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**Experiment and Quantification of Weight: Late-Renaissance and Early Modern Medical, Mineralogical and Chemical Discussions on the Weights of Metals**

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**Abstract**

This paper explores how a set of observations on the weight of lead were interpreted and assessed between the 1540s and the 1630s across three different interconnecting disciplines: medicine, mineralogy and chemistry. The epistemic import of these discussions will be demonstrated by showing: 1) the changing role and articulation of experience and quantification in the investigation of metals; and 2) the notions associated with weight in different disciplinary frameworks. In medicine and mineralogy, weight was not considered as a specific subject of inquiry in itself, but as a “sign” indicating other relevant properties of metals. In contrast, the chemistry tradition was increasingly concerned with the specific investigation of weight as a property of matter, as seen in the debates that took place in the “chemical revolution.” In addition, this study will reveal the versatility, polysemy, and parallel purposes of the recourse to experiential knowledge in different contexts, where the same “facts” operate within different disciplines.

**Keywords**

weight – lead – quantification – experiments – calcination of metals – conservation of mass – Galen – Georg Agricola – Vannoccio Biringuccio – Julius Caesar Scaliger - Girolamo Cardano - Gabriele Falloppio - Andrea Cesalpino - Girolamo Mercuriale - Peter Monau, Giovanni Battista Cortesi - Johann Gerhard - Jean Rey

**1 Introduction**

From antiquity onwards, attention has been drawn to the remarkable propensity of lead ores and leaden objects to increase their volume and weight under certain conditions. Much later, in the sixteenth century, newer examples and the observation that lead gains in weight when heated were integrated with the ancient observations. As a result, a corpus of customary or standard observations were transmitted and discussed in very different kinds of texts from the late Renaissance to the early seventeenth century, a period when several scientific disciplines were emerging or taking new directions.

The widely circulated observations on the weight of lead were repeated by many sources, the most significant of which will be analyzed in this article: Julius Caesar Scaliger, Girolamo Cardano, Gabriele Falloppio, Andrea Cesalpino, Jean Bodin, Girolamo Mercuriale, Peter Monau, Giovanni Battista Cortesi, Johann Gerhard, and Jean Rey. Although most of them were physicians, they were interested in these observations for different reasons, some of which were not related to medical matters. Accordingly, I distinguish three modes of interpretation of the standard observations, taking as criteria the topics at stake and the disciplines to which these topics belonged: medicine, mineralogy, and chemistry. This does not entail, however, that these three modes of interpretation were neatly separated. On the contrary, part of the aim of this paper is to show how these modes of interpretation interconnected in dynamic and interesting ways, involving the traditions, methods, practices and theories of the different disciplines.

Although lead is not exceptional among metals for increasing in weight and volume under the circumstances considered in the standard observations, various commentators had supported a traditional view that this increase in the weight of lead was remarkable and even exceptional. In particular, the calcination of lead played a significant role in the history of chemistry. All metals become heavier with calcination, but lead is readily calcined and gains markedly in weight when transformed into litharge. Perhaps for this reason it was the first metal to be recorded as gaining weight when strongly heated, long before the “chemical revolution” explained this phenomenon in terms of oxidation. Indeed, this augmentation effect was crucial for Lavoisier’s experimental and quantitative research, and his refutation of the phlogiston theory. By the 1770s, when he first turned his attention to this matter, some authors still expressed doubts about the reality of the augmentation effect in calcinations. Concerning lead, however, the effect was so well attested, over such a long period of time, that it was hardly doubted. The calcination of lead became, therefore, a paradigmatic case in debates on calcination and combustion, and remained so for a long time until Lavoisier’s solution finally predominated.[[1]](#footnote-2)

This article will reconstruct the pre-Lavoisier debates around observations on the weight of lead, when augmentation because of calcination was usually linked to other kinds of observations noticing changes in weight. Combustion and the weight of gases were not yet the focal points in considering these facts that they would become in the eighteenth century. Instead, the variations in weight were taken into consideration alongside other observations, and used in attempts to prove or to refute opinions regarding important topics of medicine, mineralogy, and chemistry, like the pharmaceutical properties of substances, the process of generation and growth of metals, and the causes of the increase in weight observed during calcination. These observations were often presented in tandem to reinforce the arguments, and acquired different implications depending on their contexts. By exploring the different connotations that weight had before the crucial role it acquired in the quantitative and experimental program of eighteenth-century chemistry, one can trace the various roles that it played in different disciplinary frameworks and can observe how the conception of weight evolved until it became slowly narrowed to its quantitative meaning as related to the quantity of matter.

**2 The First Sources**

A testimony by Pliny (23-79 AD) was perhaps the first of the Western written sources noting the outstanding capacity of lead to grow rapidly and abundantly in abandoned mines.[[2]](#footnote-3) However, Pliny’s observation does not deal specifically with the increase *in weight* of lead. I have identified three main sources reporting those standard observations concerned with the *weight* of lead which were most often discussed: Galen (129-ca. 200), Vannoccio Biringuccio (1480-1539?) and Georg Agricola (1494-1555). Their observations were not experiments specifically designed for the purpose of investigating the weight of lead; and the augmentation effect, at least in the case of Galen and Agricola, seem to have been a property known from testimonies. While Galen noted the growth of lead’s volume and weight, Biringuccio and Agricola drew attention only to the increase in weight.

Galen’s reports are found in the treatise on *Properties of Simple Drugs* (*De simplicium medicamentorum facultatibus*), the first major work on pharmacology after the *Materia medica* (70 AD) of Dioscorides (30-90 AD). In this work the medicinal properties of mineral substances are associated with their elementary composition. Lead has the property to refrigerate, which derives from its having not only “a lot of wet substance frozen by cold” but also a lot of airy substance. Moreover, lead has only a little of earthy substance. This elementary composition is proved by several observations. The first one is perhaps a variation of Pliny’s report. If Pliny claims that *lead mines* are the only ones that increase notably once abandoned, Galen said that lead is the only *substance* that increases when it is lying in subterranean damp rooms. The second observation states that leaden chains securing statues increase their volume in open air:

You will have the following sign [signum] that it [lead] certainly takes part in the airy substance: Lead is the only thing that we have known which increases in volume [moles] and weight [pondus] when it lies in subterraneous rooms containing damp air, to the point that whatever leaden objects are put there, the place rapidly becomes filled up by them. In addition, the leaden chains by which statues are fastened to their base have been seen repeatedly to increase and even swell up to the point that crystals hang from the stones like excrescences.[[3]](#footnote-4)

Galen’s use of the word *signum* (*sēmeion*) is worth noting here, since the notion of the “sign” played an important role in his medicine and was crucial in several disciplines of Renaissance science. The Galenic tradition conceived signs as things that are evident to the senses and reveal something hidden or unknown. Signs are discovered by empirical observation and can only provide probable knowledge, since they do not allow the observer to draw demonstrative conclusions. In the specific case of medicine, the recognition of signs enables the physician to infer the cause of the present state of the patient body and to foresee the appropriate treatment.[[4]](#footnote-5) When Galen says that the increase in weight and volume of lead is a sign of lead’s predominantly airy composition, he ‘reads’ the piece of lead as a physician would interpret the body of a patient. Changes in weight and volume are evident to the senses and reveal something hidden and unknown, namely the elementary composition of lead. Besides, Galen explicitly points out the conjectural character of what can be inferred from these signs: they are “probable marks” (*probabiles notae*) of lead’s humidity and cold.[[5]](#footnote-6)

What was at stake in this Galenic treatise was the determination of the composition of substances, to infer what medicinal effects they might have. Galen drew attention to the weight and the volume, insofar as they were signs revealing the internal composition in terms of the Aristotelian four elements. In this context, neither weight nor volume in themselves were a matter of concern. The same was true for the precise measurement and quantification of their changes. Galen took for granted that there is a relationship between a substance’s airy composition and its capacity for growth in volume and weight, but he did not provide an explanation of this relationship. As we shall see, some authors in their reception of these Galenic reports would try to fill this gap. Within the sources examined in this article, Galen’s observations were by far the most quoted. His interpretation of these phenomena was particularly influential among physicians who were concerned mainly with the medical implications of his interpretations.[[6]](#footnote-7) This I refer to as the ‘medical reception’ of these ideas.

Another tradition in the observation that lead increases in weight comes originally, as far as I know, from Agricola’s account on the origin of metals in *De ortu et causis subterreanorum* (1546).[[7]](#footnote-8) Although Agricola himself was a physician interested in minerals for their medical uses, nowadays he is most known for being the most important Renaissance writer on mining. In this book, he introduced, against other theories, the view that stones are generated from a “lapidifying juice,” which transforms vegetable and animal substances into stones. One evidence, among others proving such a view, is the way in which some metals, like iron and lead, showed a propensity to grow. In this context, Agricola referred to Galen’s report of lead laying in damp subterranean rooms. Owing to his belief that an argument from authority is not enough – that a “good philosopher” must refute others’ views not upon authority but upon “the judgment of senses and reasons” –he accordingly added his own observation that the leaden roof tiles of magnificent buildings have been found much heavier after some years, to the point that sometimes they must be replaced by lighter brass tiles.[[8]](#footnote-9) The weight of lead is not studied in Agricola as a topic in itself, any more than it is in Galen. Although Agricola did not use the word “*signum*” to this effect, he might have subscribed to Galen’s semiotic approach by claiming that changes in the weight of lead and other metals indicate something hidden to the senses, namely the characteristics of the natural process of the generation and growth of metals. Since Agricola assumed that the lapidifying juice generates all kinds of metals, he was not interested in claiming that lead represents an exception. His goal was debunking older theories and arguing for a new one. His interpretations of these phenomena were important for their mineralogical implications, for what I will call the ‘mineralogical reception.’

The third standard observation dates back to the work of Vannoccio Biringuccio, author of *De la pirotechnia* (1540), an influential treatise on mining and metallurgy. This work combines first-hand experience with practical and artisanal knowledge, and endorses an Aristotelian view integrated with some atomistic stances. In the chapter devoted to lead mines and the generation of lead, the author notes that this metal increases in weight markedly when burned in a reverberatory furnace, and offers quite a precise estimate of an augmentation of “8 or perhaps 10 per hundred.”[[9]](#footnote-10) Biringuccio notes that this is an “admirable thing” (*cosa mirabile*), since the weight ought to decrease by the action of fire that consumes some parts. He solves this anomaly by claiming that the increase is due to the removal of the lighter parts that were in the lead before being heated. Likewise, animals become heavier at the point of their death on account of the exhalation of the spirits that kept them alive.[[10]](#footnote-11) This explanation is grounded on postulates of the Aristotelian theory of the four elements, according to which heavy bodies (composed of the elements earth and water) tend naturally downwards towards the center of the universe, while air and fire move naturally upwards towards the periphery. In addition, it assumes that pneumatic matter has “negative weight,” making lighter the dense bodies in which it is contained:

all heaviness tends to the center and the denser a body is the heavier it is within its species. Since those watery and airy parts are removed by the fire from this composition of lead as from a poorly mixed metal, and since all its natural porosity is closed (through which the air used to enter that by its nature and power held it suspended under its influence with a certain lightness), the lead, brought to this point, falls back into itself like a thing abandoned and lifeless. Thus it comes to retain more of its ponderosity in the same way that the body of a dead animal does, which actually weighs much more than when alive. For, as is evident, the spirits that sustain life are released and, since it is not possible to understand how these can be anything but substances with the qualities of air, the body remains without the aid of that which made it lighter by lifting it up toward the sky, and the heaviest part of the element has its natural force increased and is drawn toward the center. Thus the above difficulty is resolved by explanation.[[11]](#footnote-12)

This observation, which had lasting repercussions up to the eighteenth-century debates, differs from the other standard observations on account of its experimental and quantitative import. In the cases previously discussed, observations were not actual interventions in the physical world as a means for gaining knowledge, and can therefore hardly be considered experiments in the modern sense of the term.[[12]](#footnote-13) However, Biringuccio describes a situation in which materials are intentionally manipulated with epistemic goals. The whole process was probably designed with a practical purpose where careful attention was drawn to results. In addition, Biringuccio provides a careful measurement of the quantitative changes. We do not know if he carried out the experiment or if he drew on other sources, but he was indeed interested in recording as exactly as possible the variations in weight.

Although Biringuccio was the first author, or one of the first, to notice the increase in weight of calcined lead, his authority concerning this phenomenon gained very little attention in the following centuries. This phenomenon became much more widely known through a later writing, *De subtilitate* (1550), one of the most successful miscellaneous works of the Renaissance, authored by the physician Girolamo Cardano (1501-1576). In referring to the calcination of lead, Cardano was concerned with giving support to his hylozoistic conception of metals. He believed that, like the rest of the sublunary world, metals have souls and are therefore living beings generated and nurtured from celestial heat.[[13]](#footnote-14) Biringuccio’s account served perfectly his aims, since the exhalation of pneumatic matter (identified by Cardano with metallic and animal souls) accounted for the changes in weight of lead and the bodies of animals.[[14]](#footnote-15) Surely, however, Biringuccio’s concerns were far removed from Cardano’s hylozoistic ontology. In Biringuccio, weight is not taken as a sign indicating a hidden component of lead (namely, its soul), but as an indication in itself, namely of the quantity of matter. The explanation he gave points towards an of understanding of what is going on when the quantity of a substance increases. More precisely, it tries to explain why a substance augments in weight when strongly heated. About two hundred years later, quantification and exact measurement became fundamental skills to address this question. For this reason, observations of the augmentation in the weight of lead during calcination was crucial to what I will call the “chemical reception.”[[15]](#footnote-16)

**3 Weight and the Elementary Composition of Lead in the Medical Reception**

The medical reception addressed the customary observations in relation to the pharmaceutical properties of lead. Authors challenging Galen’s interpretation of these phenomena were in fact questioning the matter theory on which his whole interpretation of health and illness relied. A significant critical response appeared in *De metallis et fossilibus,* a pharmaceutical treatise on metals and fossils first published in 1564 by the Italian physician Gabriele Falloppio (1523-1562)*.*[[16]](#footnote-17) While accepting the medicinal effects postulated by Galen, Falloppio disagreed as to their causes, since he thought that lead is mostly composed of earthy matter and he often described bodies as composed of particles rather than elements. On the one side, his strategy consisted in minimizing the notion of an airy composition of lead and in discrediting Galen’s empirical support. On the other side, he introduced further observations and interpreted them to argue for the predominance of earthy parts.

Accordingly, Falloppio admitted that inside lead there are “some thin [*tenues*] aery parts” and maintained that Galen’s observations could only serve to make it “evident” that lead is a rare metal. He freely reconstructed Galen’s argument incorporating a reference to the rarity of lead, not present in the original. Thus, he attributed to Galen the following rationale: lead is rare; everything rare is either airy or fiery; lead is not fiery: therefore, it is airy. He unjustly reproached Galen for not having noted that lead not only increases in volume, but also in weight.[[17]](#footnote-18) In any case, Falloppio expressed doubts about the reality of Galen’s observations. In the first instance, if it is true that lead augments in volume and weight in damp places, it should also “decrease in warm air.” If that augmentation did actually happen, it must be due to an inner power (*a facultate interna*), and the same should also happen in all metals.[[18]](#footnote-19) Secondly, Falloppio affirmed that he “never saw” lumps in leaden chains, but if something like this should appear, it is nothing but airy parts which became altered and turned into earthy parts.[[19]](#footnote-20) Overall, Galen is accused of inconsistency in his account of the properties of lead: if he says that metals are earthy and, therefore, dry substances, and says that they contain some fiery substance, how can he claim that lead neither dries nor warms up, but moistens and cools?

Falloppio offered an estimate of the increase in weight of lead on calcination, that differed from those of Biringuccio and Cardano. He noted that lead becomes ten to fifteen per cent heavier on calcination and believed that this remarkable augmentation makes it evident that, like the other metals, it is predominantly composed of earthy parts.[[20]](#footnote-21) Falloppio was fully aware that he was questioning Galen’s authority regarding the composition of lead; for this reason he may have thought it necessary to verify the effects of calcination and carry out the experiment himself. In addition, Falloppio believed that the observation about lead roof tiles also indicated the earthy composition of lead, and he claimed that they become heavier by ten per cent or more when they are mixed with the humidity of the medium.[[21]](#footnote-22)

Falloppio’s criticism of Galen’s authority influenced other physicians. This can be seen in the letters exchanged in 1581 between Girolamo Mercuriale (1530-1606), a prominent medicine professor at the University of Padua, and Peter Monau (1551-1588), physician of the imperial court of Rudolph II.[[22]](#footnote-23) In these letters, they debate whether the changes in weight depended on the elementary composition of lead. Their positions reflected their different attitudes towards Galen’s authority and that of Aristotle: while Mercuriale opposed Galen for misunderstanding Aristotle, Monau defended him.

The debate started when Monau pointed out that Galen’s description of lead is hard to reconcile with the fact that lead is “heavy and ponderous” (*gravis et ponderosius*). It is scarcely probable that bodies containing a large proportion of air could be compact and dense, since air requires some space and cavities to blow freely.[[23]](#footnote-24) Mercuriale’s answer recommended a reliance not so much on Galen but rather on “Aristotle, the senses and reason,” according to which metals are produced by the influence of celestial bodies upon the watery and earthly vaporous matter lying in the bowels of the earth.[[24]](#footnote-25) Thus, metals are mixtures, composed of water and earth, and, therefore, the heaviest bodies.[[25]](#footnote-26) Furthermore, if it is true that leaden roof tiles increase in weight, the cause must be that their surface dissolves and mixes with external matter.[[26]](#footnote-27)

Monau’s reply adopted a conciliatory strategy, by claiming the compatibility of the four elements of natural philosophy with the four humors of medicine and the two principles of chemistry. Besides, he offered further proofs in favor of Galen’s idea, including the post-mortem increase in the body weight of animals, which he explained in terms of the influence exerted by external matter.[[27]](#footnote-28) Against Agricola’s report, Monau explained that the long-term exposure of tiles to dry and humid air impedes their growth.[[28]](#footnote-29) However, Mercuriale protested that this was a misinterpretation and warned that volume should not be confused with weight: *if* it is true that the roof tiles grow, they would do so not in volume but in weight.[[29]](#footnote-30) In this context, he resorted to the example of calcined lead that becomes one tenth part or more heavier because its watery parts were converted to ashes and earth.[[30]](#footnote-31) Mercuriale’s estimation coincides with that of Falloppio, and probably draws upon it, as a confirmation that lead mainly consists of water and earth. Thus, the differences between Monau and Mercuriale turn on the authority of Galen as good interpreter of Aristotle and restate some of Falloppio’s strictures against Galen.

A defense of Galen against Falloppio’s and Mercuriale’s criticisms is found in the *Miscellaneorum medicinalium* (1625) of Giovanni Battista Cortesi (ca.1553-ca. 1634), a physician who taught medicine at Messina and who today is mostly known for his contributions to plastic surgery.[[31]](#footnote-32) He discussed the weight of lead when considering the medical uses of leaden plates.[[32]](#footnote-33) Cortesi’s analysis is remarkable for the attention paid to proof (*probatio*), confirmation (*confirmatio*), and demonstration (*demonstratio*) by experiment (*experientia*) of the positions in the debate. His practical approach, too, is worth noting since each view is often checked by means of specific examples of therapeutic uses.

Cortesi did not show an unconditional submission to Galen’s authority but rather subjected his authority to a critical examination. He recognized that Falloppio was right when accusing Galen of inconsistency (577D-578G) and offered his own solution to the problem of the properties of lead (579A-582F). As for the specific issue of the increase of lead, he largely followed Monau’s account (583B-D), and accepted as valid the empirical “proofs” by which Galen believed himself to “demonstrate” and “confirm by experience” his view (577D-578G). He refuted Falloppio’s stance on the calcination of lead for being false and contrary both to “experience and reason.” Contrary to tradition, he claimed that roasted lead does not increase but diminish in weight because of the consumption of parts caused by fire (584E-F). Against Mercuriale and Falloppio, Cortesi added that Galen never said that lead increases when surrounded by air under all circumstances, but strictly referred to lead placed in damp rooms and in calm air. The observations about leaden roofs do not appear among his empirical proofs, and according to Cortesi he should not as a consequence be reproached for being inconsistent in this regard (583D-584F).[[33]](#footnote-34)

As can be seen, the discussion about the augmentation of lead in these sources was particularly centered on whether or not Galen’s authority about the pharmaceutical properties of lead could be maintained. As we have seen in Agricola, and in line with the general attitude of physicians of the time,[[34]](#footnote-35) authors in this strand judged that good arguments should be based on careful examination by “sense and reason.” Hence, they agreed that arguments on authority are the weakest ones, especially when experience of the senses contradicts textual reports. Accordingly, the strategy of Monau and Cortesi, supporters of Galen’s view, was not to appeal to blind submission to authority, but to restate the value of the standard Galenic observations, by discrediting the observations contradicting them. Likewise, Falloppio and Mercuriale discredited the standard Galenic observations to favor an alternative account. Moreover, Falloppio resorted to his own experience when casting doubt on the standard observations of leaden chains, and he checked, perhaps by direct experimentation, the quantitative change produced by calcination. Thus, all the exponents of the medical discussion argued that the final judgment on the real nature of the weight of lead needed ultimately to be based on experience. However, I do not claim that each author reached his theory on the weight of lead *through experimentally oriented research*. Rather, what these cases show is that authors thought that experiential support was a necessary requirement for the scientific validity of their views. For instance, if Falloppio actually performed experiments on calcination, he might have designed them not to investigate the weight of lead in itself, but to convincingly refute Galen’s long-established theory on the properties of lead. Among these authors, the very nature of weight was not an issue, but rather what was at stake was what weight might reveal about lead’s hidden composition and its therapeutic effects.

**4 The Mineralogical Reception**

Other sources used the standard observations on the increase of lead as proofs for arguing for or against alternative doctrines on the origin of metals. They were not directly concerned with the quantitative calculation of changes in weight and volume, considered in themselves. Changes in weight were considered only insofar as they denoted the conditions in which metals grow. In contrast to the medical reception, the role of the traditional authorities was not important. While Aristotle’s theory provided the basis for most discussions, mineralogy did not have a long-established tradition and neither was it a university discipline. There was no stark authoritative body of doctrines in dispute. As we shall see, the standard observations on lead were scrutinized from different methodological approaches.

In the Late Renaissance, the Italian medical doctor and botanist Andrea Cesalpino (1524/5-1603) wrote a book on minerals and metals, *De metallicis* (1596).[[35]](#footnote-36) Cesalpino adopted an Aristotelian approach and endorsed the view that metals originated from the vaporous exhalations of earth, so that water is their dominant element. In addition, within this framework, he reconsidered the alchemical view according to which metals are formed from the concurrence of sulfur and mercury. In Cesalpino’s interpretation, the “exceptional” increase in the weight of lead is caused by its high amount of “dry and inflammable exhalation,” identified with Galen’s “airy substance.”[[36]](#footnote-37) This substance coagulates the humid exhalation surrounding lead, bringing about a kind of filth upon its surface which consequently “increases [lead’s] substance.” Since other metals lack such exhalation, they do not increase as much.[[37]](#footnote-38)

Regarding calcination, Cesalpino went further than just repeating arguments from the authorities, but he also gave new factual evidence, apparently obtained from first-hand experiments. At the same time, he avoided polemics and simply provided his own explanations. Thus, he argued, counter to the received opinion, that the weight of lead actually diminishes on calcination. This can be proved by the fact that, if ashes are reconverted to lead, a lesser quantity of lead is obtained. That notwithstanding, he explained that ashes increase in weight from eight to ten per cent due to the soot struck against the furnace’s walls, which, when forced, is absorbed in the ashes’ pores. Unlike lead, the other metals give the soot back and therefore do not become heavier.[[38]](#footnote-39) In this way, Cesalpino’s strategy provides a variation of an already known experiment. Calcination is regarded as the “most admirable” proof of lead’s exceptionality, for providing a quantitative indication of its remarkable variations. This rough experimental approach bears some resemblance to the strategy that Jean Rey would adopt in the seventeenth century.[[39]](#footnote-40)

The emphasis on the exceptionality of lead continues in the *Decas quaestionum physico-chymicarum* (1643) of Johannes Gerhard (1598/99-1657), professor of medicine and dean at the University of Tübingen.[[40]](#footnote-41) This work is a kind of florilegium, collecting a wide variety of authorities from ancient to early modern times, written in humanist style as a doxography of medieval alchemical writers. Gerhard supported the theory of the generation and growth of metals and believed lead to be a case in point which can convince us “most evidently” of this doctrine.[[41]](#footnote-42) He did not think it necessary to test the canonical experiences empirically, and he attacked those who, like Falloppio, challenged them, invoking the rule that one must accept the majority view of experts.[[42]](#footnote-43) In this way, he sought to harmonize the differences among authors.

Gerhard regarded the canonical observations of Galen and Agricola, along with reports from Pliny and Boccaccio on the growth of lead in abandoned mines, as instances of lead’s regeneration.[[43]](#footnote-44) Drawing on a medieval source, he noted that the peculiarity of lead of always increasing, and more so outdoors and in the open air than under the earth, is established as a “universal theorem obtained from the observations of chemists and miners.”[[44]](#footnote-45) Accordingly, he listed a large series of reports “demonstrating” this peculiarity, including calcination.[[45]](#footnote-46) He derided Falloppio for being the only writer testifying against experts, who are to be accorded the most credence, and he presented (pseudo-) Geber as an authority debunking him.[[46]](#footnote-47) Gerhard claimed that the lamps of leaden chains are produced when the subtlest parts of lead are exhaled and altered while taking substance from external matter, as happens in the nutrition of plants. He drew on one alchemical source, Petrus Bonus Lombardus, in arguing that the ultimate cause of this phenomenon is the “volatile [non fixae] sulfuric parts” spread all over lead.[[47]](#footnote-48) Gerhard’s attempt at conciliating different trends led him to claim that Cesalpino’s “dry and inflammable exhalation” and Galen’s “airy substance” are what the chemists called “volatile sulfuric parts.”[[48]](#footnote-49)

In this mineralogical tradition, Cesalpino’s introduction of variations into the received reports on calcination showed a move towards first-hand experiments, which would become the methodological basis for explaining the augmentation of the weight of lead. In contrast, Gerhard’s florilegium was quite different in character. He considered the standard observations only to confirm his assumed doctrine on the growth of metals, once they were shared by a unanimous corpus of authorized expert testimonies. But still, in this reception, weight in itself was not the topic under investigation; rather, one could say, the real focus of the investigation was a sign revealing something hidden: how metals generate and regenerate in their ores.[[49]](#footnote-50)

**5 The Chemical Reception**

The chemical reception considered the standard observations from the point of view of matter theory and was closely related to the investigation of the weight of pneumatical bodies. This approach entailed that the weight of lead was a matter of investigation in itself: not as a sign indicating something hidden, or a secondary issue of another subject, for which the variations of the weight of lead simply served as a proof or confutation. In this tradition, the augmentation of the weight of lead during calcination provided the most relevant factual evidence.

It is not surprising that the *Exotericae exercitationes* (1557), the famous confutation of Cardano’s *De subtilitate* written by the Aristotelian physician and classical scholar Julius Caesar Scaliger (1484-1558), objected to Cardano’s hylozoistic interpretation of calcination. According to Scaliger, what is taken away from calcined lead is not its soul, but its internal airy parts.[[50]](#footnote-51) A similar explanation is offered by the lawyer and polymath Jean Bodin (1530-1596) in his encyclopedic dialogue *Universae Naturae Theatrum* (1596).[[51]](#footnote-52) It is worth pointing out that in the same book, Bodin engaged in a systematic investigation of the measurement of the weight of different substances and offered a comparative list of the weights of different metals and other materials.[[52]](#footnote-53) However, he did not link this investigation with the issue of the weight of lead. It seems that Bodin did not think that a basis in evidence was necessary to establish his position on the issue, which apparently derived from the purely speculative assumption that pneumatic entities have the power of making bodies lighter.[[53]](#footnote-54)

A work by Jean Rey (ca. 1582-ca. 1645), published in 1630 and which remained almost ignored for a century and a half, is a turning point in the chemical reception and in the whole question of weight as a property of matter. A French physician educated at Montpellier, Rey was a practitioner at Le Bugue. He wrote the *Essays de Jean Rey Docteur en Medecine, sur la recherche de la cause pour laquelle l'Estain et le Plomb augmentent de poids quand on les calcine*, in reply to apothecary Pierre Brun’s request for an explanation of why tin and lead increase their weight on calcination.[[54]](#footnote-55) Although Rey corresponded with Marin Mersenne, who followed his corpuscular explanation of the phenomenon, this piece did not seem to have attained wide circulation until the chemist Pierre Bayen (1725-1798) drew attention to it in 1775. [[55]](#footnote-56) Two years later, Nicholas Gobet (ca. 1735-ca. 1781) edited an annotated reprint of the *Essays*, at a time when Lavoisier was propounding his first theoretical speculations into the increase in weight of metals on calcination and into the part played by air in that phenomenon. Rey’s work today is credited for maintaining, some hundred and fifty years before Lavoisier, the crucial role played by air in the augmentation of weight.[[56]](#footnote-57) Assuming a quantitative and experimental approach and a particulate theory of matter, he enquired not only whence the additional weight comes, but also what replaced the weight lost in exhalations.[[57]](#footnote-58) After careful investigation, he concluded that lead and tin gain weight due to the fact that air, having been rendered denser, heavier and adhesive by the intense and sustained heat of the furnace, becomes attached to the most minute particles of calx (XVI, 36).

Positivist-Whig interpretations had attributed to Rey a distrust of the balance stemming from “his philosophic bias,” and the claim that “weight must be examined by the reason and *not* by the balance” (my italics). [[58]](#footnote-59) However, Rey clearly recognized that the reason as well as the balance are necessary: “the examination of the weight of a thing is made in two ways, viz. with the reason, or with the balance.”[[59]](#footnote-60) The use of the balance “or” the use of reason were not thought of as an exclusive disjunction by him, but as two possible and complementary ways. Like Marin Mersenne, Rey thought that information provided by the senses, even if it has been gained by means of an instrument of precision like the balance, must be disciplined by and submitted to the conclusions of reason.[[60]](#footnote-61) He characterized his methodological approach as a process in which reason corrects and/or complements the inexact, misleading or insufficient information obtained from the balance. While weight can be investigated by both, different and even contradictory results can be obtained. That is because while reason is always exact and is not conditioned by any medium, the balance is often misleading and can only weigh things in air, or – with much difficulty – in water (VIII, 17).[[61]](#footnote-62) In addition, Rey admitted the possibility of introducing thought experiments when necessary, for overcoming the shortcomings of the balance. One can appreciate how he combined both resources in the crucial case of the weight of air, “which was recognizable by other means than the balance [namely, by reason]: and that even through this latter, a portion [of air], previously altered and made denser, could manifest its weight.”[[62]](#footnote-63)

The “weapons of reason” (*armes de la raison*) allowed Rey to combat one error inherited from traditional Aristotelianism, namely that air and fire are absolutely light bodies. The same “weapons” led him to formulate explicitly a version of what today is known as the principle of conservation of the quantity of matter:

The weight is so closely united to the primary matter of the elements that they can never be deprived of it. The weight [poids] with which each portion of matter was endued at the cradle, will be carried by it to the grave. In whatever place, in whatever form, to whatever volume it may be reduced, the same weight always persists.[[63]](#footnote-64)

The idea of the conservation of matter was postulated since antiquity and was especially present in the atomistic tradition. Besides Rey, the Flemish iatrochemist Jean Baptiste van Helmont (1577-1644), who is also well-known for his use of the balance, implicitly applied this principle in his experiments.[[64]](#footnote-65) Both Rey and Van Helmont conceived of the conservation of the quantity of matter in terms of the weight determined by the balance, at a time when mass and weight were not distinguished. They thought that the weight that is gained by a substance when altered or transmuted must be as much as the weight that has been lost by another substance. That means that matter is never destroyed and its total quantity is always conserved.[[65]](#footnote-66) Although both Rey and Van Helmont engaged in quantitative and experimental research, they did not believe it necessary to the test this principle, which they used as a basis for the interpretation of experimental results and to establish quantitative changes in weight.[[66]](#footnote-67)

Given the central role played by air in Rey’s explanation of the augmentation of weight brought about by calcination, it was very important for him to demonstrate that air has weight (II-XIV). That could only be obtained by reason, which tells us that all bodies, including air and fire, are heavy. The upward motion of air and fire is not due to a natural tendency to move in that direction, but it is caused by the downward motion of the heavier elements. Reason also dictates that a portion of an element is not heavy when weighed in its own element (VI-IX): if air weighed in air shows no weight, we should not thereby conclude that it is weightless. Thus, despite the importance of quantitative methodology practiced by Rey, the ultimate foundation for his explanation of the augmentation of weight remains a priori.

Having concluded that air is heavy, Rey did not discuss authorities nor comment on the long-established traditions related to the augmentation of weight. Instead he introduced a body of what we might call “collateral experiments,” mostly intended to prove the density and heaviness of the air and its quantitative changes. He reported experiments exhibiting three distinct ways in which air can become heavier: by admixture of heavier foreign matter (e.g., vapors or exhalations); by compression of its parts; and by separation from its less heavy parts (IX-XI). Against a long-established view, this third method consisted in a demonstration that “simple homogeneous” substances like air can be made denser by separating them from their less heavy parts (XII-XIV). This is how air is made both denser and heavier in metallic calcination: the intense heat produced in the furnace, or by the rays of the sun, brings about the separation of the air’s less heavy parts; this separation leaves behind the denser parts and the air is thereby heavier.

Throughout this investigation, Rey was careful to observe both the volume and the weight of the substances examined, and to establish in a rudimentary fashion the relationship between density and specific weight (without coining a different term to distinguish specific from absolute weight). The degree of density depends on the quantity of the material particles positioned in a certain space, but the principle of conservation of the quantity of matter requires that every material particle always maintains its weight (VI, 14). Thus, he noted that when air is compressed, its weight increases because it is made denser, so that an augmentation in density implies an augmentation in weight (X, 20-22). For that reason, he insisted on a direct correlation between weight and volume (XV, 35).

Finally, Rey dealt with the increase in the weight of lead after calcination. To begin with, he carefully refuted the explanations of Cardano, Scaliger and Cesalpino (XVII-XIX). [[67]](#footnote-68) He also rejected alternative explanations offered by a contemporary unnamed colleague (XX-XXIV), according to whom the increase in weight either derives from the vessel, is caused by vapors, is caused by the volatile and mercurial salt emitted by the charcoal, or is caused by humidity attracted by the calx.[[68]](#footnote-69) Notably, the experiment he presented as the definitive empirical proof refuting the previous accounts and confirming his theory of weight was not a new experiment on lead, but an experiment on the calcination of antimony reported by Hamerus Poppius.[[69]](#footnote-70) Using the calcination of another mineral under different circumstances, Rey nevertheless sought to show that the previous explanations were wrong (XXV).

Rey supported the long-established view that the augmentation in the weight of lead is extraordinary among metals, but he offered a novel explanation of this fact. He observed that the calx of lead and tin may not increase in weight indefinitely. That is because, when weight augmentation occurs by mixing solid with liquid matter, there is a maximum point of saturation beyond which matter cannot been adhered to any longer: “when all is saturated, it can take up no more” (XXVI, 52).[[70]](#footnote-71) The range of saturation permitted by each calx depends on the amount of exhalable (sulfuric) and evaporable (mercurial) matter expelled on calcination. Unlike lead and tin, the calces of other minerals, of plants and animals, have much matter of this sort and, consequently, they lose a large proportion of weight. However, they produce little ashes so as to attract enough air to recover the great loss of weight caused by calcination. From these experiments, Rey derived a kind of law prescribing limits for saturation: “Nature in her inscrutable wisdom had set limits which she never oversteps” (XXVI, 52).[[71]](#footnote-72)

Rey’s solution to the problem posed by Brun, about the cause of the increase in weight of tin and lead on calcination, constitutes the first specific experimental and quantitative investigation of the weight of lead. Rey’s first-hand experiments with the balance allowed him to arrive at an account for the increase in weight, establishing whence the additional weight derives. Rey regarded the experimental evidence provided by the balance, and organized by reason, as crucial to finding a solution to this problem. That is why, from the set of received observations, Rey only examined calcination: this was the only phenomenon whose parameters could be experimentally controlled and quantified through the balance. However, the principle of conservation of the quantity of matter provided the ultimate foundation for his general view of the weight of lead. Ray did not rely on this principle because of experimentation, but he instead assumed it a priori.

**6 Conclusion**

In this study of the issue of the weight of lead from the Late Renaissance to the early seventeenth century, I have identified a set of observations that were differently interpreted and assessed by three overlapping disciplines, based on different concerns, theoretical assumptions and methodological approaches. A comparative approach to these three receptions allows us to draw some general concluding remarks.

First of all, it is worth noting the ground-breaking role of quantification in the formation of the conception of the weight of lead. In the medical and mineralogical contexts, the discussion on the weight of lead was not a matter of interest in itself, but was a secondary issue. Some authors in the medical context, for example, considered the augmentation of lead and its changes in weight as signs of its elementary composition and, by extension, its potential pharmaceutical effects. The mineralogical approach conceived these changes as indicators of the growth of lead, evidence of which was used to support or reject competing theories on the generation and growth of metals. Only in the chemical approach, concerned with a theory of matter, was weight considered an important feature, in and of itself. Weight was no longer seen as a ‘sign’, but as a quantitative property of matter, clearly differentiated from other quantitative properties like density and rarity. This concern with the quantification of matter can be seen as a part of the emergence of early modern chemistry, given the date of Rey’s investigation in 1630.

Only when the weight of lead turned into a specific subject of inquiry in itself, did the quantitative methodological approach take center stage. If representatives of the medical approach judged that “reason and experience” provided the superior form of validation, and limited their recourse to authorities, Rey still subscribed to “reason and experience,” but did not give any role to authorities. In their place, he introduced the balance. For Ray, the balance did not replace experience; on the contrary, he considered it as an instrument allowing a more proper way of arguing from experience in quantitative terms. However, the balance was still thought to be an imperfect, limited, and unreliable tool; a tool that needed the assistance of reason. The intervention of reason was needed, above all, for providing the most fundamental tenets, addressing questions over the conservation of the quantity of matter, for example, or the weight of pneumatic substances. In this way, the balance – properly complemented, illuminated, and controlled by reason – became the instrument *par excellence* for quantifying the weight of matter objectively. This significant replacement of “observation in general” with “observation measured by the balance” and assisted by reason, is indeed indicative of a deep change in the practices of conceiving and investigating weight in more accurate and exact ways.

This survey also shows the several functions of the use of experiential knowledge. We have seen how the same observations could find alternative uses in each discipline and acquire different meanings depending on the contexts in which they are inserted. They were employed to investigate three main subjects in relation to lead and metals: their medicinal properties, their generation and growth, and the causes of their increase in weight on calcination. In relation to each subject, observations and experiments could be used to support different interpretations, and even to concurrently support opposing theories.

Finally, this study suggests that experience, both through observations and experiments, was a versatile and polysemic component of the scientific discourses discussed in this article. We have seen how the standard understandings about lead could operate differently from one discipline to another, without carrying over the contexts of the emergence of these understandings. Observations and experiments were transformed to a certain extent, providing new meanings and implications that could make full sense inside the specific context in which they were reinterpreted. Disciplinary cross-fertilization, and the conciliatory positions developed by many of the authors discussed in this paper, allowed for the emergence of this versatility and polysemy.

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1. For an excellent survey of the debates on calcination in pre-Lavoisier chemistry, see Henry Guerlac, *Lavoisier – the Crucial Year: The Background and Origin of his First Experiments on Combustion in 1772* (Ithaca, NY, 2019), first ed. 1959, ch. 4, “The Mysterious Calcination of Metals.” Cf. James R. Partington and Douglas McKie, “Historical Studies on the Phlogiston Theory. I. The Levity of Phlogiston,” *Annals of Science*, 2 (1937), 361-404. [↑](#footnote-ref-2)
2. Pliny, *Natural History*, trans. Harris Rackham et al., 10 vols. (London and Cambridge, MA, 1938-1962), XXXIV, xlix, 164-165: “mirum in his solis metallis, quod derelicta fertilius revivescunt.” [↑](#footnote-ref-3)
3. “Quod vero et aëriae sit particeps, hoc habeto signum. Omnium quae nouimus, vnicum plumbum tum mole ipsa, tum pondere augetur, si condatur in aedibus subterraneis aerem habentibus turbidum, ita vt quaecumque illic ponantur, celeriter situm colligant. Tum etiam plumbea statuarum vincula, quibus earum pedes annectuntur, saepenumero creuisse visum est, & quaedam adeo intumuisse, vt ex lapidibus dependerent crystalli modo verrucae.” Claudius Galenus, *De simplicium medicamentorum facultatibus libri XI*, tr. Thedoricus G. Gaudanus (Paris, 1530), IX, 222 (modern ed. Karl Gottlob Kühn, *Medicorum Graecorum opera quae extant* [Leipzig, 1819-1833], vol. XII, 230-231). [↑](#footnote-ref-4)
4. On Galen’s view on signs and the conception of signs in Renaissance medicine, see Ian Maclean, *Logic, Signs and Nature in the Renaissance: The Case of Learned Medicine* (Cambridge, 2007), ch. 5.1. [↑](#footnote-ref-5)
5. Galen, *De simplicium medicamentorum facultatibus*, ed. Kühn, 231: “Atque hae probabiles quidem sunt humiditatis eius frigiditatisque notae, prius quam experiaris: caeterum scientificae & certae per experientiam cognoscuntur.” “Nota” was another Latin word usually employed in Renaissance medicine for referring to signs; see Maclean, *Logic, Signs and Nature in the Renaissance,* 149. [↑](#footnote-ref-6)
6. The experiences were mostly quoted directly from Galen’s text in the Latin translation by Gaudanus (see Caroline Petit, “La Tradition latine du traité des simples de Galien: Étude préliminaire,” *Medicina nei secoli*, 25 (2013), 1063-1090), or else from the most famous Renaissance commentary on Dioscorides’ *De materia medica* by Pietro Andrea Mattioli, *Commentarii in libros sex Pedacii Dioscoridis Anazarbei, De medica materia* (Venice, 1554), 5.58, 595-596); see Saskia Klerk, *Galen Reconsidered: Studying Drug Properties and the Foundations of Medicine in the Dutch Republic ca. 1550-1700* (PhD thesis, Utrecht University, 2015), 34. [↑](#footnote-ref-7)
7. On this treatise, see Hiro Hirai, *Le Concept de semence dans les théories de la matière à la Renaissance de Marsile Ficin à Pierre Gassendi* (Turnhout, 2005), 111-134. [↑](#footnote-ref-8)
8. Georg Agricola, *De ortu et causis subterreanorum* (Basel, 1569), V, 61: “plumbeas certe tegulas, quibus magnificas aedes tegi uidemus, multo grauiores, aliquot post annis, inueniunt, ijs qui prius pondus notarunt: atque adeo quidem it eas persaepe, propter nimiam grauitatem aeneis permutare necesse sit.” James R. Partington, *A History of Chemistry*, 4 vols. (London, 1961-1970), I, 51, wrongly suggests that Agricola quotes Galen in reporting this observation. [↑](#footnote-ref-9)
9. Vannoccio Biringuccio, *The Pirotechnia of Vannoccio Biringuccio*, trans. and ed. Cyril S. Smith and Martha T. Gnudi (New York, 1990), 58. Andrea Bernardoni, “Biringuccio, Vannoccio,” in Marco Sgarbi (ed.) *Encyclopedia of Renaissance Philosophy* (Cham, 2018), claims that Biringuccio was the first author noting this fact, while Partington and McKie, “Historical Studies on the Phlogiston Theory,” 363, claim that Biringuccio was “one of the first” to do so. For a general presentation of Biringuccio, see Bernardoni, “Biringuccio, Vannoccio,” and Alberto Tenenti, “Il contesto mentale della pirotechnia,” *Intersezioni*, 20 (2000), 447-456. I wish to thank the journal’s anonymous referee for letting me know about Biringuccio’s presentation of this observation, elsewhere usually attributed to Girolamo Cardano. [↑](#footnote-ref-10)
10. The explanation of the increase in weight of post-mortem bodies resembles the account held by the ancient Greek medical tradition (second century BC); see *Anonymus Londinensis* *ex Aristotelis iatricis Menonis et aliis medicis eclogae,* ed. Hermann Diels (Berlin, 1893), 40-XXXIII, 43. [↑](#footnote-ref-11)
11. Biringuccio, *The Pirotechnia*, 58-59. Cf. Vannoccio Biringuccio, *De la pirotechnia,* (Venice, 1540), fols. 14v-15r (modern ed. Aldo Mieli [Bari, 1914], 109-110): “che ogni grave tende al centro,et ogni corpo, quanto è più denso, più è nella sua spetie grave. Et di questa tal composition di piombo essendoli levato dal fuocho, come a metallo mal misto, quelle parti acquee et aeree, e richiuso ogni sua porosità naturale in la quale soleva entrare l’aere, quale per sua natura e potentia lo teneva in certa leggerezza suspeso nela sua regione, che essendo così condotto, recascha tutto come cosa abbandonata e morta, in se medesimo, e così viene a restare più ne la sua ponderosità, come ancho el somigliante si dimostra advenire a un corpo de uno animal morto, qua1 con effetto più assai pesa che vivo. Perchè, come si vede, essendo resoluti gli spiriti cho sustengano la vita, quali non si può comprendere che sieno che sustantie con qualità d'aere, resta il corpo senza [quell´] aiuto cbe verso il ciel alzandolo l'aleggeriva, et a quella parte de l’elemento più grave se gli accresce la forza naturale, e lo tira verso il centro, e così per tal ragione si solve tal dubio sopra dettovi.” [↑](#footnote-ref-12)
12. On up-to-date interpretation of early modern experimentation, see Friedrich Steinle, *Exploratory Experiments: Ampère, Faraday, and the Origins of Electrodynamics*, trans. Alex Levine (Pittsburgh, PA, 2016), ch. 7, esp. 302-305. [↑](#footnote-ref-13)
13. On Cardano’s mineralogy, see Hirai, *Le Concept de semence,* 135-156. [↑](#footnote-ref-14)
14. Girolamo Cardano, *De subtilitate libri XXI*, in *Opera omnia* (Lyon, 1663), vol. 3, V, 440: “Clarius idem fit ex experimento: nam plumbum cum in cerussam vertitur, ac uritur, tertiadecima parte sui ponderis augetur.” I quote the English translation from Girolamo Cardano, *The* De Subtilitate *of Girolamo Cardano*, tr. John M. Forrester, intr. John Henry, 2 vols. (Tempe, 2013), I, 293. Although Cardano’s description and explanation of the changes in the weight of lead bear close resemblances to those of Biringuccio, it is worth nothing, however, that his account is far shorter and that the quantitative estimations of the increase in weight do not coincide: eight or ten per hundred (Biringuccio’s) and one thirteenth part (Cardano’s). One still can wonder whether Cardano carried out the experiment himself or whether he perhaps drew on another source. [↑](#footnote-ref-15)
15. For an early and throughout scholarly account of the importance, novelty, and repercussions of Biringuccio’s observation of the calcination of lead, see Aldo Mieli, *De la pirotechnia de Vannocio Biringuccio*, vol. 1, 108 n. 8; see also Partington and McKie, “Historical Studies on the Phlogiston Theory,” 363-364. [↑](#footnote-ref-16)
16. The book gathers Falloppio’s lessons delivered at Padua in 1557. [↑](#footnote-ref-17)
17. Gabriele Falloppio, *De metallis atque fossilibus*, in *Opera genuina omnia*, vol. 1 (Venice, 1606), cap. XXII, 385-386. [↑](#footnote-ref-18)
18. Ibid.*,* 386: “quod plumbi quantitas augetur in aere crasso, frigido, et humido, ego non credo verum esse hoc, quia si cresceret in aere frigido, necessario decrescere in calido, et sic si augeretur hyeme, decresceret aestate sub sole, et si plumbum augeretur a facultate interna alia quoque metalla augerentur, quia et ipsa poros habent in quibus reicipitur aer: tamen videmus quod non augentur, nisi sint in prorio loco, ubi sit et proprius lapis.” In this case, Falloppio seems to agree with Pliny’s statement (Pliny, *Natural History*, XXXIV, xxxix, 167), but not with Galen, who presents the case as if lead increased in any place. [↑](#footnote-ref-19)
19. Ibid.*,* 386-387: “ego nunquam verrucas illas vidi et si fierent, crescerentque hyeme arbritor, quod aestate decrescerent et abolerent, et si qua auctio apparet, non est quia auctum sit plumbum in mole, sed quia in pluvia ex alijs intrinsecis derasus est lapis, et sic ad imminutionem lapidis, videtur quod plumbi quantites fuerit aucta.” This quotation reproduces the passage from Falloppio, *Opera quae adhuc extant omnia* (Frankfurt, 1634), 365, which states “quia in pluvia et alijs extrinsecis derasus est lapis” instead of “in pluvia ex alijs intrinsecis derasus est lapis” (*De metallis*, 387). [↑](#footnote-ref-20)
20. Ibid.*,* 386: “quod autem in plumbo dominetur terra, patet ex plumbo usto, quia augetur quantitas, quo ad pondus. Si enim acceperitis centum libras plumbi, et exuratis, deinde ponatis cinerem illum in trutinam, videbitis, quod ponderabit centum et decem libras, vel centum et quindecim libris: hoc autem non esset, si in plumbo dominaretur aqua, et non terra.” [↑](#footnote-ref-21)
21. Ibid.*,* 387: “Quoniam ratio cur plumbi pondus augeatur est, ut dicunt philosophi, quia qualitas illa terrestris in plumbo dominans, dum est mixta cum humiditate, refrangitur ab ipso. Unde cum non retineat sua integram naturam, non potes ita ponderare.” [↑](#footnote-ref-22)
22. This exchange was compiled in Lorenz Scholz, comp., *Epistolarum philosophicarum: medicinalium ac chymicarum* […] (Frankfurt, 1598); see Nancy Siraisi, *Communities of Learned Experience: Epistolary Medicine in the Renaissance* (Baltimore, MD, 2013), 31-34. [↑](#footnote-ref-23)
23. Scholz, *Epistolarum*, letter 213 (Monau to Mercuriale, Prague, January 9, 1581), cols. 358-360. [↑](#footnote-ref-24)
24. ####  The locus classicus of this theory is Aristotle, Meteorologica, book 4.

 [↑](#footnote-ref-25)
25. Siraisi, *Communities,* 31-32. However, Mattioli simply reproduces Galen’s text and does not add any comment of his own on this matter. Siraisi’s mistake derives from a wrong reading of the Latin passage, which explicitly refers to Galen. My reading coincides with Cortesi’s; see Giovanni Battista Cortesi*, Miscellaneorum medicinalium decades denae* (Messina, 1625), 578D. [↑](#footnote-ref-26)
26. Scholz, *Epistolarum*, letter 89 (Mercuriale to Monau, Padua, February 17, 1581), cols. 134-136. [↑](#footnote-ref-27)
27. Scholz, *Epistolarum*, letter 214 (Monau to Mercuriale, Vienna, 1583, cols. 362– 363. [↑](#footnote-ref-28)
28. Ibid., cols. 360-365. [↑](#footnote-ref-29)
29. As Cortesi was to recognize later, Mercuriale was here engaging in a *fiduciaria reprobatio* (Cortesi, *Miscellanearum*, 578H), which was a method of the post-medieval *ars disputandi* that admitted what was objected in order to refute it. Undoubtedly, Cortesi was by far a more careful reader of Mercuriale than Monau. For a definition of *fiduciaria reprobatio*, see Ammonius Hermias, *In V. Porphyrii voces commentarii per Joannem-Baptistam Rasarium latinitate donati* (Venice, 1549), fol. 57 v*.* [↑](#footnote-ref-30)
30. Scholz, *Epistolarum*, letter 90 (Mercuriale to Monau, Vienna, December 20, 1583), col. 136: “Nam idem plumbum, si comburatur, decima atque etiam amplius parte, quam antea ponderare conspicitur.” The discussion continues in Monau’s letter to Mercuriale (letter 215, Prague, January 16, 1584, cols. 368-369) and in Mercuriale’s to Monau (letter 91, Vienna, March 30, 1584, col. 141) but without significant additions for our topic. [↑](#footnote-ref-31)
31. On Cortesi, see Augusto De Ferrari, *Dizionario Biografico degli Italiani*, Volume 29 (1983), 763-765 <www.treccani.it/enciclopedia/giovanni-battista-cortesi\_(Dizionario-Biografico)>, last accessed 28 July 2020. [↑](#footnote-ref-32)
32. Cortesi, *Miscellaneorum*, Decas octava, VIII, 574-586. The use of leaden plates is presented by Pliny, *Natural History*, XXXIV, l-lii, 247-248. [↑](#footnote-ref-33)
33. References between parentheses in this paragraph belong to Cortesi, *Miscelleanorum*. [↑](#footnote-ref-34)
34. See Maclean, *Logic, Signs and Nature in the Renaissance*, ch. 5.3 and ch. 6. [↑](#footnote-ref-35)
35. On Cesalpino’s mineralogy, see Hirai, *Le concept de semence,* ch. 7. [↑](#footnote-ref-36)
36. Andrea Cesalpino, *De metallicis libri tres* (Rome, 1596), ch. VII, 183-186. In the edition I quote there is a typo in the page number 184 (which is paginated as “180”). [↑](#footnote-ref-37)
37. Cesalpino, *De metallicis,* 180-181. [↑](#footnote-ref-38)
38. See Partington, *History of Chemistry,* II, 90-91. [↑](#footnote-ref-39)
39. See section 5 below. [↑](#footnote-ref-40)
40. Johannes Gerhard*,*Decas*quaestionum physico-chymicarum selectiorum et graviorum, omnibus tam Hermeticae quam Peripateticae philosophiae* […] (Tübingen, 1643), 21-30. [↑](#footnote-ref-41)
41. Ibid.*,* 21-22. [↑](#footnote-ref-42)
42. On Gerhard, see Hiro Hirai and Hideyuki Yoshimoto, “Anatomizing the *Sceptical Chymist*: Robert Boyle and the Secret of His Early Sources on the Growth of Metals,” *Early Science and Medicine*, 10 (2005), 453-477, at 455-456. [↑](#footnote-ref-43)
43. Giovanni Boccaccio reports the growth of lead in abandoned mines in Etruria; see Giovanni Boccaccio de Certaldo, *De montibus, sylvis, fontibus* [*…*](Venice, 1473), without pagination [f. 9 r] = *Tutte le opere di Giovanni Boccaccio* (Milan, 1998), v. VII-VIII, t. 2, 1848. Daniel Sennert, *De chymicorum cum Aristotelicis et Galenicis consensu et dissensu* (Wittenberg, 1619), cap. IX, 234, later quotes Gerhard with regard to the growth of metals in abandoned mines, but he overtly denies that lead constitutes an exception. On Sennert’s texts, see Hirai and Yoshimoto, “Anatomizing the Sceptical Chymist.” [↑](#footnote-ref-44)
44. Gerhard, *Decas*, 22-23: “*universale ex chymicorum & metallariorum observatione Theorema constituit, quod proprium et peculiare sit plumbo inter metalla semper augmentari, et hoc sub divo magis et aëre, quam sub terra”* (italics in the original). Gerhard takes this statement from a passage in Thomas de Cantimpré, *Liber de rerum natura,* a medieval compendium anonymous until the eighteenth century; see Cynthia M. Pyle, “The Art and Science of Renaissance Natural History: Thomas of Cantimpré, Pier Candido Decembrio, Conrad Gessner, and Teodoro Ghisi in Vatican Library Ms. Urb. Lat 276,” *Viator*, 17(1996), 265-321. Cantimpré’s reference to lead was later quoted in the famous natural history of Vincent de Beauvais, *Speculum naturale* (Cologne, 1494),liber VII, cap. Xl, fol. 74v and Thomas Cantimpratensis, *Liber de natura rerum*, ed. by H. Boese, vol. 1 (Berlin, 1973), book XV, cap. VII, 377. [↑](#footnote-ref-45)
45. Gerhard, *Decas*, 22-23. Gerhard misquotes *De subtilitate*: “Cum vero aceto [*plumbo* in the original] in cerussam vertitur aut uritur, tertia decima parte sui ponderis augetur, ut refert Cardanus De subtilitate, liber V.” Perhaps the misquote originates from the fact that *cerussa* was usually manufactured by steeping lead shavings in vinegar (Latin *acetum*); see Pliny *Natural History*, XXXIV, liv, 175 and 176, and Falloppio, *De metallis*, 392-393; see also Susan Stewart, “Gleaming and Deadly White: Toxic Cosmetics in the Roman World in Peter Wexler,” in Philip Wexler, ed., [*History of Toxicology and Environmental Health*](https://www.sciencedirect.com/science/book/9780128015063), Toxicology in Antiquity II (Amsterdam, 2015), 80-84. [↑](#footnote-ref-46)
46. Gerhard, *Decas,* 26. Gerhard’s free quotation of pseudo-Geber corresponds to the following passage of the modern edition by Newman: “Non est autem in actu quod magis in substantia sibi [sole] conveniat quam iupiter et luna, in pondere autem et surditate et putrescibilitate saturnus.” (Book 1 <30> li 31-34, p. 339); English translation: “There is none which agrees more [with Sun] in weight, muteness, and putrefiability than Saturn,” ibid., 672. Cf. another passage where pseudo-Geber opposes the view of “some fools” who say that “lead much approaches gold in its nature” (Book 1 <32> li. 21-27 pp. 342-343; English trans., ibid., 674). [↑](#footnote-ref-47)
47. Gerhard, *Decas,* 24. [↑](#footnote-ref-48)
48. Ibid., 25. [↑](#footnote-ref-49)
49. For another reception of Galen from an experimental approach, see Francis Bacon, *Sylva sylvarum*, in *The Works of Francis Bacon*, eds. James Spedding, Robert Leslie Ellis, and Douglas Denon Heath, vol. 2 (London, 1859), “Experiment Solitary, touching the Growth, or Multiplying of Metals” # 797, 598-599; and *Historia densi et rari,* in Graham Rees, ed., *The Oxford Francis Bacon*, vol. 13 (London, 2000), 55-56; 166. [↑](#footnote-ref-50)
50. Julius Caesar Scaliger, *Exotericarum exercitationum liber quintus decimus, de subtilitate, ad Hieronymum Cardanum* (Paris, 1557)*,* Exc. CI, # 18, fol. 152v; Ex. CIV, # 17, fol. 164v. On Scaliger’s opposition to Cardano’s hylozoism, see Kuni Sakamoto, *Julius Caesar Scaliger, Renaissance Reformer of Aristotelianism: A Study of His Exotericae Exercitationes* (Leiden–Boston, MA, 2016), ch. 2. [↑](#footnote-ref-51)
51. Jean Bodin, *Universae Naturae Theatrum* (Frankfurt, 1587)*,* 263-264. [↑](#footnote-ref-52)
52. Bodin, *Universae Naturae Theatrum*, 259-261. See Ann Blair, *The Theater of Nature:* *Jean Bodin and Renaissance Science* (Princeton, NJ, 1997), 100-101; Cesare Pastorino, “Weighing Experience: Experimental Histories and Francis Bacon’s Quantitative Program,” Early Science and Medicine, 16 (2011), 542–570; and the papers by Clucas and Pastorino in this issue. [↑](#footnote-ref-53)
53. A similar view is to be found in Francis Bacon; see Silvia Manzo, *Entre el atomismo y la alquimia. La teoría de la materia de Francis Bacon* (Buenos Aires, 2006), 212-213. [↑](#footnote-ref-54)
54. *Essays de Jean Rey, Docteur en Medecine* […] *Nouvelle Edition* [...] *Avec des Notes par* M. *Gobet* (Paris, 1777). In the text, I will quote in brackets the essay and page numbers from the English translation, *Essays of Jean Rey, Doctor of Medicine: On an Enquiry into the Cause Wherefore Tin and Lead Increase in Weight on Calcination* (Edinburgh, 1904). On Rey, see Douglas McKie, “On Five Hitherto Unrecorded Copies of Jean Rey’s Essays,” *Ambix*, 6 (1958), 136-139; and Partington, *A History of Chemistry*, II, 631-636. [↑](#footnote-ref-55)
55. Antonio Clericuzio, *Elements, Principles and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century* (Dordrecht, 2000), 49-50. [↑](#footnote-ref-56)
56. McKie, “On Five,” 136-137. For that reason, Lavoisier was accused of plagiarism; see Marco Beretta, “The Historiography of Chemistry in the Eighteenth Century: A Preliminary Survey and Bibliography,” *Ambix*, 39 (1992), 1-10, at 5-6. [↑](#footnote-ref-57)
57. Clericuzio, *Elements*, 51-53. [↑](#footnote-ref-58)
58. Douglas McKie, “Some Early Work on Combustion, Respiration and Calcination,” *Ambix* 1 (1938), 143-165, at 144-146; Robert P. Multhauf, “On the Use of the Balance in Chemistry,” *Proceedings of the American Philosophical Society*, 106 (1962), 210-218, at 210. For a study of the positivist and Whig interpretation of the “chemical revolution,” see John G. McEvoy, “Positivism, Whiggism, and the Chemical Revolution: A Study in the Historiography of Chemistry,” *History of Science*, 35 (1997), 1-33. [↑](#footnote-ref-59)
59. Rey, *Essays*, VI, 14. I have considerably modified the English translation. Cf. Rey, *Essays de Jean Rey,* 23: “l’examen du poids de quelque chose se fait en deux façons; sçauoir, ou à la raison, ou à la balance.” [↑](#footnote-ref-60)
60. On Mersenne’s approach to relation between reason and the senses in scientific experience, see Peter Dear, *Discipline and Experience. The Mathematical Way of the Scientific Revolution* (Chicago, 1995), 132-136. [↑](#footnote-ref-61)
61. Rey, *Essays de Jean Rey,* 29: “l’examen des pesanteurs qui se fait à la balance, differe grandement de celuy qui se fait à la raison. Cettui-ci n’est vsité que par l’homme judicieux; celuy-là le plus rustaud le practique. Cettuy-ci est tousiours iuste; celuy-là, n’est gueres sans deception. Cettui-ci n’est point attaché à quelque circonstance de lieu; celuy-là, ne s'exerce communément que dans l'air, & par fois dans l'eau, mais auec malaisance.” [↑](#footnote-ref-62)
62. Rey, *Essays*, XVI, 37. Cf. Rey, *Essays de Jean Rey,* 68: “A cette cause m’a-il fallu faire voir que l’air auoit de la pesanteur: qu’elle se cognoissoit par autre examen que ce’luy de la balance: & qu’à icelle mesme vne portion, prealablement alterée & espessie, pouuoit manifester son poids.”  [↑](#footnote-ref-63)
63. Rey, *Essays*, VI, 14. Cf. Rey, *Essays de Jean Rey,* 23-24: “Auec les armes de cette raison i'entre hardiment en la lice pour combattre cet erreur, & soustiens que la pesanteur est tellement joincte a la premiere matiere des elemens, qu’elle n’en peut estre deprinse. Le poids que chaque portion d’icelle print au berceau, elle le portera iusques à son cercueil. En quelque lieu, soubs quelle forme, à quel volume qu'elle, soit reduitte, tousiours un mesme poids.” [↑](#footnote-ref-64)
64. James R. Partington, “ Joan Baptista van Helmont, ” *Annals of Science*, 1 (1936), 359-384, at 368; Guerlac, *Lavoisier – The Crucial Year,* xiv-xv. [↑](#footnote-ref-65)
65. William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago, IL, 2005), 68-71. [↑](#footnote-ref-66)
66. On the *a priori* origin of the principle of conservation of matter, see Émile Meyerson, *Identity and Reality* (London, 1930), ch. 4 (on Rey, see p. 172-173); first French ed. 1903. Meyerson’s interpretation was first published more than a century ago; however, his general claim is still considered valid by newer studies; see, for instance, Roberto de Andrade Martins, “Émile Meyerson and Mass Conservation in Chemical Reactions: A priori Expectations versus Experimental Tests,” *Foundations of Chemistry*, 21 (2019), 109-124. [↑](#footnote-ref-67)
67. Rey mentions Andreas Libavius’ treatment of the question; see Andreas Libavius, *Syntagma, Arcana Chymica* (Frankfurt, 1611), liber VI, cap. X, p. 225. Libavius rejects Cesalpino’s explanation, but as Rey points out (*Essays*, XIX-XX), he does not provide an alternative explanation; see Partington, *A History of Chemistry,* II, 256. [↑](#footnote-ref-68)
68. It has been suggested that Rey is alluding to Theodore Deschamps, apothecary and physician from Bergerac, who, like Brun and Rey, corresponded with Mersenne; see Partington, *A History of Chemistry,* II, 635 and Clericuzio, *Elements,* 51-55. [↑](#footnote-ref-69)
69. Hamerus Poppius, *Basylica antimonii* (Frankfurt, 1618), cap. III, 21-22. To some extent, this recalls the Baconian variation of experimental patterns. On variation in Bacon’s experimental methodology, see Dana Jalobeanu, “Disciplining Experience: Francis Bacon’s Experimental Series and the Art of Experimenting,” *Perspectives on Science*, 24 (2016), 324-342. [↑](#footnote-ref-70)
70. Rey, *Essays de Jean Rey,* 101: “mais quand tout en est affublè, elle n'en sçauroit prendre dauantage.” [↑](#footnote-ref-71)
71. Ibid., 100: “La nature par son inscrutable sagesse, s'est ici mise des barres qu’elle ne franchit iamais.” [↑](#footnote-ref-72)