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SOMMARIO

TRANSMUTING TINCTURES. WATER OF SULPHUR, QUICKLIME, AND 'WASHES' IN GRAECO-EGYPTIAN ALCHEMY

Matteo Martelli

Abstract · This paper explores the technology of what Graeco-Egyptian alchemists called 'water of sulphur' or 'divine water,' one of the key colouring agents at the basis of their attempts to turn metals into gold or silver. Early conceptions of metallic transmutation arose from the lived experiences of the practitioners who tested the properties of this liquid compound in their workshops and interpreted, at the same time, its written formulas. In order to better understand the alchemy of dyeing waters, the textual analysis of Greek, Syriac, and Arabic sources is combined with experimental replications of the procedures described in these writings.

Keywords · Alchemy, Dyes, Quicklime, Divine Water, Gold-making, Silver-making, Zosimus of Panopolis, Pseudo-Democritus.

Setting the scene

The quest for metallic transmutation hallmarked alchemical traditions across distant civilisations, from Hellenistic Egypt to China. To explain the emergence of transmutation theories in Graeco-Egyptian alchemy, scholars have long pointed to the legacy of Platonic and Aristotelian natural philosophy. In the 30s, Arthur John Hopkins described alchemy as "a child" of Greek philosophy, which the Alexandrians successfully applied to the realms of metals: in a nutshell, this craft was «Aristotelian philosophy put to practice».[1] Twenty years later, André-Jean Festugière insisted on the combination of Egyptian metalworking with a mélange of Platonic and Aristotelian philosophy

matteo.martelli@unibo.it, University of Bologna, Italy.

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[1] Hopkins 1934, p. 57 (see also pp. 13-31). On some limitations and pitfalls of this study, see the review by Wilson 1935. Hopkins, for instance, did not consider the Aristotelian distinction between mechanical combination (*sunthesis*) and 'chemical' mixture (*mixis*): on this point, see Viano 2015b (with earlier bibliography).

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(with a pinch of «mystical reveries»).[1] Plato and Aristotle provided the authors of alchemical treatises with the necessary theoretical vocabulary to explain the metallic transformations they strove to bring about.[2] Within this philosophical framework, early practitioners conceptualized their attempts to transmute base metals into gold, relying on metallurgical operations that had been devised by generations of craftsmen in their workshops.

By the same token, the sinologist and historian of science Joseph Needham identified ancient Greek alchemy with a kernel of artisanal knowledge interpreted through the lens of Greek natural philosophy. In his monumental work *Science and Civilisation in China*, Needham recognized three main areas of expertise encapsulated in Chinese alchemical writings: *aurifiction* (the imitation of gold), *aurifaction* (the making of gold), and *macrobiotics*, that is, the attempt to produce a universal medicine capable of prolonging life.[3] Although they showed little preoccupation for the prolongation of life in their extant writings,[4] Graeco-Egyptian alchemists clearly embraced the goal of metallic transmutation and described various procedures for turning base metals into silver and gold. Needham framed his interpretation of this transmutational intent by contrasting the techniques of *aurifiction* with the philosophy of *aurifaction*. In his view, Graeco-Egyptian craftsmen – such as blacksmiths, goldsmiths, and metallurgists – practised a wide range of techniques that were meant to make base metals look like gold or silver. Indeed, such craftsmen were capable of producing metallic alloys that simply *resembled* gold or silver,

[1] See Festugière 1950, pp. 218-219: «L'alchimie gréco-égyptienne, d'où ont dérivé toutes les autres, est née de la rencontre d'un fait et d'une doctrine. Le fait est la pratique, traditionnelle en Égypte, des arts de l'orfèvrerie. La doctrine est un mélange de philosophie grecque, empruntée surtout à Platon et à Aristote, et de rêveries mystiques». On this important definition, see, among others, Halleux 1979, pp. 62-63; Viano 2005, pp. 91-95; Martelli 2019, pp. 14-17.

[2] See Cristina Viano's original studies on this subject, in particular, Viano 1996, 2005, 2015a and 2018. Dufault 2015, on the other hand, has questioned the influence of Aristotelian philosophy on the early phases of Graeco-Egyptian alchemy, in particular on the writings of Zosimus of Panopolis and Synesius. On the possible influence of Stoicism on Graeco-Egyptian alchemical writers, see Rinotas 2017.

[3] Needham 1974, pp. 8-12.

[4] Scattered references to 'the medicine of life' (τὸ φάρμακον τῆς ζωῆς), capable of restoring health and resurrecting bodies, are found in the Greek alchemical *Dialogue of the Philosophers and Cleopatra* (ed. Reitzenstein 1919), which was questionably associated to Chinese alchemy by Mahdihassan 1979. The dating of this dialogue, which shows some similarities with the work *Ostanes the Philosopher to Petasius* (see Philonenko 1992), is uncertain: the most recent studies tend to consider it as a Byzantine compilation (see Carlotta 2017).

and they were always aware that their products were *imitations*.[1] Needham contrasted this awareness of craftsmen with the (false) hopes of alchemists, who believed that base metals could be perfected and actually turned into gold (or silver) as good as natural gold (or silver). «This was the conviction of philosophers rather than artisans», Needham states.[2] In his opinion, *aurifactors* belonged to a different social group than craftsmen: they were «educated dilettanti» who based their own *aurifactive* dream on a simplified Peripatetic theory of matter. Indeed, it was in Aristotle that Needham ultimately located the roots of those philosophical concepts from which the very idea of metallic transmutation arose.[3]

As we shall see, a fresh and more nuanced reading of our earliest Graeco-Egyptian sources calls for a revision of this rigid dichotomy, as well as challenging Needham's approach, which tends to downplay the transmutational endeavours of early practitioners. In his interpretation, their work rested on a technology that became meaningless once detached from the workshops of the skilled artisans, who were able to detect simple imitations from real gold. Against this view, I argue that the idea of transmutation is firmly rooted in the materiality of the diverse technologies that were developed by ancient alchemists. Indeed, they mastered a broad array of techniques that provided different models for conceptualizing the colour changes that metals underwent before their eyes. Lived experiences of dyeing, in particular, shaped the mind of ancient practitioners and oriented their reasoning about the properties and behaviour of natural substances: their colour, texture, volatility, solubility, capacity of readily combining with each other and producing durable transformations. Relics of this embodied knowledge are encapsulated in ancient alchemical recipes, which can be properly assessed through sound philological analysis and replications in modern laboratories.[4] Experimental

[1] See, *e.g.*, Needham 1974, p. 10 (italics mine): «*Aurifiction* we define as the *conscious imitation of gold* (and by extension, with suitable variation of nomenclature, silver and other precious substances such as gems and pearls), often with specific intent to deceive […] the proto-chemical artisan must be aware that his product would not stand up to the fundamental test of cupellation. He must therefore know it to be, *in the workshop sense, 'false'*; though the very same processes may be employed by the philosophical proto-chemist to give a result which was considered, in the philosophical sense, genuine».

[2] *Ibidem* (italics mine): «*Aurifaction*, on the other hand, we define as the belief that it is possible to make gold […] indistinguishable from, and as good as (if not better than), natural gold, from other quite different substances, notably the ignoble metals. This was the conviction of philosophers rather than artisans, as we shall see. *The self-deception of the proto-chemical philosopher is essential in this definition*» etc.

[3] Needham 1974, pp. 21-29.

[4] On this methodology, see, *e.g.*, Fors, Principe, Sibum 2016. Lawrence Principe, William Newman, and Jennifer Rampling fruitfully explored many practices of early

replication does not simply help us to investigate whether a single recipe "works", it also opens an invaluable window into the processes that ancient alchemists witnessed in their workshops, and provides an avenue for reconsidering how their lived experiences marked their thinking and writing.

A case in point is the technology of 'the water of sulphur' (ὕδωρ θείου) or 'divine water' (θεῖον ὕδωρ), a liquid mixture that the third-century alchemist Zosimus of Panopolis identified with the transmutational agent *par excellence*.[1] Its different formulas and applications are integral to the body of practical knowledge that underpinned early conceptions of metallic transmutation. Alchemical theories and beliefs did not exist in a vacuum, but were moulded by practices that ancient alchemists founded recorded in the foundational writings of their art. Reading and experimenting guided their hands and their mind, as Zosimus' practical exegesis of earlier alchemical recipes will exemplify.[2]

Dye baths and water(s) of sulphur

The dry sands of Egypt have preserved two invaluable witnesses to the variety of dyeing techniques that were known in Graeco-Roman Egypt. Two collections of more than two-hundred and fifty recipes in total, the so-called Leiden and Stockholm papyri (3rd-4th century AD),[3] transmit detailed instructions on different methods for colouring metals, stones, and wool. The same areas of expertise are covered by the earliest extant work of the Greek alchemical corpus, Pseudo-Democritus' four books on dyeing (1st century AD).[4] This overlap is not coincidental. As scholars have long noted, the papyri often include recipes that also appear in the works of contemporary and later alchemists, including: the medieval *Mappae clavicula*, which draws on a lost treatise by Zosimus;[5] the

modern alchemists in laboratory. For Graeco-Egyptian and Arabic alchemy, see, *e.g.*, Marchini *et alii* 2022; Moureau, Thomas 2016; Principe 2018.

[1] Ancient alchemists played with two almost identical terms, the noun θεῖον, 'sulphur' and the adjective θεῖος, 'divine'. See Viano 1997; Martelli 2009.

[2] Jennifer Rampling coined the expression 'practical exegesis' (Rampling 2014) to meaningfully describe: «the reinvention of earlier practices through successive cycles of testing and reinterpreting written sources» (Rampling 2020, p. 354; see also pp. 97-99).

[3] Hereafter *P.Leid.* (the Leiden papyrus) and *P.Holm.* (the Stockholm papyrus). Critical edition and French translation in Halleux 1981.

[4] The fourth-century alchemist Synesius described these books as βαφικαὶ βίβλοι, «books on dyeing»; See Martelli 2013, pp. 122-123.

[5] Halleux 1981 refers to many recipes of the *Mappae clavicula* in his commentary on various techniques described in the Leiden and Stockholm papyri; see also Caprotti 2013. On the Greek origin of the *Mappae clavicula*, see Halleux, Meyvaert 1987.

Syriac alchemical books preserved under the name of Graeco-Egyptian authors (Democritus and Zosimus first of all);[1] and the recipe collection *Deep Tincture of Stones, Emeralds, Rubies, and Jacinths from the Book taken out from the Sancta Sanctorum of the Temples* transmitted by Byzantine alchemical manuscripts.[2]

Recipes are procedural texts that mainly record sequences of actions and lists of ingredients. Simple verbs like 'to triturate' (τρίβειν), 'to melt' (χωνεύειν), or 'to boil' (ἕψειν) encapsulate habits of the hand developed by practitioners through countless repetitions of the same actions. Some recipes also include claims on the nature of the produced substances. In this respect, rather than testifying to a shared awareness of producing imitations – the awareness of *aurifictive* practitioners according to Needham's distinction[3] – the Leiden and Stockholm papyri echo a plurality of voices reasoning about the blurred distinction between natural and artificial goods (gold, silver, gemstones, pearls, and purple).[4] A case in point are the recipes for gemstones and pearls in the Stockholm papyrus. For instance, a recipe for the making of emeralds (*P.Holm.* 17) describes the final product as «an emerald similar to the natural one» (σμάραγδον ὅμοιον τῇ φύσει), while the following recipe for the making of pearls (*P.Holm.* 18) explains how to produce a pearl that is better than the natural ones (ὑπὲρ τὸν φυσικόν).[5] Scattered in the recipes we also find remarks that allow us to glimpse into the mind of practitioners. They noted that the 'power' (δύναμις) of pure verdigris materializes in the green vapours that arise when verdigris is diluted in vinegar and heated (*P.Holm.* 17).[6] Before being 'quenched' into water, quicklime is described as holding an

[1] See Halleux 1981, *passim* (single explanatory notes on various recipes of the papyri); Baroni 2013.

[2] Hereafter *Deep Tincture of Stones*; see Lagercrantz 1913, pp. 99-103; Halleux 1981, pp. 74-75 (and *passim*). The Byzantine alchemical recipe-book, transmitted by MSS *Parisini* gr. 2325 (ff. 160v-173v) and 2327 (ff. 147r-155v) is edited by M. Berthelot and C-É. Ruelle in the second volume of their *Collection des anciens alchimistes grecs* (hereafter *CAAG*), pp. 350-364.

[3] See Needham 1974, p. 18: «the papyri were the work of technicians who intended to deceive, while the writings of the Corpus (alchemicum) were set down by chemical philosophers who believed that gold in some sense had really been produced in their operations».

[4] See Martelli 2019, pp. 11-14 and especially Blanco Cesteros 2023 (forthcoming), who questions Needham's distinction on the basis of a fresh analysis of the recipes in the Leiden and Stockholm papyri.

[5] See Halleux 1981, pp. 115-116. On recipes for gemstones, see also the article by Chiara Ballestrazzi in «Technai» 14 (2023).

[6] See Halleux 1981, pp. 115-116. When these green vapours stain the lids of the dye vats, the procedure is successfully accomplished: see *P.Holm.* 71, 88 (Halleux 1981, pp. 129, 132-133).

invisible fire inside (*P.Holm.* 61).[1] Quartz is said to have a particular 'kinship' (συγγένεια) with beryl: because of their 'likeness' (ὁμοιότης), the first can be easily turned into the second (*P.Holm.* 63).[2]

Practitioners strove to imbue transparent quartz with liquid tinctures. Through preliminary treatments they wanted the dye to soak into the stones, thus producing a durable colour. The treatment called *araiosis* (ἀραίωσις, lit. 'rarefaction') was meant to make stones porous so that they could readily absorb the dyes. Dyes, in contrast, were to be fixed by means of styptic drugs.[3] Some methods were tailored to specific kinds of stones, while others were used across different crafts.[4] Indeed, the same technology designed to dye textiles was applied to minerals. In particular, the Leiden and Stockholm papyri include many wool dyeing recipes, which instruct how to produce different shades of purple by using substitutes of the expensive Tyrian dyestuff. Likewise, gemstones were dyed blue, red or green. In both areas of expertise, the same preoccupations emerge: how deep can drugs penetrate bodies with different texture and degrees of stiffness? Can these bodies absorb the tincture diluted in the dye baths? How stable are the produced colours?

The use of dye baths was also applied to metals. Various recipes of the Leiden papyrus describe how to ground different minerals (or plants) in water (or other liquids), thus producing dye baths for metals.[5] One of these recipes (*P.Leid.* 87) deals with the preparation of the 'divine water' or 'water of sulphur':

Ὕδατος θείου εὕρεσις· ἀσβέστου δραχμὴν μίαν, θείου τὸ ἴσον προλελειωμένον συνθεὶς ἐν ἀγγείῳ ἔχε ὄξος δριμὺ ἢ οὔρου ἀφθόρου. Ὑπόκαιε ἕως τὸ ὑγρὸν τὸ ἐπιπεμφθὲν ὡς αἷμα φανῇ, ὅπερ ἀποσειρώσας διὰ τὴν τρυγίαν καθαρίως χρῶ.[6]

The discovery of the water of sulphur (or divine water): mix one drachma of quicklime and the same quantity of sulphur previously ground in a vessel. Add strong vinegar or the urine of a youth. Heat from underneath until the supernatant liquid looks like blood; filter to remove sediment and employ it neat.

[1] See Halleux 1981, p. 126. On this point, see also below, pp. 132-133.

[2] See Halleux 1981, p. 127.

[3] Halleux 1981, pp. 47-48; Lippmann 1919, pp. 15-16.

[4] See, for instance, *P.Holm.* 92 (Halleux 1981, p. 133), which describes a mordanting bath that could be used for quartz and leather.

[5] See, *e.g.*, *P.Leid.* 65 (Halleux 1981, p. 99): Ἀσήμου καταβαφή. Κινναβάρεως μέ(ρος) α´, στυπτηρίας σχιστῆς μέρος α´, κιμωλίας γῆς μέ(ρος) α´, θαλάσσῃ ἀπόδευσον καὶ χρῶ, «Colouring silver in depth. Cinnabar, one part, scissile alum, one part, Cimolian earth, one part, dilute in sea water and use» (similar to *P.Leid.* 79, Halleux 1981, p. 102).

[6] Halleux 1981, p. 104.

The recipe does not explain how to use this 'water', and we cannot exclude that it had multiple applications. Its use as a styptic drug for quartz is recorded in the Stockholm papyrus,[1] sometimes with the addition of alum, as also confirmed by the recipe-book *Deep Tincture of Stones* mentioned above.[2] In *P.Leid.* 88, the water of sulphur is mixed with various ingredients (orpiment, pyrite, salt, etc.) and used to treat silver, which was previously mixed with mercury and a part of gold.[3] A similar procedure appears in a late Byzantine recipe-book transmitted by the MS *Holkhamicus* gr. 109 (15th century). A recipe for turning silver into gold includes the following formula for the water of sulphur: yellow sulphur, one pound; quicklime, one and a half pound; the two substances are boiled in rainwater and filtered. Eventually, other ingredients are added, and silver is dipped into the liquid mixture.[4]

Zosimus confirms that silver was exposed to the action of 'divine water': it was dipped into this hot solution and thus transformed into gold.[5] The same application is also reported in the later Arabo-Latin and Byzantine traditions, for instance in the Byzantine alchemical handbook known as *The Anonymous of Zuretti*.[6] The treatise includes a recipe for the water of sulphur, which instructs one to mix one part of sulphur and one part of salt ammoniac (ἅλς ἀμμανιακός) or natron (νίτρον) – both basic salts that can replace quicklime in the solution. The mixture is then di-

[1] *P.Holm.* 51 (Halleux 1981, p. 124): Κρυστάλλου στῦψις. Πρὸ τοῦ βάλλειν αὐτὸν βάπτεσθαι. ἀσβέστου μέ(ρος) α΄, θείου ἀπύρου μέ(ρος) α΄ τρίψας πρόσμειξον ὄξος καὶ θὲς τοὺς λίθους, «*Stupsis* for crystal. Before one puts it in for colouring. Grind 1 part of quicklime and 1 part of natural sulphur. Add vinegar and put the stones in it» (Caley 1927, p. 987).

[2] Alum is added to sulphur and quicklime according to the procedures described in *P.Holm.* 40, 68 (Halleux 1981, pp. 122, 128) and in *Deep Tincture of Stones*, 46 (*CAAG* II 363,9-11).

[3] Halleux 1981, p. 105.

[4] Recipe H8 in Colinet 2010, pp. 24-25. The recipe lists cinnabar, burnt copper, vitriol, realgar, and mercury among the ingredients that are added to the water of sulphur.

[5] Zosimus, *Authentic Memoirs*, IV 90-91 (Mertens 1995, p. 20): τοῦτο τοῦ ὕδατος τοῦ θείου τοῦ ἀθίκτου ἔχει δύναμιν καὶ φύσιν. Ἐὰν ζεστῷ τῷ ὕδατι ἐπιβάψῃς ἄργυρον, ἔσται ἀνεξάλειπτον, «this (water) has the power and nature of the water of untouched sulphur. If you dip silver in this boiling water, it (i.e., its colour) will become indelible». Various dyeing liquids were referred to as 'divine water' or 'water of sulphur' by Zosimus. It was also produced through multiple distillations of eggs, as explained in *Authentic Memoirs*, IX (Mertens 1995, pp. 30-33): here the distillate is first coagulated and then laid on silver, which is thus turned into gold (p. 33, ll. 71-73). Silver is treated with various kinds of divine water also in Zosimus' *Chapters to Eusebeia* (*CAAG* II 147,19-21; 150,1-3; 167,6-8).

[6] The earliest witness to this anonymous alchemical handbook is MS *Vaticanus* gr. 1134 (14th century), which was first discovered and edited by Alessandro Olivieri (whence the title of *Anonymous of Zuretti*). Critical edition and French translation in Colinet 2002.

luted in water, boiled and filtered to produce a red water (ὕδωρ ἐρυθρόν). The recipe then reads: ὁσάκις ἂν χρίσῃς ἐκ τούτου τοῦ ὕδατος νόμισμα λευκὸν ἢ δακτύλιον, χρύσεον χρῶμα ἐνφαίνει κτλ., «if you smear this water on a white (*i.e.*, silver) coin or ring, a golden colour will come into sight» etc.[1] This Byzantine section is based on the recipe *De aqua sulphurea* ('On sulphureous water') from the short Latin *Book of Twelve Waters*, which likely draws on (still unidentified) Arabic sources.[2] Interestingly, the Latin recipe exhibits variations in manuscripts with respect to the ratios of sulphur to basic salt: while some versions report a one-to-one ratio, other prescribes to use two parts of sulphur to produce the red solution.[3] The colour of the 'divine water' was perhaps interpreted as a sign of its dyeing capacity; the alchemically produced gold, indeed, was sometimes described as red and the *chrusopeia* conceptualized as the emergence of the blood hidden in the body of silver.[4]

Lawrence Principe followed the instructions of the Leiden papyrus and replicated the recipe in his laboratory in Baltimore. Principe found that urine and vinegar produce a red liquid (Fig. 1) with astonishing dyeing capacity, such that if a silver coin is dipped into this hot mixture for a few seconds, it becomes golden.[5] With Principe's assistance, a team of chemists and I replicated the same procedure in the laboratory of the Chemistry Department "G. Ciamician" in Bologna.[6] We mixed equal amount of quicklime and sulphur in vinegar: the 'solution,' which is yellow at the beginning of the procedure (Fig. 2), turns darker while it is gently heated (Fig. 2.1). After about an hour, the hot liquid was filtered, resulting in a red "water' that distinctively smelled like rotten eggs. We also experimented with different proportions between the ingredients. For instance, quicklime and sulphur were mixed in water with a one to

[1] Recipe 51.2 in Colinet 2002, pp. 85-86. See also recipe 49.3 (p. 84).

[2] On the possible Arabic origin of the *Liber duodecim aquarum*, see Ruska 1939, pp. 67-81; Colinet 2002, pp. lv-lvi. For instance, the Arabic compilation *The Treasure of Alexander* (*Ḏaḫīrat al-Iskandar*) includes a long section on dyeing alchemical waters (Raggetti 2022), which, however, does not overlap with the Latin treatise.

[3] One version reads: *Aqua sulphurea. Crocei sulphuris partem unam, salis nitri partem unam* etc. (ed. Colinet 2002, p. 85; MSS: Palermo Aq 10; Paris, BNF lat. 6514 and 7156); another version reads: *De aqua sulphurea. Crocei sulphuris partem 2, salis nitri partem 1* (ed. Ruska 1939, p. 70; MSS: London, Sloane 1754; Munich, CLM 405).

[4] See Olympiodorus' commentary on Zosimus' lost work *On Action* (*CAAG* ii 92,14 f.): ἡ ψυχή… ἐπιδεικνύει ἐν τῷ ἀργύρῳ τὸ πυρροῦν αἷμα, τουτέστιν τὸν χρυσόν, «in silver (the dyeing) soul… shows the red blood, that is, gold» (see also *CAAG* ii 96,20-21).

[5] Principe 2013, pp. 10-11 and plate 1.

[6] I warmly thank Lawrence Principe and the team of chemists working on the replications of alchemical recipes in Bologna: Lucia Maini, Marianna Marchini, and Giacomo Montanari. The experimental data presented in this paper rest on their laboratory work.

two ratio.[1] The solution was heated for about two hours at 100-150°C and filtered, resulting in a red solution (Fig. 3): when dipped into this hot liquid, a well cleaned silver coin was dyed golden (Fig. 3.1).

Fig. 1. Water of sulphur (quicklime to sulphur ratio: 1:1; urine or vinegar). L. Principe's laboratory, Baltimore. Courtesy of L. Principe.

As the comparison with the later tradition confirms, the Leiden papyrus is not an isolated source reporting the formula for the water of sulphur. Its heading is nevertheless remarkable, since the recipe is presented as *the discovery* or *invention* (εὕρεσις) of our water. Such a remark is not introduced for any other procedure recorded in the two papyri, so that one might wonder whether the recipe captures an important technical innovation. No inventor is however mentioned, and nothing prevents the recipe from being copied from an earlier source. Already in the first century AD, Pseudo-Democritus listed the water of sulphur prepared with quicklime in his catalogue of substances for the making of gold.[2] He also recorded 'the water of quicklime' (ὕδωρ ἀσβέστου) and 'the water of untouched sulphur' (ὕδωρ θείου ἀθίκτου) in another catalogue of liquid dyes referred to as *zomoi* (ζωμοί), 'sauces, washes'.[3] Interestingly, Zosimus of Panopolis lists many of these *zo-*

[1] We used six grams of sulphur and three grams of quicklime. Modern chemical literature still reports «a method for preparing calcium polysulfide solution by reacting calcium oxide with sulfur in water at 100°C and mass ratio of the components S : CaO : H2O = 10 : 5 : 85» (Levchenko *et alii* 2015, p. 1043). A similar method to produce 'solfuro di calce liquido' ('liquid calcium sulphide') was already reported by the Italian chemist Giuseppe Orosi (1816-1875): quicklime, 14 parts; sulphur, 36 parts; water, 150 parts; they are boiled for 1 hour (by adding water if it evaporates). See Orosi 1849, p. 892.

[2] See Pseudo-Democritus, *Catalogues*, 1 (Martelli 2013, p. 116, ll. 7-8).

[3] See Pseudo-Democritus, *Catalogues*, 2 (Martelli 2013, pp. 116-119). Interestingly, the term ζωμός is also recorded in a recipe of the Stockholm papyrus (*P.Holm.* 15, Halleux 1981, p. 115): Σαπφείρου βαφή. Τὸ δὲ σαπφείριον προβάπτεται χολῇ χελώνης καὶ μεταβάλλεται εἰς τὸν ζωμὸν τοῦ ἀμεθύστου ἐπὶ τὰς αὐτὰς ἡμέρας τὰ λοιπά, «Dyeing of lapis lazuli. The lapis lazuli employed is first dipped in the bile of a tortoise and then placed in the wash (*zomos*, i.e., dye bath) for amethyst for just as many days as for this and so forth» (transl. by Caley 1927, p. 983, slightly modified).

Fig. 2. Initial boiling of the water of sulphur (quicklime to sulphur ratio: 1:1; vinegar). Laboratory of the Chemistry Department, Bologna. Picture by M. Marchini.

Fig. 2.1. Water of sulphur gently boiled for 30 minutes (quicklime to sulphur ratio: 1:1; vinegar). Laboratory of the Chemistry Department, Bologna. Picture by M. Marchini.

moi as kinds of divine water in various sections of his work.[1] One of these catalogues is also preserved in Syriac translation and opens a section of Zosimus' ninth book explicitly devoted to the water of sulphur (*miā d-kebrītā* in Syriac). First, he distinguishes white and yellow waters which are used in every alchemical operation (such as washing, diluting, and dyeing). Then he continues by reporting a recipe for the water of sulphur, which shows similarities with the Leiden papyrus formula.[2] Unlike the papyrus, however, Zosimus does not present this water as a fresh discovery, but as something already famous and widely appreciated at his time (MS Mm. 6.29, ff. 65v-66r):

ܡܝܐ ܕܟܒܪܝܬܐ ܐܬܥܒܕ ܒܫܘܠܦܐ ܐܝܟ ܡܝܐ ܕܚܠܒܐ ܐܝܟ ܕܐܬܥܒܕ ܒܫܘܠܦܐ ܡܝܐ ܕܚܠܒܐ ܐܝܟ ܕܐܬܥܒܕ ܒܫܘܠܦܐ ܡܝܐ ܕܚܠܒܐ ܐܝܟ ܕܐܬܥܒܕ ܒܫܘܠܦܐ ܡܝܐ ܕܚܠܒܐ ܐܝܟ ܕܐܬܥܒܕ ܒܫܘܠܦܐ ܡܝܐ ܕܚܠܒܐ ܐܝܟ ܕܐܬܥܒܕ ܒܫܘܠܦܐ

[1] See Mertens 1995, p. 147.

[2] This section on the water of sulphur is transmitted by Cambridge University Library, MS Mm. 6.29 (15th century), ff. 64r-68r. The text is unedited, but a partial French translation is available in Berthelot, Duval 1893, pp. 250-253. This section partially overlaps with the ninth alchemical book included in two manuscripts kept at the British Library, Egerton 709 and Oriental 1593. See Berthelot, Duval 1893, pp. 48-50 (Syriac text) and 87-90 (translation).

Fig. 3. Filtered water of sulphur (quicklime to sulphur ratio: 1:2; water). Laboratory of the Chemistry Department, Bologna. Picture by M. Marchini.

Fig. 3.1. Colouring of silver coins dipped into the water of sulphur (quicklime to sulphur ratio: 1:2; water). Laboratory of the Chemistry Department, Bologna. Picture by M. Marchini.

ܠܥܠ ܘܟܣܐ ܘܫܘܥ ܒܛܝܢܐ. ܘܫܒܘܩ ܥܕܡܐ ܕܢܝܒܫ ܘܟܕ ܩܪܝܪܐ ܫܓܘܫ ܫܠܝܡܐܝܬ.
ܘܣܝܡ ܥܠ ܢܘܪܐ [66r] ܬܘܩܕܬܐ ܙܒܢܐ ܣܓܝܐܐ. ܐܢ ܕܝܢ ܣܢܝܩܐ ܥܠ ܡ̈ܝܐ ܫ̈ܚܝܢܐ.
ܐܪܡܐ ܒܗ ܘܫܒܘܩ ܫܟܝܢ. ܘܗܕܝܢ ܨܦܝ ܘܫܒܘܩ. ܘܡܫܟܚܬ ܕܛܐܦ ܐܝܟ ܚܡܪܐ.
ܥܠ ܗܘ ܕܝܢ ܫܟܢܐ ܕܐܝܬ ܒܩܕܪܐ ܐܪܡܐ ܡ̈ܝܐ ܫ̈ܚܝܢܐ ܘܟܣܐ ܘܒܫܠ. ܘܬܘܒ
ܫܚܘܩ ܘܫܒܘܩ ܦܐܪ ܘܐܫܘܕ ܫ̈ܟܢܐ ܕܡܢ ܩܕܪܐ. ܘܐܪܡܐ ܐܢܘܢ ܠܡ̈ܝܐ ܘܒܫܠ ܒܗ
ܒܕܡܘܬܐ. ܘܨܦܝ. ܘܡܫܟܚܬ ܠܗܘܢ ܠܡ̈ܝܐ ܕܛܦܝܢ ܒܕܡܘܬ ܕܡܐ. ܐ̈ܢܫܝܢ ܕܝܢ ܒܬܘܩܢܐ
ܗܢܐ ܬ̈ܝܢܐ ܕܫܒ̈ܪܐ ܪܡܝܢ ܚܠܦ ܡ̈ܝܐ. ܘܐܚܪ̈ܢܐ ܚܠܐ. ܘܐܚܪ̈ܢܐ ܡ̈ܝ ܩܛܡܐ ܕܩܝܣܐ
ܕܠܢ ܐܝܟ ܕܬܘܩܢܐ ܕܥܒܕܗܘܢ. ܘܐܚܪ̈ܢܐ ܟܕ. ܒܬܪ ܕܐܬܬܩܢ ܒܚܕ ܡܢ ܡ̈ܐܢܐ.
ܪܡܝܢ ܠܗ. ܗܢܘ ܕܝܢ ܒܒܫܘܬܐ ܐܘ ܒܩܢܕܝܠܐ. ܐܘ ܐܦ ܒܡ̈ܐܢܐ ܐܚܪ̈ܢܐ ܐܝܠܝܢ
ܕܪ̈ܚܡܝܢ.

Now we are going to talk also about another water, the one which is mentioned in other letters. So (this is) the famous water of sulphur, which is praised everywhere. Here it is: quicklime,[1] 2 parts; sulphur,[2] 1 part. Wash a vessel and fill it with water until it overflows; cover (the vessel), seal it with clay and let it dry. When it is cold, stir it well and put over a burning fire for a long time. If hot water is needed, add it and let (the water) rest. Let it settle and put aside: you will find that (the water) has become as red as wine. Add hot water to what is left in the vessel, cover and boil. Then pound it, let it cold down, take what is left out of the vessel, add water and boil in the same way. Filter and you will find the water that has become red like blood. For this preparation, instead of water, someone add urine of youths, others vinegar, others water of ashes (i.e., lye) of our wood, which (is suitable) for the preparation that they make. Others, once (the ingredients) have been prepared, put (the liquid) in one of (these) vessels, namely in a phial, in a lamp or in other vessels that they like.[3]

It is important to realize that Zosimus marked each of his books with a letter of the Greek alphabet, as reported in the Byzantine lexicon *Suda* (10th century)[4] and confirmed by the Greek and Syriac traditions.[5] In what remains of his books, the water of sulphur (or divine water) is indeed ubiquitous. He reports to have explained its composition

[1] The Syriac term *kelšā* is the standard translation for the Greek ἄσβεστος, 'quicklime' (translated both as *al-kils* and as *al-nūra* in Arabic, with the second term also referring to 'slaked lime'); see Käs 2010, vol. 2, pp. 1095-1099 and Goltz 1972, pp. 222-223.

[2] The Syriac term *kebrītā* (see also the Arabic *al-kibrīt*) usually translates the Greek θεῖον, 'sulphur'; see Käs 2010, vol. 2, pp. 917-922 and Goltz 1972, p. 223.

[3] An Arabic version of this recipe is included in the *Tome of Images* (*Muṣḥaf al-ṣuwar*), a dialogue between Zosimus and his pupil Theosebeia, which appears to be a compilation of Zosimus' passages already circulating in Arabic translation: see Hallum 2009. The work is transmitted by a single witness, İstanbul Arkeoloji Müzeleri Kütüphanesi, MS 1574; a facsimile of the MS is available in Abt 2007, and its English translation in Abt, Fuad 2011. The recipe for the water of sulphur is reported at fol. 162v of the Istanbul manuscript; translation in Abt, Fuad 2011, p. 460.

[4] See the entry devoted to Zosimus in *Suda* ζ 168 Adler and Mertens 1995, pp. xcvii-ci.

[5] See Mertens 1995, pp. lxxxix-xci. The Syriac tradition, in particular, transmits twelve books (books 3-5 were epitomized into a single book), six of which are marked by a letter of the alphabet. See Martelli 2014a, pp. 201-203.

(σύνθεσις) in the section of his books entitled *On Composition*, the amount of its components in the section *On Weights*, and the heating method in the section *On Heating*.[1] It remains unclear, however, whether he refers to the preparation described in the Leiden papyrus. In fact, Zosimus explicitly acknowledges to interpret any liquid substance mentioned by earlier authors (especially Pseudo-Democritus) as a reference to the water of sulphur, thus extending this name to a wide set of dyeing liquids produced through different technologies.[2] On the other hand, the Syriac recipe, as already remarked, is very close to the Leiden papyrus. In comparison with the papyrus, Zosimus prescribes to use water rather than urine or vinegar, which are however mentioned at the end of the Syriac text as possible substitutes preferred by other practitioners. He also records a different ratio of quicklime to sulphur: two to one rather than one to one as in the Leiden papyrus. Moreover, before being filtered, the liquid is boiled various times according to Zosimus' directions. A brief reference to a similar method also occurs in a passage preserved in Greek, which is included in Zosimus' short chapter *On Yellowing* (Περὶ ξανθώσεως):

Τὸ δὲ ἀπολελυμένον ὕδωρ θεῖον τὸ δι' ἀσβέστου μέρη δύο, καὶ θείου μέρος ἕν, τὸ ἐν χύτρᾳ ἑψημένον καὶ ἀποσειρούμενον καὶ πάλιν ἑψούμενον, τουτέστι τὸ ὕδωρ τὸ θεῖον, τὸ εἰς ἄμφω χρώματα βαλλόμενον.[3]

The divine water (understood) in a general sense, the one with two parts of quicklime, one part of sulphur, which is boiled in a pot, filtered, and boiled again, that is the divine water, the one which enters (the procedures for) both colours (i.e., for dyeing white and yellow).

Both the Greek and the Syriac texts provide clear instructions, which we could follow in laboratory. Two parts of calcium oxide (quicklime) and one part of powdery sulphur were mixed in water and heated for an hour and a half. After letting the mixture cool down and decanting, we obtained a dark red water (Fig. 4), which was consistent with the description in the Syriac recipe: «it will become as red as wine». The second part of the procedure is less straightforward, since Zosimus prescribes to take out what is left in the vessel, add water, and boil again. The wine-red water was filtered, resulting in an orange-brown solution (Fig. 4.1); then the yellow solid filtrate was put back in the flask and more water added. After heating the solution and decanting it, we obtained an orange-brown liquid (Fig. 4.2) which was filtered according to Zosimus'

[1] Zosimus of Panopolis, *On the Treatment of the Body of Magnesia*, 5 (*CAAG* II 189,15-120,1). Zosimus also refers to his authentic book *On Compositions* (*'al rūkābe*) in the last recipe of the Syriac section on the water of sulphur (MS Mm. 6.29, f. 68r): see Berthelot, Duval 1983, p. 253.

[2] See Martelli 2009, pp. 8-10.

[3] *CAAG* II 208,14-17.

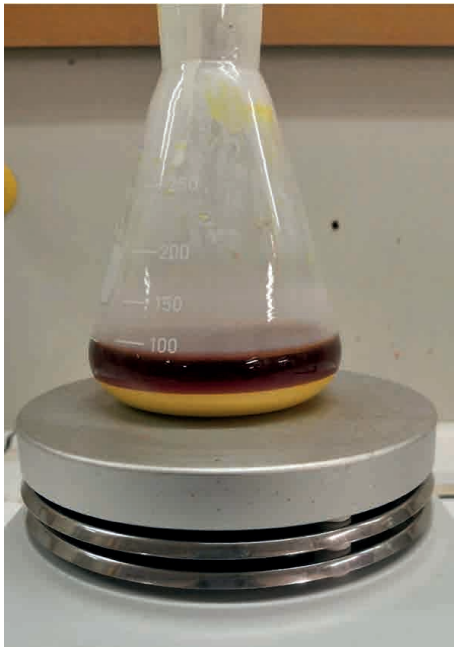

FIG. 4. Water of sulphur gently boiled for 1 hour and a half (quicklime to sulphur ratio: 2:1, water). Laboratory of the Chemistry Department, Bologna. Picture by G. Montanari.

FIG. 4.1. Filtered water of sulphur (quicklime to sulphur ratio: 2:1, water). Laboratory of the Chemistry Department, Bologna. Picture by G. Montanari.

instructions. When heated a little more, the liquid became darker (FIG. 4.3)[1] and was used to treat a clean silver coin that, after being dipped into this liquid for a few seconds, became golden (FIG. 4.4). The colour and sheen of the dyed coin is stable and durable.

In the procedure, after adding calcium oxide to the water solution it is necessary to wait for a few minutes in order to have the conversion into calcium hydroxide (the so-called 'quenched lime'). Indeed, the reaction of calcium hydroxide and sulphur yields polysulphides,[2] soluble in water and producing an orange to red liquid. When they react with silver, a thin layer of silver sulphide appears on the surface of the coin. We must note, at this point, that silver sulphide is black. However, if the silver sul-

[1] We had to heat the filtered liquid a bit more, since the water of sulphur must be warm to react with silver.

[2] See already *CAAG* I 47; BERTHELOT 1893, pp. 85-86; HALLEUX 1981, p. 181.

Fig. 4.2. Filtrate of the water of sulphur boiled again in water (quicklime to sulphur ratio: 2:1, water). Laboratory of the Chemistry Department, Bologna. Picture by G. Montanari.

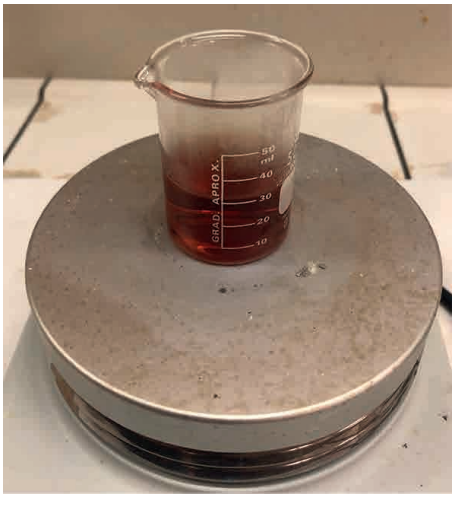

Fig. 4.3. Water of sulphur that, after being boiled twice and filtered, is heated again (quicklime to sulphur ratio: 2:1, water). Laboratory of the Chemistry Department, Bologna. Picture by G. Montanari.

phide layer on the coin is of the order of 10-100 nm, a golden yellow colour is observed, due to the interference of light. Temperature, concentration, and the length of time that silver remains dipped into the solution are crucial factors in the procedure. Indeed, various colour changes arise, as noted by Lawrence Principe: «when a polished piece of silver is dipped into it (*i.e.*, the water of sulphur), the metal quickly becomes tawny, then golden, then coppery, then bronzy, purple, and finally brown».[1] Some samples of the different shades that we observed when replicating the recipes are reported below (Fig. 5-7).

Fig. 4.4. Colouring of a silver coin dipped into the water of sulphur that has been boiled twice and filtered (quicklime to sulphur ratio: 2:1; water). Laboratory of the Chemistry Department, Bologna. Picture by G. Montanari.

[1] Principe 2013, p. 11.

Fig. 5-7. Various shades on coins dipped into the water of sulphur. Laboratory of the Chemistry Department, Bologna. Pictures by M. Marchini.

Penetration and stability of tinctures: the role of quicklime

Many colours – as well as unpleasant scents – were experienced in ancient workshops, where Graeco-Egyptian alchemists experimented with temperature, proportions of ingredients, and various liquids. While testing and devising the formulas for the water of sulphur, they were witnesses to the diversity of colour changes resulting from the reactions between the substances at stake. This spectrum of transformations was conceptualized in the framework of a broader discourse on the stability of tinctures and the dyeing properties of natural substances, both in dry and wet mixtures. Pseudo-Democritus warned young practitioners against a distracted and hasty approach to the art of alchemy, urging them to test ingredients with good judgment. Taking physicians as models, they were expected to carry out a close examination of the species:

…οἷον εἰ τόδε μέν ἐστι σμηκτικόν, τόδε δὲ ἐπιβλητέον, καὶ εἰ τόδε μέν ἐστιν βαπτικόν, τόδε δὲ ἁρμοστέον, καὶ εἰ τόδε τὴν ἐπιφάνειαν ποιεῖ, καὶ εἰ κατὰ τὴν ἐπιφάνειαν ἔσται φευκτὸν καὶ ἐκ τοῦ βάθους φεύξεται, καὶ εἰ τόδε μέν ἐστι πυρίμαχον, τόδε <δὲ> προσπλακὲν πυρίμαχον ποιεῖ κτλ.

…whether one species can cleanse, another can be applied; whether one species can dye, another can combine; and whether one species can make things bright and, with respect to brightness, whether it is vanishing and vanishes from inside; and whether one species can resist fire, and another, when mixed, can make things fire-resisting etc.[1]

These were the principles (ἀφορμαί) that guided any good practitioner in his dyeing operations, as Zosimus remarks while commenting on Pseudo-Democritus' passage.[2] The use of dye baths fostered the idea that a

[1] Pseudo-Democritus, *On Natural and Secret Questions*, 16 (Martelli 2013, pp. 96-97 = *CAAG* II 47).

[2] Zosimus of Panopolis, *On the Exposition of Principles*, *CAAG* II 204,12-15.

colouring agent, when diluted in a liquid, was absorbed by the metals that were dipped into it. By penetrating their structure, it could transform the metals from inside. In the previous section, we have already discussed a similar model in reference to the colouring of gemstones. In this respect, a telling analogy between the two technologies is drawn in a section of the recipe-book *Deep Tincture of Stones*. First, the anonymous compiler singles out the three pillars of Pseudo-Democritus' dyeing method for both metals and stones: letting the dye sink in (*eiskrisis*/εἴσκρισις), tinging (*baphe*/βαφή), and fixing the dye (*katoche*/κατοχή).[1] He then specifies that Pseudo-Democritus, Maria the Jewess, and Zosimus used to prepare a single 'wash' (*zomos*/ζωμός) capable of performing the threefold action.

The water of sulphur exemplifies this methodology. Its colouring action is explained by Zosimus within a larger discussion on the volatility of sulphurous substances, namely substances that can dye but do not resist fire:

> Διὰ τοῦτο οὖν ὡς ἴδιον μὲν καὶ αὐτὸ (*i.e.*, τοὐναντίον) θειῶδες ἀφ' οὗ καὶ ὕδωρ θείου ἀθίκτου κέκληται· διατί καὶ τοὐναντίον; ἐπειδήπερ τοὐναντίον ὕδωρ πυρός. ἐπιρρέον γὰρ ὡς ὕδωρ οὐκ ἐᾷ ἐκεῖνα πυρώδη ὄντα ἐξηθαλῶσθαι καὶ φεύγειν· ἀλλὰ θάπτει αὐτὰ τῇ ὑγρότητι, καὶ κατέχει ἕως βάπτωσιν.[2]
>
> For this reason, the sulphurous substance, after which we name the water of untouched sulphur, also (takes) its opposite as its own property. Why its opposite too? Because water is opposed to fire. For it (*i.e.*, the water of sulphur) flows like water and prevents those substances that are flamelike from being burnt into soot and fleeing. Indeed, it buries these substances under its moisture, and holds them back until they dye.

References to the dyeing properties of sulphur are ubiquitous in Graeco-Egyptian alchemical writings. Pseudo-Democritus, for instance, recommended adding a pinch of sulphur to the dyeing drug, so that it could easily sink in.[3] Zosimus used the term 'sulphur' (θεῖον) to refer to a whole class of colouring substances which included sulphur, orpiment, and realgar.[4] None of these ingredients can resist fire and they all evapo-

[1] Similar lists of three basic operations also appear in Zosimus' writings: see *Chapters to Theodoros*, 3 (*CAAG* II 215,21-216,1: τὸ κατόχιμον, καὶ πυρίμαχον καὶ βαφικόν). See also the anonymous chapter *On Powder* (*CAAG* II 205,3: βαφή, εἴσκρισις, κάτοχος); Berthelot-Ruelle's tentative attribution of this chapter to Zosimus has been questioned: see Letrouit 1995, p. 36, n. 93.

[2] Zosimus of Panopolis, *On What is a Substance and What is without Substance according to the Art*, 2 (*CAAG* II 168,18-23).

[3] Pseudo-Democritus, *On the Making of Silver*, 8 (Martelli 2013, pp. 112-113 = *CAAG* II 53,5-6).

[4] See Martelli 2014b, pp. 32-33. Scholars have sometimes linked the origins of al-

rate easily, resulting in unstable tints. Their dilution into a liquid to prepare the water of sulphur was meant to make them fire-resisting, so that they could penetrate the metals and provide a stable long-term dye. The observation of the colour changes that the sulphur-quicklime solution undergoes when heated – from yellow to orange-brown and red – might have served as empirical evidence to the fact that the dyeing agent was indeed retained by the water.

We must recall, at this point, that sulphur is not soluble in water: calcium hydroxide (produced when quicklime is 'quenched' in water) must react with sulphur to yield the formation of the red calcium polysulphides solution, which is our water of sulphur. Such a modern chemical explanation is obviously distant from Zosimus' language and ideas. Nevertheless, he did discuss the properties of quicklime in his writings. Furthermore, he routinely referred to the water of sulphur as the one *prepared by means of quicklime*, a recurring phrase that seems to emphasize the role played by the ingredient in the mixture.

To quicklime Zosimus dedicated an entire chapter of his *Authentic Memoirs*, whose opening lines read:

> Δῆλα ὑμῖν ποιοῦμαι· γινώσκεται γὰρ ὅτι ὁ λίθος ὁ ἀλαβαστρίτης ἐγκέφαλος κέκληται διὰ τὸ κάτοχον αὐτὸν εἶναι πάσης βαφῆς φευκτῆς.[1]
>
> I am going to make things clear. It is known that the *alabastrites* stone is called 'the brain' because it is capable of holding back every fugacious dye.

The term *alabastrites* refers to a calcareous substance, probably eggshells in this context.[2] When calcinated, they produce quicklime (*asbestos*), as also confirmed by the Byzantine *Lexicon on the Making of Gold*: «alabaster (*alabastros*) is quicklime, the one (produced) from eggshells».[3] Interestingly, another entry explains that the 'divine water' is the water prepared by means of quicklime and alabaster.[4] We may wonder whether the addition of quicklime to the water of sulphur was understood as a method for holding fugacious tinctures like sulphur in the water and making them fire-resisting. Alabaster's retentive capacity was already praised by Maria the Jewess, who referred to *alabastros* as the whitest stone capable of restraining whatever does not resist fire.[5]

chemy itself to ancient manipulations of sulphur (see Hammer Jensen 1921, pp. 41, 44) or arsenic minerals (Multhauf 1966, pp. 108-109).

[1] Zosimus of Panopolis, *Authentic Memoirs*, xiii 1-3 (Mertens 1995, p. 48).

[2] See Mertens 1995, p. 48, n. 1, who also discusses its association with the brain.

[3] *CAAG* ii 4,14-15: Ἀλάβαστρός ἐστιν ἄσβεστος, ἀπὸ τῶν φλοιῶν τῶν ὠῶν κτλ.

[4] *CAAG* ii 8,10-11: θεῖον ὕδωρ ἐστὶ τὸ ἀπολελυμένον τὸ δι' ἀσβέστου καὶ ἀλαβάστρου.

[5] Maria's quotation is reported by the seventh-century alchemist Stephanus of Alexandria in his *Ninth Lecture*, ll. 97-98 (Papathanassiou 2017, p. 216): οὕτως ἡ Μαρία· κά-

Zosimus' chapter *On Quicklime* is also preserved in Arabic translation, as part of the larger treatise *On Sulphurs*: the Arabic text confirms that alabaster «restrains every dye which does not remain».[1] This information is somehow expanded in the Arabic compilation *Tome of Images*, a dialogue between Zosimus and his pupil Theosebeia. Here Zosimus claims that alabaster is called quicklime (*al-kils*), because fire is concealed in both substances.[2] A similar note is also found in a recipe of the Stockholm papyrus, where quicklime is said to keep fire inside, after being removed from the furnace.[3] In the *Tome of Images*, Zosimus adds another important piece of information when he says: «you must know that everything that is born in fire is capable of fighting fire».[4] Quicklime can be easily conceptualised as a 'born in fire' substance, as it is produced when calcareous substances, such as eggshells or seashells, are burnt to ashes. Indeed, Zosimus explains that the first substance which does not 'flee' (*i.e.*, does not quickly evaporate when heated) is «quicklime that comes out of the seashell».[5] As such, it is opposed to the sulphurs that do not resist fire:[6]

قالت. فأبنني عن قولك امّا الكبريت والزرنيخ والزند ريخ تحترق وتفنى سرياً وان النار تأكلها سرياً.

قال. قد اعلمتك دلك وانا اعلمك انك ان خلطت الملح والشب والنطرون والكلس والمكرصيون في ماء امسك بعضها بعضاً ان طبخن بنار لينة.

She (Theosebeia) said: Explain me your statement: "as for[7] sulphur, orpiment, and realgar, they burn and are consumed quickly and the fire eats them quickly".

He (Zosimus) said: Indeed, I gave you that teaching, and now I teach you that, if you mix salt, alum, natron, quicklime, and *makraṣiyūn* (*sic*) in water,[8] they hold each other when they are cooked with a gentle fire.

τοχος (*sic*; *lege* κάτοχον?) πάντων τῶν πυριφεύκτων ἀλάβαστρον, τὸν πάνυ λευκότατον λίθον, τὸ ἐγκέφαλον κτλ. Interestingly, in this passage too the white stone is referred to as 'the brain'.

[1] Zosimus' Arabic treatise *On Sulphurs* is unedited; for a detailed description of its contents and a close comparison with Zosimus' Greek corpus, see Hallum 2008, pp. 132-192 and 280-287.The passage on alabaster has been edited and translated in Hallum 2009, p. 84: لأنّه يحبس كل صبغ <لا> يقر.

[2] On the *Tome of Images*, see above p. 126, n. 3. The passage on the *alabastros* stone and quicklime is edited and translated in Hallum 2009, p. 84 (*Tome of Images*, f. 220r): وأمّا الكلس فلاستجنان النار فيه كما استجنت النار في كلس العامة, «As for (why we call alabaster) quicklime, this is due to fire being concealed within it just as fire is concealed within common quicklime».

[3] *P.Holm.* 61 (Halleux 1981, p. 126): Ἄσβεστον, μηδέπω λυθεῖσαν ὕδατι ἴδιον ἔχουσαν μετὰ τὴν κάμινον τὸ ἀφανὲς ἔνδοθεν πῦρ, «Quicklime that, if not yet diluted in water, after (burning in) the oven keeps its own fire hidden inside».

[4] *Tome of Images*, f. 74v17: فاعلم ان كل شيء يكون ولادته في النار فهو مقاتل النار.

[5] *Tome of Images*, f. 94v2-3: الكلس الذى يخرج من الصدف.

[6] *Tome of Images*, f. 95r3-6.

[7] Perhaps we should read ان instead of امّا.

[8] Abt, Fuad 2011, p. 325 translate the term as 'marcasite'. Its usual name is *marqašīṯā* or *mārqašīṯā* (see Käs 2010, vol. 2, pp. 992-997).

There is no reason to doubt that the same mechanics here described for quicklime and the related substances was postulated for sulphur, orpiment, and realgar too. They were restrained in water and saved from being consumed by fire, when mixed with quicklime (or with some of the other substances in the list). A lesson that might have been learned from the workshop practice, when these ingredients were actually mixed to prepare the water of sulphur.

The fact that Zosimus attributed a central role to quicklime in the making of dyeing waters is confirmed by his reading of Pseudo-Democritus' recipes. Zosimus devoted particular attention to the last recipe of the book *On the Making of Silver*, which, unlike most Democritean formulas, records the amount of the ingredients to be used. A *ζomos* is prepared and metallic leaves are dipped into it to remove their 'shadow'. The recipe reads: [1]

Δέξαι ἀρσενίκου οὐγγίαν μίαν, καὶ νίτρου οὐγγίας τὸ ἥμισυ, καὶ φλοιοῦ φύλλων Περσαίου ἁπαλῶν οὐγγίας δύο, καὶ ἅλατος ἥμισυ, καὶ συκαμίνου χυλοῦ οὐγγίαν μίαν, <στυπτηρίας> σχιστῆς τὸ ἴσον. Λείου ὁμοῦ ἐν ὄξει, ἢ οὔρῳ, ἢ ἀσβέστῳ στακτῇ, ἕως γένηται ζωμός· εἰς τοῦτον τὰ ἔνσκια πυρὶ κατάβαπτε πέταλα, καὶ ἀποσκιώσεις. Ἡ φύσις τὴν φύσιν κρατεῖ.

Take orpiment, one ounce, and soda, a half-ounce, and the skin of the tender leaves of *Persaion*, two ounces, and salt, a half-ounce, and mulberry juice, one ounce, and the same amount of scissile <alum>. Grind together in vinegar, or urine, or filtrate of quicklime, until a wash (*ζomos*) is formed: dip into this wash the dark metallic leaves while heating them, and you will make them 'shadowless'. Nature masters nature.

Both in the Baltimore and Bologna experimental trials, we followed the ancient text's directions and tried to replicate the recipe in laboratory. All ingredients can be identified with confidence, except for one of the two plants mentioned. [2] In fact, the identification of *Persaion* is debated: [3] for the sake of convenience, we picked up the green leaves of any plant growing in the University campus. We used both vinegar and filtrate of quicklime, and in both cases, after mixing the listed ingredients and heating them for a while, we produced a yellow *ζomos* (Fig. 8).

[1] Pseudo-Democritus, *On the Making of Silver*, 9 (Martelli 2013, pp. 112-115 = *CAAG* II 53,7-11).

[2] *Sukaminos* (συκάμινος) is identified with blueberry (Andrè 1985, p. 253; Amigues 2006, p. 337), which has been used for replicating Pseudo-Democritus' recipe. Given the Egyptian background of his books, we cannot exclude that he meant the Egyptian *sukaminos* (συκάμινος ἡ Αἰγυπτία), 'fig, sycamore'. We must note, however, that for other Egyptian ingredients Pseudo-Democritus specified their region of origin: Αἰγύπτιος κόγχος (Martelli 2013, p. 79, l. 31 = *CAAG* II 42,17); κόμμι ἀκάνθης Αἰγυπτίας (Martelli 2013, p. 116, l. 13).

[3] See Martelli 2013, p. 233, n. 23.

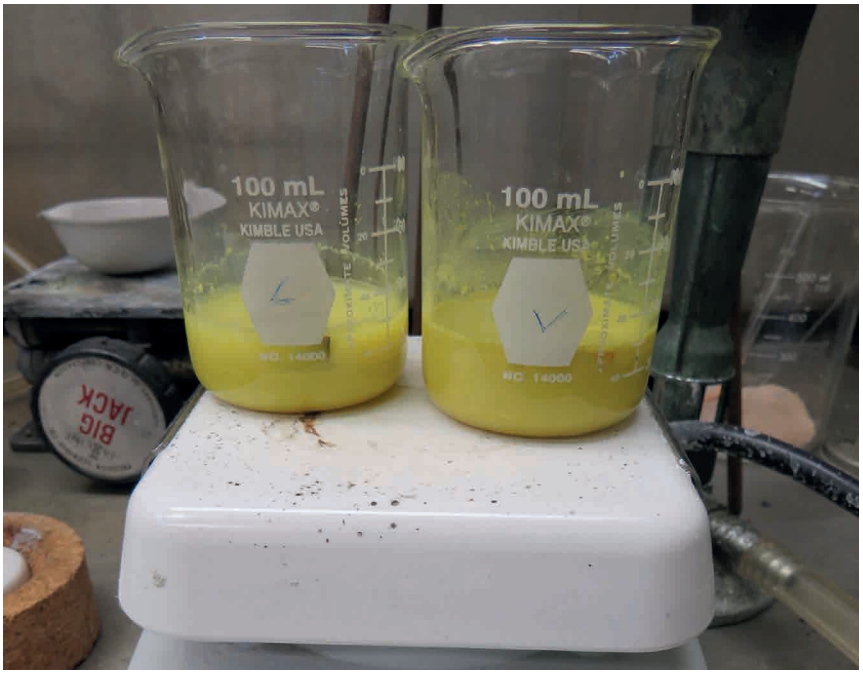

Fig. 8. Pseudo-Democritus washes (*ζomoi*) prepared with filtrate of quicklime (L) and vinegar (V). L. Principe's laboratory, Baltimore. Picture by L. Raggetti.

Fig. 8.1. Various shades of silver on copper coins dipped into Pseudo-Democritus' wash prepared with filtrate of quicklime (L). Laboratory of the Chemistry Department, Bologna. Author's picture.

At the end of the recipe, Pseudo-Democritus instructs us to dip dark metallic leaves into the *ζomos*, without specifying the metal to be used. Here, he only says that its 'shadow' will be removed after the treatment. In his reading of the recipe, Zosimus shows no doubt in identifying the metal with copper. Furthermore, he explains that the copper leaves be-

Fig. 8.2. Colouring of two copper coins dipped into Pseudo-Democritus' wash prepared with filtrate of quicklime (L). L. Principe's laboratory, Baltimore. Picture by L. Raggetti.

Fig. 8.3. Colouring of a copper coin dipped into Pseudo-Democritus' wash prepared with filtrate of quicklime (L) and filtered. L. Principe's laboratory, Baltimore. Picture by L. Raggetti.

come white after being dipped into the *zomos*.[1] After all, the recipe is part of the *Book on the Making of Silver*, which usually describes procedures for whitening (λευκαίνειν) metals, especially copper.[2]

[1] Zosimus of Panopolis, *On the Detailed Presentation of the Work*, 8 (*CAAG* II 161,10-16). Moreover, the adj. ἀσκίαστος always qualifies copper in Pseudo-Democritus' recipes.

[2] Pseudo-Democritus' reference to the shadow of copper leaves might also suggest interpreting the recipe as a method for cleansing oxidized copper. In our replications, we dipped an oxidized copper leaf into both solutions, but no noticeable colour change was brought about.

The replication confirmed that one of the two liquids has dyeing capacity. When dipped into the *zomos* prepared with quicklime, copper readily changes its colour and becomes from silvery to smoke-grey (Fig. 8.1). The shade and shine depend on the time of exposure and the concentration of the solution, which works better if filtered. After some practice, we were able to make copper look astonishingly like silver (Fig. 8.2-8.3).

By way of contrast, the coin underwent no colour change when dipped into the *zomos* prepared with vinegar (Fig. 9, on the left). As in the case of the water of sulphur, the role of quicklime is pivotal in the procedure, since a basic solution is necessary for the orpiment (an arsenic sulphide) to 'dissolve,' resulting in a reactive solution that can attack the surface of copper.

As mentioned above, the centrality of quicklime seems to be acknowledged by Zosimus in his interpretation of the recipe. In a section dealing with the right amounts of ingredients to be used in dyeing procedures, he commented on the technique described in Pseudo-Democritus' text, which is quoted almost *verbatim*:[1]

Ἔχει οὖν ἐν τῇ ὑστέρᾳ τῶν ζωμῶν· ἀρσενίκου οὐγγίαν α´, καὶ νίτρου ἥμισυ, καὶ φλοιῶν φύλλων Περσέας ἁπαλῶν οὐγγίας β´, καὶ ἅλας ἥμισυ, καὶ συκαμίνου χυλοῦ οὐγγίαν α´, καὶ στυπτηρίας σχιστῆς τὸ ἴσον[2] συλλειώσας ὅλα ὁμοῦ ἐν ὄξει ἢ οὔρῳ ἢ ἀσβέστου στακτῇ,[3] ἕως γένηται ζωμός. Εἶτα ἔνσκια πυρὶ[4] καταβάπτει πέταλα καὶ ἀποσκιώσεις ποιεῖ. Δεῖ οὖν τὰ λείποντα πάντα βάλλειν, πρό γε πάντων, ἀσβέστου μέρη β´ πρὸς θείου καὶ ἀρσενίκου καὶ σανδαράχης μέρος α´, καὶ τὸ ὕδωρ·[5] καὶ ποιήσαντες ὕδωρ λευκὸν μαρμάρῳ παρεμφερές, ἐν αὐτῷ ποτίζειν ἢ ἑψεῖν τρούλλῳ[6] τὸ προειρημένον σύνθεμα.

In the last (recipe) of the washes (Democritus) maintains orpiment, one ounce, and soda, a half-ounce, and the skins of the tender leaves of *Persea*, two ounces, and salt, a half-ounce, and mulberry juice, one ounce, and the same amount of scissile alum, mixing all together in vinegar or urine or filtrate of quicklime, until a wash is formed. Then he dips dark (metallic) leaves while heating them and carries out the procedures for making them 'shadowless'. So, we must add everything that is missing, first of all (we must add) two parts of quicklime to

[1] Zosimus of Panopolis, *On Weights*, 2 (*CAAG* II 178,18-179,4). The text as edited by Berthelot-Ruelle has been revised after a fresh reading of the most important witnesses: MSS *Marcianus* gr. 299 (ff. 153^{v}-154^{r} = **M**), *Parisini* gr. 2325 (f. 139^{v} = **B**) and 2327 (f. 127v = **A**). A selection of variants is recorded in the following notes.

[2] MS **M** reads τοῖς, MSS **BA** read τούτοις. I've corrected the text by following Pseudo-Democritus' recipe.

[3] MS **M** has στάκη, MSS **BA** read σταλακτῇ ἔνωσον and omit ἕως γένηται ζωμός.

[4] All MSS read ἐν σκιᾷ πυρός, which was corrected on the basis of Pseudo-Democritus' recipe.

[5] MS **M** reads τὸ υ$^{\Delta}$ υ$^{\Delta}$ (perhaps a diplography); MSS **BA** read τὰ υ$^{\Delta T}$ υ$^{\Delta T}$.

[6] MS **M** reads τρούλλου.

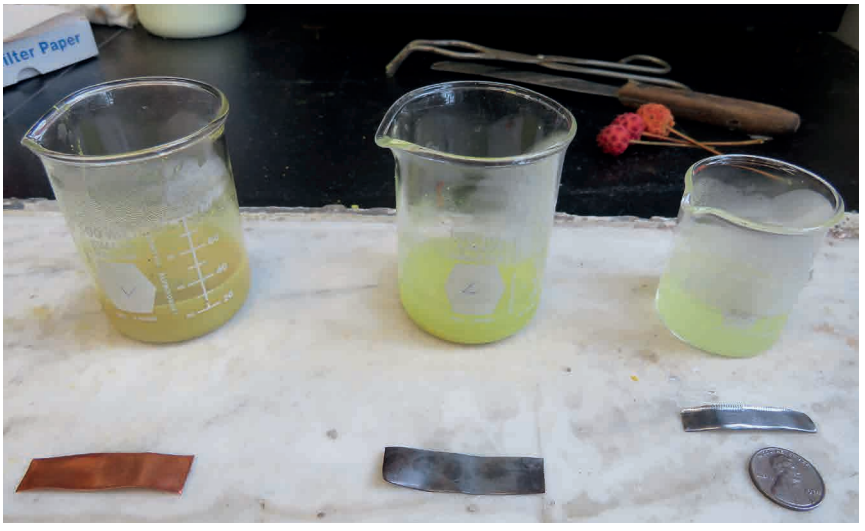

Fig. 9. Different colour changes of copper dipped into Pseudo-Democritus' washes: on the left, wash prepared with vinegar (V); in the centre, wash prepared with filtrate of quicklime (L); on the right, filtered wash prepared with filtrate of quicklime. L. Principe's laboratory, Baltimore. Picture by L. Raggetti.

one part of sulphur, orpiment, and realgar, and to water. After preparing a water as white as marble, use this water to moisten or boil the above-mentioned mixture in a vessel.

Quicklime is the first ingredient that one should add to Pseudo-Democritus' formula, Zosimus immediately recommends thus acknowledging its strategic role in the preparation of the dyeing *zomos*. He also specifies the amount of quicklime to be used – the same that is also recorded in his recipe for the water of sulphur. Its addition, indeed, makes it possible to prepare a basic solution in which the arsenic mineral (orpiment in Pseudo-Democritus' recipe) can be diluted. The mention of sulphur along with orpiment and realgar (another arsenic mineral) is likely due to Zosimus' classification of the three ingredients, which belonged to the same class of dyeing substances that he called 'sulphurs' (see above). It is notable that, in his comment on the recipe, he makes no mention of the vegetal ingredients, and their role in Pseudo-Democritus' recipe remains unclear. Interestingly, in a list of substances that must be diluted in water for the making of dyeing waters, Zosimus lists «lime, which is called mulberry juice».[1] The list is mainly taken from Pseudo-Democritus' cata-

[1] Zosimus of Panopolis, *On the Detailed Presentation of the Work*, 2 (*CAAG* II 159,16): τίτανος, ὅς προσκέκληται ὀπὸς συκαμίνου.

logues and proves how Zosimus interpreted the term 'mulberry juice' as a codename for lime, which provides a further evidence for the relevance that he attributed to this mineral, as well as his classificatory framework. Laboratory experiments confirm that a simple *ʒomos* prepared with quicklime and arsenic minerals in water – with no plants in it – has the same dyeing properties as the wash described in Pseudo-Democritus' recipe.[1]

Zosimus' reading of Pseudo-Democritus' recipe exemplifies what Jennifer Rampling called «practical exegesis».[2] In interpreting this earlier text, Zosimus relied on his own workshop practice, which was marked by lived experiences of colouring metals with the water of sulphur. These experiences informed his examination of the behaviour and interaction of those substances that entered the formulas for alchemical waters. In the books of the founders of alchemy Zosimus looked for effective formulas and methodological principles that could guide his own experiments and procedures, in a continuous effort to conceptualise the colour changes and transformations he witnessed while manipulating a wide range of materials. He tested natural substances, classified various types of tinctures, and explored the mechanics of dyeing in workshops and libraries. It was from this dynamic combination of reading, experimenting, and theorizing that Zosimus' idea of transmutation emerged, not from a separation of philosophy and experimentation, as Needham described, but from a lived practice of alchemical tinging.

*

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Bibliography

Theodor Abt, *The Book of Pictures. Muṣḥaf as-ṣuwar by Zosimos of Panopolis. Facsimile with an Introduction* (*Corpus Alchemicum Arabicum*, II.1), Zurich, Living Human Heritage, 2007.

Theodor Abt, Salwa Fuad, *The Book of Pictures. Muṣḥaf as-ṣuwar by Zosimos of Panopolis. Edited with Introduction and Translation* (*Corpus Alchemicum Arabicum*, II.2), Zurich, Living Human Heritage, 2011.

Suzanne Amigues, *Théophraste. Recherches sur les plantes*, tome V, livre IX, Paris, Les Belles Lettres, 2006.

Jacques André, *Le noms des plantes dans la Rome antique*, Paris, Les Belles Lettres, 1985.

[1] A forthcoming publication will illustrate these replications and discuss them in the framework of Zosimus' alchemy.

[2] See above, p. 118, n. 2.

Sandro Baroni, *Mappae clavicula e la tradizione in siriaco di Zosimo di Panopoli*, in *Mappae clavicula. Alle origini dell'alchimia in Occidente*, edited by Sandro Baroni, Giuseppe Pizzigoni, Paola Travaglio, Saonara, il Prato, 2013, pp. 237-242.

Marcelin Berthelot, *La chimie au Moyen Âge*, I. *Essai sur la transmission de la science antique au Moyen Âge*, Paris, Imprimerie nationale, 1893.

Marcelin Berthelot, Rubens Duval, *La chimie au Moyen Âge*, II. *L'alchimie syriaque*, Paris, Imprimerie nationale, 1893.

Marcelin Berthelot, Charles-Émile Ruelle, *Collection des anciens alchimistes grecs* (= *CAAG*), 3 vols., Paris, Steinheil, 1887-1888.

Miriam Blanco Cesteros, *The Perception of (Re)production Processes in the Leiden and the Stockholm papyri*, in *Les alchimistes grecs: recettes, doctrines et milieux*, edited by Matteo Martelli, Cristina Viano, Bologna, Pàtron, 2023 (forthcoming).

Earle R. Caley, *The Stockholm Papyrus. An English Translation with Brief Notes*, «Journal of Chemical Education», IV, 8, 1927, pp. 979-1002.

Gaia Caprotti, *Mappae clavicula: prescrizioni della prima alchimia storica nei precedenti di lingua greca*, in *Mappae clavicula. Alle origini dell'alchimia in Occidente*, edited by Sandro Baroni, Giuseppe Pizzigoni, Paola Travaglio, Saonara, il Prato, 2013, pp. 219-236.

Vincenzo Carlotta, *La morte e resurrezione dei corpi nel* Dialogo dei filosofi e di Cleopatra *e nel* Liber de compositione alchemiae *di Morieno*, in *Appropriation, Interpretation and Criticism: Philosophical and Theological Exchanges Between the Arabic, Hebrew and Latin Intellectual Traditions*, edited by Alexander Fidora, Nicola Polloni, Turnhout, Brepols, 2017, pp. 93-120.

Andrée Colinet, *Les alchimistes grecs X. L'Anonyme de Zuretti ou l'Art sacré et divin de la chrysopée par un anonyme*, Paris, Les Belles Lettres, 2002.

Andrée Colinet, *Les alchimistes grecs XI. Recettes alchimiques (Par. Gr. 2419; Holkhamicus 109). Cosmas le hiéromoine, Chrysopée*, Paris, Les Belles Lettres, 2010.

Olivier Dufault, *Transmutation Theory in the Greek Alchemical Corpus*, «Ambix», LXII, 2, 2015, pp. 215-244.

Andrè-Jean Festugière, *La Révélation d'Hermès Trismegiste*, I. *L'astrologie et les sciences occultes*, 2nd edition, Paris, Gabalda, 1950.

Hjalmar Fors, Lawrence M. Principe, H. Otto Sibum, *From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science*, «Ambix», LXIII, 2, 2016, pp. 85-97.

Dietlinde Goltz, *Studien zur Geschichte der Mineralnamen in Pharmazie, Chemie und Medizin von den Anfängen bis Paracelsus*, Wiesbaden, Steiner, 1972.

Robert Halleux, *Les textes alchimiques*, Turhout, Brepols, 1979.

Robert Halleux, *Papyrus de Leyde, Papyrus de Stockholm. Fragments de recettes*, Paris, Les Belles Lettres, 1981.

Robert Halleux, Paul Meyvaert, *Les origines de la* Mappae clavicula, «Archives d'histoire doctrinale et littéraire du Moyen Âge», LXII, 1987, pp. 5-58.

Benjamin C. Hallum, *Zosimus Arabus*, PhD dissertation, Warburg Institute, 2008.

Benjamin C. Hallum, *The* Tome of Images: *an Arabic Compiltation of Texts by Zosimos of Panopolis and a Source of the* Turba Philosophorum, «Ambix», lvi, 1, 2009, pp. 76-88.

Ingebor Hammer Jensen, *Die älteste Alchymie*, Copenhagen, Hovedkom-missionær, Høst & Søn, 1921.

Arthur John Hopkins, *Alchemy, Child of Greek Philosophy*, New York, Columbia University Press, 1934.

Fabian Käs, *Die Mineralien in der arabischen Pharmakognosie. Eine Konkordanz zu mineralischen Materia medica der klassischen arabischen Heilmittelkunde nebst überlieferungsgeschichtlichen Studien*, 2 vols., Wiesbaden, Harrassowitz, 2010.

Otto Lagercrantz, *Papyrus Graecus Holmiensis (P.Holm.). Recepte für Silber, Steine und Purpur*, Uppsala-Leipzig, A.-B. Akademiska Bokhandeln-Harrassowitz, 1913.

Jean Letrouit, *Chronologies des alchimistes grecs*, in *Alchimie. Art, histoire et mythes*, edited by Didier Kahn, Sylvain Matton, Paris-Milano, s.é.h.a.-Arché, 1995, pp. 9-93.

Lyudmila M. Levchenko, A. A. Galitskii, V. Kosenko, Aleksey K. Sagidullin, *Development of Semi-Industrial Synthesis of Calcium Polysulfide Solution and Determination of the Content of Sulfide Ions in Solution*, «Russian Journal of Applied Chemistry», lxxxviii, 9, 2015, pp. 1403-1408.

Edmund O. von Lippmann, *Entstehung und Ausbreitung der Alchemie, mit einem Anhage zur älteren Geschichte der Metalle*, Berlin, Springer, 1919.

Syed Mahdihassan, *A Comparative Study of Greek and Chinese Alchemy*, «American Journal of Chinese Medicine», vii, 2, 1979, pp. 171-181.

Marianna Marchini, Massimo Gandolfi, Lucia Maini, Lucia Raggetti, Matteo Martelli, *Exploring the Ancient Chemistry of Mercury*, «pnas», cxix, 24, 2022, pp. 1-8.

Matteo Martelli, *"Divine Water" in the Alchemical Writings of Pseudo-Democritus*, «Ambix», lvi, 1, 2009, pp. 5-22.

Matteo Martelli, *The Four Books of Pseudo-Democritus*, Leeds, Maney, 2013.

Matteo Martelli, *L'alchimie en syriaque et l'oeuvre de Zosime*, in *Les sciences en Syriaque*, edited by Émilie Villey, Paris, Geuthner, 2014a, pp. 191-214.

Matteo Martelli, *Properties and Classification of Mercury between Natural Philosophy, Medicine and Alchemy*, «aion. (Filol.)», xxxvi, 2014b, pp. 17-47.

Matteo Martelli, *L'alchimista antico. Dall'Egitto greco-romano a Bisanzio*, Milano, Bibliografica, 2019.

Michèle Mertens, *Les alchimistes grecs* iv.1. *Zosime de Panopolis, Mémoires authentiques*, Paris, Les Belles Lettres, 1995.

Sébastien Moureau, Nicolas Thomas, *Understanding Texts with the Help of Experimentation: The Example of Cupellation in Arabic Scientific Literature*, «Ambix», lxiii, 2, 2016, pp. 98-117.

Robert P. Multhauf, *The Origins of Chemistry*, London, Oldbourne, 1966.

Joseph Needham, *Science and Civilisation in China*, 2. *Chemistry and Chemical Technology. Spagyrical Discovery and Invention: Magisteries of Gold*, Cambridge, Cambridge University Press, 1974.

Giuseppe Orosi, *Farmacologia teoria e pratica o farmacopea italiana*, Livorno, Mansi, 1849.

Maria K. Papathanassiou, *Stephanos von Alexandria und sein alchemistisches Werk. Die kritische Edition des griechischen Textes eingeschlossen*, Athens, Cosmosware, 2017.

Marc Philonenko, *Un esprit ténébreux et puant (Alchimistes grecs 296,13)*, «Comptes-rendus des séances de l'Académie des Inscriptions et Belles-Lettres», cxxxvi, 3, 1992, pp. 651-662.

Lawrence M. Principe, *The Secrets of Alchemy*, Chicago-London, The University of Chicago Press, 2013.

Lawrence M. Principe, *Texts and Practices: The Promises and Problems of Laboratory Replication and the Chemical Explanation of Early Alchemical Processes*, in *Greek Alchemy from Late Antiquity to Early Modernity*, edited by Efthymios Nicolaidis, Turnhout, Brepols, 2018, pp. 159-169.

Lucia Raggetti, *Alchemical Waters Run Deep. The Four Waters and Their Use in The Treasure of Alexander*, «Nuncius», xxxvii, 2022, pp. 675-692.

Jennifer M. Rampling, *Transmuting Sericon: Alchemy as 'Practical Exegesis' in Early Modern England*, «Osiris», xxix, 2014, pp. 19-34.

Jennifer M. Rampling, *The Experimental Fire. Inventing English Alchemy, 1300-1700*, Chicago, The University of Chicago Press, 2020.

Richard Reitzenstein, *Zur Geschichte der Alchemie und des Mystizismus*, in *Nachrichten von der Königlichen Gesellschaft der Wissenschaften zu Göttingen*, Berlin, Weidmannsche Buchhandlung, 1919, pp. 1-37.

Athanasios Rinotas, *Stoicism and Alchemy in Late Antiquity: Zosimus and the Concept of Pneuma*, «Ambix», lxiv, 3, 2017, pp. 203-219.

Julius Ruska, *Pseudepigraphe Rasis-Schriften*, «Osiris», vii, 1939, pp. 31-94.

Cristina Viano, *Aristote et l'alchimie grecque: La transmutation et le modèle aristotélicien entre théorie et pratique*, «Revue d'histoire des sciences», xlix, 2-3, 1996, pp. 189-213.

Cristina Viano, *Gli alchimisti greci e l'«acqua divina»*, in *Atti del vii Convegno di storia e fondamenti della chimica (L'Aquila, 8-11 ottobre 1997)*, edited by Franco Calascibetta, «Rendiconti della Accademia nazionale delle scienze detta dei xl. Parte ii. Memorie di Scienze Fisiche e Naturali», 5, xxi, 2, 2, 1997, pp. 61-70.

Cristina Viano, *Les alchimistes gréco-alexandrins et le Timée de Platon*, in *L'alchimie et ses racines philosophiques. La tradition grecque et la tradition arabe*, edited by Cristina Viano, Paris, Vrin, 2005, pp. 91-107.

Cristina Viano, *Une substance, deux natures: les alchimistes grecs et le principe de la transmutation*, «Chôra. Revue d'études anciennes et médiévales», xiii, supplement, 2015a, pp. 309-325 (*Dualismes: Doctrines religieuses et traditions philosophiques*, edited by Fabienne Jourdan).

Cristina Viano, Mixis *and* Diagnôsis*: Aristotle and the "Chemistry" of Sublunary World*, «Ambix», lxii, 2, 2015b, pp. 203-214.

Cristina Viano, *Graeco-Egyptian Alchemy*, in *The Cambridge History of Science*, i. *Ancient Science*, edited by Alexander Jones, Liba Taub, Cambridge, Cambridge University Press, 2018, pp. 468-482.

William Jerome Wilson, *Review of "Alchemy, Child of Greek Philosophy" by Arthur John Hopkins*, «Isis», xxiv, 1, 1935, pp. 174-177.

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