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Metallurgy and Metalworking Techniques

Maria K. Papathanassiou

The art of metalworking in Byzantium was heir to an ancient tradition transmitted by age-old techniques developed in antiquity in the broad area of the eastern Mediterranean.¹ Various metal objects dating from the Bronze Age and found in excavations in Greece, on the coasts of Asia Minor, and in Egypt bear witness to this long tradition. A good deal of data regarding the techniques of metalworking is found in the form of literary descriptions in the ancient texts. For example, in the *Iliad* (18.369–79, 410–17, 468–77) there is an excellent description of the forge of Hephaistos, the blacksmith god, with much information on the way he was working, the kind of metals he used, and the techniques he employed to make the shield of Achilles. On the other hand, representations of the work carried out in mines and in workshops appear in ancient Greek black-figure and red-figure vase painting. Some of these workshops were simple forges for fashioning weapons and tools, while others were the workplace of true artists, where bronze statues were cast² and marble statues were covered with ivory or gold.

These techniques, transmitted from generation to generation, survived and were improved over time. From the Hellenistic age on, the desire for luxuries and for conspicuous wealth extended into the lower social strata. As a result, there was increased need for the production of luxury goods, albeit at moderate price. Gold and silver-smiths sought techniques that would allow them successfully to make precious metal alloys and imitate precious and semiprecious stones. Already in the early fourth century, the papyri of Leiden and Stockholm³ include recipes that refer primarily to various techniques for processing gold and silver, in particular: (a) “doubling” (δίπλωσις), which must be understood as a decrease in the degree of purity of an alloy of a precious metal without a change in its color, rather than a doubling of the mass of the metal itself); (b) dyeing (βαφή), dipping hot metals into a cold liquid, usually water, to harden

¹ M. Papathanassiou, “Αρχαία μεταλλοτεχνία καὶ φυσικὲς θεωρίες ὡς βάσεις τῆς ἐλληνικῆς χημείας,” Ἡ ἱστορικὴ ἐξέλιξη τῆς Χημείας στὴν Ἑλλάδα, *Proceedings of the Panhellenic Symposium of the Association of Greek Chemists, October 14–15, 1994* (Athens, 1996), 35–53.

² *I bronzi di Riace* (Novara, 1981).

³ R. Halleux, *Les alchimistes grecs*, vol. 1, *Papyrus de Leyde, Papyrus de Stockholm, Fragments de recettes* (Paris, 1981).

them);⁴ (c) making black silver;⁵ (d) gilding and silvering metal objects; (e) methods of testing the purity of the metals; (f) book illumination with gold and silver (χρυσογραφία/ἀργυρογραφία); (g) the processing and imitation of precious and semiprecious stones; and even (h) dyeing cloth.

Technical recipes found in chemical Byzantine codices dated from the tenth to the fifteenth century⁶ refer to the same branches of metalworking, especially to gold and silverwork. The content of these codices is related to that of the papyri mentioned above. On this basis we can distinguish the following groups of recipes: (a) dyeing copper and iron, the manufacture of dies (τυπάρια), thin gold leaves (χρυσοπέταλα), and so on; (b) cleaning pearls and methods for making imitation pearls; (c) the work of the goldsmith, especially refining (purifying) and welding gold and silver, illuminating books with gold and silver, and making wires.⁷

In these texts, which are authentic sources for the materials and tools employed as well as for the relevant techniques to the end of the fifteenth century, one may glimpse the effort of the craftsman to hide the secrets of his art, even when he seems to be revealing them. For this reason, although most recipes mention the general method of the work and the materials used, they omit the proportions of materials in various types of work; that is, they omit the most important information for creating a metal object successfully.

It is worth examining in detail some basic techniques such as iron tempering,⁸ that is, hardening it so that it becomes steel. In this recipe we are given the proportions of the materials used for smearing over the point or edge (ἐπάλειψη τοῦ στόματος) of iron. Special mention is made of “Indian iron,” which was tempered through a better method. An important distinction is made between the method of tempering (hardening) tools for stone carving, which do not need a sharp edge, and sharp knives and swords. There is also mention of an “Indian method for tempering iron,” which is said to have been invented by Indians and received through the Persians; the mention is dated to some year (not stated precisely) of Philip’s era.⁹ The same vagueness as to chronology is found in a recipe for dyeing copper, attributed to the Persians.

The *Souda* lexicon (ca. 11th century) states that chemistry (χημεία)¹⁰ is the making

⁴ Homer, *Od.* 9.391–93, describes the temper of iron as it becomes steel, and mentions the great scream (μέγα ἰάχοντα) of the burning metal when it is dipped into water. In the papyrus of Leiden, there are recipes for the temper of silver (Halleux, *Alchimistes grecs*, 99 §65) and gold (*ibid.*, 102 §78, 100 §67).

⁵ A. R. Giumlia-Mair and P. T. Craddock, *Das schwarze Gold der Alchimisten: Corinthium aes* (Mainz am Rhein, 1993).

⁶ M. Berthelot and C. Ruelle, *Collection des anciens alchimistes grecs*, 3 vols. (Paris 1888; Osnabrück, 1967) 2:321–93 (technical treatises).

⁷ M. Papathanassiou, “Ἀλχημεία ἢ χημικὴ τεχνολογία,” *Ἰνδικτος* 7 (1997): 97–119.

⁸ Berthelot and Ruelle, *Anciens alchimistes*, 2:342.20–345.23.

⁹ This is in a chronological system introduced in Egypt after its conquest by Alexander the Great. The first day of the era is 12 November 324 B.C.

¹⁰ The word χημεία is found in ancient Greek and Byzantine texts. According to Plutarch (*De Iside et Osiride*, 33) it means “the black earth of Egypt.” In conjunction with the Arabic article *al-*, it becomes ἄλχημεία (alchemy), which appeared as a new word in the Latin West through the translations of the relevant texts from the Arabic to Latin.

of gold and silver, old books regarding which were burned by order of Diocletian (284–305).¹¹ This should probably be related to Diocletian's fiscal reform, in which he also included the monetary system of Egypt. The striking of gold and silver coins with the image of the emperor was an exclusive imperial privilege, and those who encroached upon it were heavily punished.¹²

For this reason, a unique recipe in the oldest chemical codex, Marcianus gr. 299 (10th–11th century), assumes great significance. It describes in detail the general method of making dies (τυπάρια), that is, bronze molds (φοῦρμα) and reliefs (τύλοι) for any coin (λαβῶν νόμισμα οἶον θέλεις).¹³ The figure of the coin in relief (ἐκτύπωμα) is made with common sulfur (τεάφιον κοινὸν ἐψητόν), which is baked in a low fire (ἐλαφρὸν πῦρ) so that the impression of the coin is good and the sulfur does not burn. The materials used for the casting (χώνης) of the dies (τυπαρίων) are an iron ring (στεφάνιον σιδηροῦν), sifted quicklime (κονία κοσκινισμένη), ashes, and bronze. In this case the constituents of the bronze alloy (ἢ συγκέρασις τοῦ βροντησίου)¹⁴ are verdigris (ἰδς)¹⁵ from Cyprus (which produced the best copper) and pure tin in a proportion of 1:2 pounds; the constituents of the coloring of the coin (χρώσις τοῦ χαράγματος) are a solution of 2 pounds of blue vitriol (χάλκανθος),¹⁶ 1 pound of copper ore (χαλκίτις),¹⁷ 2 pounds of alum (στυπτηρία),¹⁸ 7 pounds of yellow ocher,¹⁹ and salt. After the workers

¹¹ *Suidae Lexicon*, ed. A. Adler, 4 vols. (Leipzig, 1928–35), 4:804, s.v. χημεία: ἡ τοῦ ἀργύρου καὶ χρυσοῦ κατασκευή: ἧς τὰ βιβλία διερευνησάμενος ὁ Διοκλητιανὸς ἔκαυσεν; 2:104, s.v. Διοκλητιανός: ὅτε δὴ καὶ τὰ περὶ χημείας ἀργύρου καὶ χρυσοῦ τοῖς παλαιοῖς γεγραμμένα βιβλία διερευνησάμενος ἔκαυσε, πρὸς τὸ μηκέτι πλοῦτον Αἰγυπτίους ἐκ τῆς τοιαύτης περιγίγνεσθαι τέχνης, μηδὲ χρημάτων αὐτοὺς θαρρῶντας περιουσίᾳ τοῦ λοιποῦ Ῥωμαίοις ἀνταίρειν.

¹² *Codex Theodosianus*, ed. P. Krüger and T. Mommsen, I.2 (Berlin 1904; repr. 1971), bk. 9.21–23. P. Grierson, “The Roman Law of Counterfeiting,” in *Essays in Roman Coinage Presented to Harold Mattingly*, ed. R. A. G. Carson and C. H. V. Sutherland (Oxford, 1956), 240–61. M. Hendy, *Studies in the Byzantine Monetary Economy c. 300–1450* (Cambridge, 1985), 320–24.

¹³ Berthelot and Ruelle, *Anciens alchimistes*, 2:375.9–377.6.

¹⁴ Βροντήσιος (bronze) most likely derives from the Persian word *biring* (copper); D. Goltz, *Studien zur Geschichte der Mineralnamen in Pharmazie, Chemie und Medizin von den Anfängen bis Paracelsus* (Wiesbaden, 1972), 188.

¹⁵ Dioscorides, *De materia medica*, ed. M. Wellmann (Berlin, 1914), 5.79: (p. 49, line 4) ἰδὸν δὲ τὸν ξυστὸν οὕτως σκευαστέον; (p. 51, lines 17–18) ὁ δὲ [ἰδς] τῶν χρυσοχόων ἀνάλογος τῷ ξυστῷ. This is verdigris [(CuC₂H₃O₂)₂ · H₂O], which is transformed into malachite [CuCO₃ · Cu(OH)₂] by the action of air and water.

¹⁶ Χάλκανθος is hydrate copper sulfate, commonly blue vitriol (CuSO₄ · 5H₂O), or hydrate ferrous sulfate (FeSO₄ · 7H₂O). Goltz, *Geschichte der Mineralnamen*, 152–54, 200.

¹⁷ Diosc., *De materia medica*, 5.99. According to Pliny the Elder (*Naturalis historia*, 34.117, 120, 121), χαλκίτις contains copper, μίσυ, and σῶρι, and it is very likely copper pyrites (CuFeS₂). The μίσυ contained in the χαλκίτις could be ferrous sulfide (FeS₂). Σῶρι, which is usually mentioned with μίσυ, could be copper sulfide (CuS). Berthelot and Ruelle, *Anciens alchimistes*, 468–69: σῶρι ἐστὶν ὡς κυανὸς ψωρόδης, εὐρισκόμενος αἰεὶ ἐν τῷ μίσυ. τοῦτο καὶ χλωρὸν χάλκανθον καλοῦσιν. Goltz, *Geschichte der Mineralnamen*, 154–57.

¹⁸ In Egypt there are all kinds of στυπτηρία, i.e., σχιστή, στρογγυλή, ὑγρή, but it is also found in other countries. Diosc., *De materia medica*, 5.106. Goltz, *Geschichte der Mineralnamen*, 161.

¹⁹ This is limonite (2Fe₂O₃ · 3H₂O), which is also called σχιστόν. Diosc., *De materia medica*, 5.93. Goltz, *Geschichte der Mineralnamen*, 147–48.

have ground these materials, sifted them, and piled them in layers in a covered pot, as is done with the thin gold leaves made by artisans who smelt gold (φύλλα τῶν χρυσοσηπητῶν),²⁰ they bake them for three hours. After these baked pieces, that is, the colored φάκια, have cooled down, they are washed with pure water, and then the artisans, after having oiled their hands, rub them with sulfur.

This technique for making a die (τυπάριον) can be used for striking either a genuine or a false gold coin, depending on whether the work is done in the imperial mint or by counterfeiters. But, as the law against counterfeiting makes clear, the metalworkers of the imperial mints themselves were so involved in counterfeiting that they were considered as the main source of false coinage and were punished more severely than private persons.²¹ If, however, they struck coinage themselves with tools stolen from the mint, and the coins had the legal composition and form, then the metalworkers were punished only for theft. In any case, the main purpose of the law against hoarding old bronze coins was to reduce the metal available for making dies, which could then be used for forgery.²²

In our text the coin whose manufacture is being discussed is the gold coin (όλοκοττινον, solidus) because of its high value (πάνυ χρήσιμος ἐκβαίνει ἢ ἀποτύπωσις τοῦ ὀλοκοττινου). However, the same bronze used for the casting of the die (εἰς αὐτὴν τὴν ἀποτύπωσιν μεταβάλλεις τὸ αὐτὸ βροντήσιον) of the gold coin as a copper alloy is appropriate for use in creating imitations of gold; and the text gives instructions for the coloring of the φάκια. In cod. Paris. gr. 2327, copied in 1478, there is a description of the fashioning of a mold for a solidus (φοῦρμας ὀλοκοττινου) made of an alloy of metals by the wax method; on this they pour silver and verdigris ground and dissolved in lemon juice.²³

The importance of metalworking in Roman and Byzantine finances may be seen not only from the relevant provisions of the Theodosian and Justinianic codes, but also from another very important text that belongs to the first group of recipes and is entitled *Differences of Lead and Gold Leaf* (Διαφοραὶ μολίβδου καὶ χρυσοπετάλου).²⁴ This account book of a goldsmith's workshop mentions the raw materials and combustibles needed, as well as the productivity of the workshop, listed according to the daily production of its craftsmen, specialists in various areas of goldwork. In this text we can clearly see the craftsmen's specializations with their names, as well as the kind of work the artisans produce.

At the start, a distinction, based on provenance, is made among the various kinds of lead used in different alloys. The sea lead (μόλυβδος θαλάσσης) is hard and dirty; to

²⁰ *Chrysoepsetes* or *archon tes kharages*: Hendy, *Studies*, 427 n. 245. See also K.-P. Matschke, "Mining," *EHB* 116.

²¹ Grierson, "Counterfeiting," 254 n. 3. Cf. Berthelot and Ruelle, *Anciens alchimistes*, 2:239.12–240.2: ὡσπερ οἱ τεχνῖται οἱ ἐπιστάμενοι βασιλικὸν τύπτειν νόμισμα οὐχ ἑαυτοῖς τύπτειν, ἐπεὶ τιμωροῦνται.

²² Grierson, "Counterfeiting," 246, 252–53.

²³ Berthelot and Ruelle, *Anciens alchimistes*, 2:326.12–26.

²⁴ *Ibid.*, 377.7–379.23.

make it less fragile they make an alloy of 50 pounds of lead σαβυήσιος and 1 pound of white tin. The lead σαβυήσιος and the lead from Dalmatia (δελματήσιος) are pure and soft, while the lead from Sardis (σαρδιανός) is soft and contains copper (ἔγγαλκος). It is evident that the reference to lead is made because there is a method of extracting silver from the very firm (πυκνότατον) lead cast from the results of sand washing (μόλυβδον χυτὸν ἀπὸ τῶν ἀμμοπλύτων), which yields 1 pound of silver per 10 pounds of common pure lead (κοινὸν καθαρὸν μόλυβδον).²⁵

The text then mentions the quantities of necessary metals, the other materials, and the combustibles for various jobs carried out in the workshop, which are carried out by special artisans. There are artisans for fashioning molds, artisans who specialize in work convected with crucibles for melting gold or silver, and artisans for filing and working with tongs (τεχνῖται εἰς πλάσιν καὶ χώνην καὶ ῥινὴν καὶ ἀρπακτῆριν). Along with forty men who work the bellows (ἐργάτας φυσηλάτας), they can produce about 5 pounds of gold and silver cakes (χρυσολιθαρίου/ἀργυρολιθαρίου) per day. There are also artisans called “goldbeaters” (πεταλουργοὶ or χρυσηλάται), who hammer gold or silver in thin leaves (πέταλα), which will later be used for silverplating (περιαργυρώσεως) and gilding (χρυσώσεως). From one cake of gold (χρυσολιθάριον), the gilder (χρυσωτής) makes in one day 150 leaves for gilding entire objects (χρύσωσις ἐν ὄλοχρύσῳ), plus 50 leaves for book illumination with gold (χρυσογραφία) and 100 leaves for gilding the edges of objects (χρύσωσις ἐν ἀκροχρύσῳ). It is also mentioned that 1 pound of gold produces 72 gold coins of the type called εὐρυζον.²⁶

Because the material loses weight (ὑποχωρεῖ) when it is processed, that is, a part of it is lost, the artisans are given a larger quantity of material, in which the future loss has already been calculated. Thus the goldbeater receives material that includes whatever is expected to be lost, by pound of weight, as the gold is melted and then made into leaves (σὺν τῆς ὕλης καὶ τὰ ὑποχωροῦντα εἰς τὴν ἔψησιν τοῦ χρυσίου καὶ τὸν ἐκπεταλισμὸν καθ’ ἐκάστην λίτραν); this additional amount is six gold coins per pound, since the loss is calculated as 2 keratia per nomisma (ὡς κατατρέχει εἰς τὸ νόμισμα κεράτια δύο).²⁷ For gilding only, the gilder receives an additional amount of three gold coins per pound of the object, because the loss is one keration per nomisma; for preparing the foundation layer on an object for gilding (ὑπόχρησιν ἤτοι ὑποσκευὴν χρυσώσεως), in the case of small statues the gilder receives three coins per pound if he uses wood and one coin per pound if he uses stone. If the gilder is an independent artisan (αὐτό-

²⁵ Ibid., 36.19–37.16.

²⁶ This is the same as ὄβρυζον, i.e., gold that, according to Pliny (33.59), has been purified by fire; hence the arabic name *ibriz* for pure (purified) gold. Goltz, *Geschichte der Mineralnamen*, 188, 256. Cf. *obryzon kharagma*: Hendy, *Studies*, 350–51, 355. R. Halleux, “Méthodes d’essai et d’affinage des alliages aurifères dans l’Antiquité et au Moyen Age,” in C. Morrisson et al., *L’or monnayé*, vol. 1, *Purification et altérations de Rome à Byzance*, Cahiers Ernest-Babelon 2 (Paris, 1985), 48.

²⁷ The 2 keratia result from the combination of 1½ keration per nomisma *hyper obryzes* (designed specifically to recover the difference between the theoretical and the actual weights of coins) and ½ keration per nomisma *hyper rhopes* (the largest fee, apparently for weighing the coins involved in a transaction), later termed *idiotikos zygos* and *chrysochoïkos stathmos*, as it is deduced from the papyri of Oxyrhynchus (late 6th century/early 7th century) in Egypt. Hendy, *Studies*, 352–53.

διον ἐργάζεται) and creates objects described in other account books (καθὼς ἐλογίσθη ἐν πολλαῖς λογοθεσίαις), the prices change; the text gives price examples by reference to work already done in well-known buildings.

This text indicates that the metals used in the workshop were gold, silver, copper of excellent quality, tin, and various kinds of lead after special processing. Other materials used were sulfur, copper ore, *misý, sinopis*,²⁸ gypsum,²⁹ *rubrica*, and *artemisia indica*. There was also wax, oil, material for hardening iron (στόμωμα), fish glue (ιχθυόκολλα), glue made from bull's hide (ταυρόκολλα), gum (κόμμι), ψαρικά (obviously the material used for the making of fish glue), and other materials of unknown composition such as σαβανικά and σοφιγυ. Finally, coal and wood were used as combustibles. The weights and measures used were the λίτρα (litra), the κεντηνάριον, the ξέστης (sextarius), the modius, the ἀμαξεία (a wagon load), the δάκτυλος, the πήχυς, and the ἐξάγιον. The coin that is mentioned is the ὀλοκόττινον or χρύσινον or εὐρυζον.

The techniques of metalworking and especially those of gold and silversmithing are much more ancient than the written tradition related to them, since they are transmitted empirically from generation to generation; this can be proved by a comparison of the techniques encountered in archaeological finds with those described in philological sources.³⁰ The texts extant in Byzantine manuscripts suggest that some techniques were influenced by those of Persia and India, evidently after the creation of Alexander the Great's immense empire, while others betray Arab influence. As far as coinage is concerned, the high quality of Roman coins and their purity at the end of the fourth century prove both the financial strength of the state and the high level of metalworking techniques. These were used not only for making weapons, tools, gold and silverware, and jewelry, but also for manuscript illumination and for the decoration of various buildings (e.g., palaces and churches³¹), especially with gold. That the luxury of Byzantine palaces rivaled that of the Arab caliphs³² and the Latin kings was a result of the excellent quality of the work of experienced craftsmen. Since ancient times, the workshops for metalworking, especially in gold and silver, and the guilds of the related artisans not only contributed to the economy but also to the political and cultural brilliance of the states involved.

²⁸ It is very likely that the reference is to the *sinopis* (red ocher/earth, *rubrica*), which is collected from the caves of Cappadocia and transferred to and sold in Sinope. The τεκτονικὴ *rubrica* is much inferior to *sinopis*; the best *rubrica* is found in Egypt and Carthage. Diosc., *De materia medica*, 5.96. Goltz, *Geschichte der Mineralnamen*, 150–51.

²⁹ This is calcium sulfate (CaSO₄), whose color varies from white to gray and light blue; in hydrate form (CaSO₄ · 2H₂O), it is white or colorless. Goltz, *Geschichte der Mineralnamen*, 172–73.

³⁰ J. Ogden, *Ancient Jewellery* (London, 1992).

³¹ Berthelot and Ruelle, *Anciens alchimistes*, 2:37.10–11: Εἰ δὲ βούλει εἰς ἔργον ἐκκλησίας ποιῆσαι. For ecclesiastical silverplate, see S. A. Boyd and M. M. Mango, eds., *Ecclesiastical Silver Plate in Sixth-Century Byzantium* (Washington, D.C., 1992). See also A. Cutler, "The Industries of Art," *EHB* 546ff, 558ff.

³² K. Vogel, "Byzantine Science," *The Cambridge Medieval History*, vol. 4, pt. 2 (Cambridge, 1967), 269–70. H. Hunger, *Die hochsprachliche profane Literatur der Byzantiner*, 2 vols. (Munich, 1978), 2:237–39.

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