

[3] Boyle's views were known in Italy from the early 1660s (Pighetti 1988: 20). By the 1680s, when Guglielmini's *Reflections* were published, Italian scholars could rely on the English translations of numerous works by Boyle, including a ten-volume edition (Boyle 1677).

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[4] See Henry Oldenburg's introductory comments on Rooke 1665: 140.

[5] As Laudan (1981: 34) has noted, in the seventeenth century "Bacon was not praised (or condemned) as an inductive philosopher so much as an experimental one."

[6] It is clear, however, that what they called induction or deduction is not a matter of replacing "some" with "all" in given sentences, but a matter of identifying a hypothesis that entails the evidence. It is not enumerative induction, but hypothetical induction. For this distinction, see Norton 2005. For an overview of the history of experimental philosophy, see Anstey and Vanzo 2016.

[7] This characterization combines (*a*) a commitment to corpuscles with (*b*) a commitment to explaining phenomena in terms of matter moving according to the laws of nature. One can endorse (*a*) without endorsing (*b*), and vice versa. Among the authors working in seventeenth-century Italy, Claude Berigard and Johann Chrysostom Magnenus endorsed (*a*), but not (*b*). It should also be noted that (*b*) expresses a commitment to a specific kind of mechanism. This is distinct from the commitment to explaining natural phenomena by analogy with the functioning of machines (which can in turn be understood in various ways: see Roux 2011).

[8] In an earlier study, Maria Laura Soppelsa (1974: 132) stated that Montanari's empirical work "appears to rule out a philosophical reflection that may attain knowledge of the first principles."

[9] Chalmers (2002: 197) claims that Boyle's experimental successes "owed nothing to his allegiance to the mechanical philosophy in the strict sense [i.e. corpuscularism as characterized in this paper] and offered no support to that philosophy." For discussion, see Anstey 2002; Pyle 2002. In this paper, I do not discuss whether this is true for Guglielmini's experimental successes, e.g., in river hydraulics.

[10] Anstey and Hunter 2008: 96. According to Anstey (2011: 4–5), corpuscularism was "legitimate […] in the eyes of experimental philosophers" as a "generic hypothesis, which was neutral on the question of the divisibility of matter." Yet, being a "speculative hypothesis," it belonged to the domain of speculative philosophy. On the experimental/speculative distinction in seventeenth-century England, see Anstey 2005.

[11] See, for example, Boschiero 2007: 190. Boschiero (2009) also argues that Montanari presented his work on capillaries in an experimentalist fashion to give the reader the impression that his "actual

experimental procedures were not corrupted by speculations about matter theory and physical causes injected into the experimental research process." Yet, the "process of knowledge-making" underlying that work was related to Montanari's "concerns as a mechanical and corpuscular natural philosopher" (ibid.: 204, 205, 207).

[12] Arguably, the same holds for Montanari, who was one of Guglielmini's teachers. See Vanzo 2016: 58–59.

[13] Magalotti 1667: Proemio a lettori, sig. +2 4. In spite of this prefatory disclaimer, "any unbiased reader" could see that many of the Cimento's experiments had "destructive implications" for "central Aristotelian doctrines" on the causes and principles of natural phenomena (Galluzzi 1981: 804).

[14] For instance, according to Caramuel y Lobkovitz (1670, 1: 712), the Investiganti academicians did not stop at performing experiments, but searched for their reasons (*rationes*) and discussed whether they confirm or destroy the Peripatetic philosophy. On the importance of searching for causes in natural philosophy and medicine, see respectively Guglielmini 1688: 6–7; Di Capua 1681: 508.

[15] See for example, Cornelio 1688: 96–100 on matter and motion as principles and 112 on corpuscles as components of matter; D'Andrea's (1995 [1685]) defense of corpuscularism and his claim that "it is unnecessary to introduce any other principles within nature than matter and motion" (D'Andrea 1995 [1673–1675?]: 151); Bianchini 1785 [*c.*1687]: 7–8 on body and motion as "mechanical principles" and 14 on corpuscles as components of body.

[16] Valletta 1975 [1691–1697]: 49. Valletta calls them atoms and uses "atom" as a synonym of "corpuscle." The quoted passage ascribes this view of principles to the "Platonic, Democritic, and Epicurean Philosophy," endorsed by Valletta.

[17] Montanari 1980: 538, 544–548. Montanari's student, Guglielmini, does not identify "the first principles of all natural things" with corpuscles, but with their figure, size and motion. See Guglielmini 1719b: 463. Among physicians, Baglivi calls "figure and motion" a "general principle that is common to all things and most evident" (Baglivi 1696: Book I, Ch. xii, § 9, p. 117). The Tuscan physician Pirro Maria Gabbrielli, who adapted the philosophy of "Democritus and Epicurus" to "the modern custom, which is based solely on experiments," identified the "principles of all things" with

"seeds [*semi*]," that is, corpuscles (Crescimbeni 1708: 201–202).

[18] Anon. 1698. On the authorship of this text, see Bernardi online, http://www.francescoredi.it/Database/redi/redi.nsf/b4604a8b566ce010c125684d00471e00/db89f5de884dcab0c12569fa005f0a14 (archived at http://www.webcitation.org/6VM1oTYtQ), http://www.francescoredi.it/Database/redi/redi.nsf/pagine/126DDC04C8A0620EC12569F300511AF2 (archived at http://www.webcitation.org/6VM1torcv).

[19] A significant exception is Donato Rossetti, who developed and published a rather detailed corpuscularist theory. He "admitted defeat" in the bitter dispute on corpuscularism that took place in Pisa in the early 1670s by leaving the city and taking up a position in Turin as Court mathematician (Bernardi online, http://www.francescoredi.it/Database/redi/redi.nsf/b4604a8b566ce010c125684d00471e00/805e5cf3a5f06a1cc12569f4003d1f7b, archived at http://www.webcitation.org/6YBK2drVg). Guglielmini developed a corpuscularist matter theory in two brief essays (1719a, 1719b), but he did not publish them.

[20] As Torrini (1979: 25) noted, this was the case, for instance, for the controversy between Francesco Redi and the Jesuit Filippo Buonanni concerning spontaneous generation.

[21] Guglielmini 1688, frontispiece. On this academy, see Cavazza 1990: 51–56.

[22] A more detailed development of their themes can be found in Guglielmini 1719 [1705]. For Guglielmini's definition of salt, see his 1719 [1705]: § iii–v.

[23] He obtained them by incinerating or calcining a substance containing salts, boiling the ash or calx in water, filtering it repeatedly with felt, and making it evaporate slowly until, after a few days, crystals appear on the bottom and the side of the container. If the crystals are dissolved in water, the process can be repeated multiple times. Crystals appear every time and their interfacial angles have always have the same measure. See Guglielmini 1688: 10–11.

[24] See for example, Guglielmini 1688: 11 and 1719 [1705]: 76 on the figure of the particles of nitre; 1719 [1705]: 74 on Descartes' doctrine of the three elements; 1719 [1705]: § vii on the infinite divisibility of matter; 1719a: 468 on space. By the 1680s, knowledge of Descartes' natural philosophy

was common among Italian *novatores*. Cartesianism had been influential in Naples since the 1640s (see e.g., Cornelio's letter *De cognatione aeris et aquae*, written in 1649, in Cornelio 1688: 387). Montanari read Descartes' natural philosophical works in 1657–1658 (Rotta 1971: 153n97). Redi asked a correspondent to purchase all of Descartes' works for him in 1665 (Bernardi online, http://www.francescoredi.it/Database/redi/redi.nsf/b4604a8b566ce010c125684d00471e00/51931bcb175458c6c12569fb0051b3d1, archived at http://www.webcitation.org/6VOGOCvac).

[25] Guglielmini 1688: 28.

[26] Steno 1669: "Explicatio Figurarum," trans. in Steno 1916: 272.

[27] The law, in Romé de L'Isle's formulation, states that the faces of crystals of the same species "can vary in their shape and in their relative dimensions, but the respective inclination of the same faces is constant and invariable in each species" (Maitte 2013: 6).

[28] Boyle 1999 [1672]: 29; see Boyle 1999 [1666–1667]: 368. Eighteenth-century authors would put forward several other views on what determined the figures of crystals. According to William Homberg, "the figures belonged to the alkalis rather than to the acids." Which figure a crystal took depended on which alkali "it had crystallized" (Burke 1966: 25). For to Johann G. Wallerius, "salt itself possessed no crystalline figure before it combined with something metallic" and "the figure of a mineral crystal was due to its metallic ingredients" (26). Torbern Bergman held that "the external configuration of salts depended upon the joint combination of acid and alkali" (27).

[29] Hattab 2011: 73; see Descartes 1965 [1637]: 256–260, trans. in Descartes 1965: 280–283; Hattab 2009: 126–135.

[30] Hattab 2011: 73. This is not to deny that some of Descartes' observations were meticulous, or that he was aware of the different roles that experiments can play. Yet, Descartes' outlook on natural philosophical explanations accords a secondary roles to experiments and observations. See Roux 2013: 52–54.

[31] Guglielmini holds that the *minima* of alum are typically paired two by two, so as to give rise to octahedra. Guglielmini's *De Salibus* (1719 [1705]: § xvii) identifies four basic, simple crystals. This view is not present in the earlier *Reflections*.

[32] This label, like the others in this section, is mine. Guglielmini calls the method of these philosophers "philosophizing through hypotheses" (1688: 4–5).

[33] Mamiani (1987: 248) noted this.

[34] As was customary for experimental philosophers, Guglielmini assigns to both experiments and observations the role of identifying the matters of fact that provide the basis for theorizing. In a posthumous treatise, Guglielmini explains that natural philosophers should aim to ascend gradually from immediate to more remote causes, until they have explained all properties of bodies in terms of their essential, fundamental properties, namely shape and size. It does not pertain to natural philosophers to explain why bodies have these essential properties and not others. See Guglielmini 1719a: 467.

[35] Guglielmini 1688: 8. His later treatise on salt, instead, follows the "synthetic" method of exposition (1719 [1705]: 81).

[36] Guglielmini 1688: 18. Guglielmini defends the view that there are such ultimate parts of matter against Descartes in his 1719 [1705]: § vii. Like Boyle (1999 [1666–1667]: 325–326), Guglielmini (1719a: 468) holds that God can divide those particles.

[37] See Leibniz 1966 [1670]: 432, trans. in Leibniz 1969: 130. For Guglielmini's correspondence with Leibniz, see Cavazza 1987.

[38] This pattern of reasoning was explicitly endorsed by Descartes, to whom Guglielmini's criticism of hypothetical philosophers alludes. See Descartes 1971 [1644]: Part 4, § 1.

[39] Guglielmini 1697, "A' benigni lettori"; see e.g., Rossetti 1669: 12; Montanari 1671: 15; Borelli 1680–1681, 2: 57, 72–73; Di Capua 1681: 164 –165; Bianchini 1785 [*ca.*1687]: 17.

[40] Montanari reported microscopic observations in his works (e.g., Montanari 1667: 12). He used to build microscopes and grind lenses. Malpighi used the microscope systematically to observe animals and plants since the 1660s.

[41] Boyle 1999 [1661], 190.

[42] Boyle 2000 [1690–1691]: 308. See also the example of Columbus at p. 214.

[43] See for example, Redi's reaction to Leeuwenhoek's observation of spermatozoa, as reported in

Bernardi online,

http://www.francescoredi.it/database/redi/redi.nsf/b4604a8b566ce010c125684d00471e00/fec5577faaaa81c0c12569fb0051ead8 (archived at http://www.webcitation.org/6VM1zGVFk).

[44] See Anderson online,

http://lensonleeuwenhoek.net/category/bibliography/Philosophical Transactions (archived at http://www.webcitation.org/6VM26YMtz).

[45] Power 1664: Preface, sig. b2. Power is more cautious at p. 155.

[46] A few decades later, Jacopo Riccati (1762: 542) would emphatically deny it.

[47] Bacon 2000 [1605]: 50. Guglielmini's Italian peers knew and employed this image. See e.g., Lana Terzi 1977 [1670]: 52.

[48] The same argumentative pattern is found in Montanari's works. They often proceed from explanations to theories, derive predictions from those theories, and then confirm those predictions empirically (e.g., Montanari 1715 [1678]: 89). For a methodological statement, see Montanari 1980: 550.

[49] There is a significant difference between Guglielmini and Boyle in this regard. Guglielmini, like the Paracelsians, appears to have held that the "first," most basic components or particles of salts are themselves particles of salts (Guglielmini 1688: 30; 1719 [1705]: §§vii, viii, xviii). Boyle (2000 [1679]: 33), instead, held that "the first Saline Concretions that were produc'd by Nature" are "made of Atoms, or of Particles, that before their conjunction, were not Saline." Boyle (1999 [1661]: 105–106) took his experiment on the redintegration of nitre to show this. While Guglielmini knew Boyle's essay on nitre, I do not know how he interpreted Boyle's experiment. On a more general level, Guglielmini's matter theory distinguishes between three layers, just like Boyle's: elements, which have only basic properties like shape and size, are indivisible by natural powers, and all composed by the same matter; their compounds, i.e. molecules; and macroscopic bodies (Guglielmini 1719a: 467, 468). On Boyle's multi-layered theory and its relation to Paracelsus' theory, see Newman's chapter in this volume.