PLINY THE ELDER ON THE MELTING AND CORROSION OF SILVER WITH TIN SOLDERS: *PRIUS LIQUESCAT ARGENTUM . . . AB EO ERODI ARGENTUM* (*HN* 34.161)

In his account of *plumbum nigrum* (lead) and *plumbum album* (tin), the Elder Pliny, among other things, says (*HN* 34.161–2): *neque argentum ex eo* [tin] *plumbatur, quoniam prius liquescat argentum, confirmantque, si minus albo nigri, quam satis est, misceatur, erodi ab eo argentum.*[1] The translation of this passage in virtually all the modern editions and studies of Book 34 of the *Naturalis Historia* involves Pliny saying that 'the silver melts before'—and in this all translations imply, although with varying interpretations, the meaning 'the silver melts before the tin', whereas *erodi ab eo argentum* is translated as 'the silver is corroded by the tin'.[2] In fact, the melting point of silver is much higher than that of tin, and the alleged corrosive effects of tin on silver similarly have no scientific basis.[3] To date the passage remains obscure, and one of the many controversial passages of the *Naturalis Historia* that have often made Pliny the subject of heavy criticism, or even mirth, for being a quite incompetent and unreliable reporter of scientific topics.[4] Despite the nearly total lack of

[1] Pliny describes the preparation and use of a lead–tin (admixed in the ratio 2:1) *tertiarium* alloy at *HN* 34.160: *tertiarium vocant, in quo dua sunt nigri portiones et tertia albi.* The *tertiarium* can be classed as what is commonly referrred to as a soft solder, since it is used at relatively low temperatures to join various metals. As is the case with all solders, lead–tin alloys have melting points (so called 'eutectic temperatures') that are lower (to an extent which is a function of alloy composition) than the melting temperatures of the separate metals: see e.g. C. T. Lynch, *CRC Handbook of Materials Science*, II: *Metals, Composites, and Refractory Materials* (Boca Raton, FL, 1984), 312. Studies and archaeometric analyses of Roman lead–tin soldered artefacts are available in e.g.: H. Maryon, *AJA* 53 (1949), 93–126; V. Fell, *Ancient Fluxes for Soldering and Brazing* (Museum Applied Science Center for Archaeology) *MASCA J* 2 (1982), 82–5; M. J. Hughes, *Solders from Classical to Medieval Times*, in J. Ellis-Jones (ed.), *Aspects of Ancient Mining and Metallurgy* (Bangor, 1988), 80–7; E. Paparazzo, 'Archaeomaterials', in J.C. Rivière and S. Myhra (edd.), *Handbook of Surface and Interface Analysis* (New York, 1998), 835–69.

[2] See e.g.: K. C. Bailey, *The Elder Pliny's Chapters on Chemical Subjects* II (London, 1932), 67 (translation), 197 (commentary); H. Rackham, *Pliny, Natural History, Libri XXXIII–XXXV* (London, 1952), 244–5; H. Le Bonniec, *Pline l'Ancien, Histoire Naturelle, Livre XXXIV* (Paris, 1953), 162 (translation), 312 (commentary); A. Corso, R. Mugellesi, and G. Rosati, *Plinio, La Storia Naturale, Libri 33–37* (Torino, 1988), 173; R. König and K. Bayer, *C. Plinius Secundus der Ältere, Naturkunde, Buch XXXIV* (München, 1989), 111 (translation), 203 (commentary); J. F. Healy, *Pliny the Elder on Science and Technology* (Oxford, 1999), 317; R. C. A. Rottländer, *Plinius Secundus d. Ä* (St Katharinen, 2000), 73 (translation), 96, n. 41 (commentary).

[3] R. C. Weast (ed.), *CRC Handbook of Chemistry and Physics* (Boca Raton, FL, 1983): the melting point of silver is 961.9°C (B-136), whereas the melting point of tin is 231.8°C (B-150). Tin is not in the least corrosive; in fact, this metal is widely used to coat metallic artefacts to *protect* them against corrosion. See e.g. M. C. Sneed and R. C. Brasted, *Comprehensive Inorganic Chemistry*, 7: *The Elements and Compounds of Group IV A* (Princeton, 1966), 216–19; N. D. Meeks, 'Tin-rich surfaces on bronze—some experimental and archaeological considerations', *Archaeometry*, 28 (1986), 133–62; N. D. Meeks, 'Surface characterization of tinned bronze, high-tin bronze, tinned iron and arsenical bronze', in S. La Niece and P. Craddock (edd.), *Metal Plating and Patination* (London, 1993), 247–65.

[4] R. French, *Ancient Natural History: Histories of Nature* (London, 1994), 196–255. As he also states in the introduction of this book (x–xi), French thinks 'science' (in the modern sense of the word) a term applicable neither to Pliny nor to any other ancient thinkers. By way of contrast,

knowledge in Pliny's time of chemical and metallurgical processes, in this article, I argue, on the basis of both philological and scientific considerations, that Pliny is not in error. In other words, while I shall not credit him with a 'scientific' knowledge superior to that available in his time (in line with Professor Healy's view, see n. 4), I shall attempt to show, through a careful analysis of this passage, that the sound and proven knowledge we possess today in chemistry and metallurgy are unambiguously consistent with the phenomena described by Pliny.

Specifically, the knowledge I derive from the passage is that silver cannot be soldered with tin when the latter metal is used alone, and any attempt to achieve soldering that requires exposure to more and more heat would involve temperatures so high as to reach the melting point of silver, although no soldering would in fact be accomplished. Conversely, when the solder contains the tin admixed with lead, but the amount of lead is below the right proportion, the silver is exposed to temperatures that—although lower than its melting point—produce corrosion of this metal, as manifested by a darkening of its surface. My interpretation relies upon the following considerations:

1. There are three metal-to-metal relations in the passage: (i) silver–tin, *argentum ex eo* [tin] *plumbatur*; (ii) tin–lead, *albo nigri*, and (iii) tin–silver, *erodi ab eo* [tin] *argentum*. In each relation a given metal is always identified unambiguously by the noun or a pronoun, and the syntactical relation existing between two given metals is equally expressed in an unmistakable way in all cases. Pliny exercises especial care over metal identification, even at the risk of making the text heavy with repetitions, so much so that *argentum* appears as many as three times in a passage as short as that studied here.[5] Since clarity seems to be his major concern, redundancy is the price he pays to accomplish his task, particularly whenever the particular metal dealt with at a certain point of the passage differs from that referred to at the point which comes immediately before. There is every reason to believe, therefore, that he would have explicitly specified *quam plumbum album* after *prius liquescat argentum*, had he

Healy (n. 2), ix, says that 'In an evaluation of Pliny science there seems no point in avoiding the use of meaningful modern technology, where appropriate' and 'there seems no sustainable objection to examining the "science" of the ancient world in the light of modern criteria, provided that the Greeks and Romans are not credited with technical knowledge that is the product of later centuries!'

Some discussion of Pliny's 'scientific' purposes and output can be found in A. Wallace-Hadrill, 'Pliny the Elder and man's unnatural history', *G&R* n.s. XXXVII (1990), 80–96.

A general study of Pliny's thought is given in M. Beagon, *Roman Nature: The Thought of Pliny the Elder* (Oxford, 1992), and a detailed analysis of Pliny's attitude towards natural phenomena in a section of the same book, titled 'Contemplation or investigation?' (42–52).

As far as metallurgical topics are concerned, see e.g. R. Halleux, 'Les deux Métallurgies du Plomb Argentifère dans *l'Histoire Naturelle* de Pline', *Rev. Phil.* 49 (1975), 72–88. This latter paper also deals with the sources utilised for Book 34, and in nn. 1 and 3 with the strong criticism of Pliny's metallurgical accounts by Forbes and Agricola, respectively. Noteworthy is also the following judgement from R. J. Forbes, *Studies in Ancient Technology* VII (Leiden, 1964), 227 'It should, therefore, be remembered that the deliberate differentiation and recognitions of several reactions is the modern phase, and the "single" method of primitive metallurgy is really a mess of reactions which could only be duplicated with much practical skill and keen observation of product and process, because the reactions were not understood as they are today.'

[5] Since this article is not concerned with Pliny's rhetorical style, my analysis is only presented in the limited context of the passage, with no claim to generality. For a detailed analysis on this subject, see e.g. Wallace-Hadrill (n. 4); Healy (n. 2), 79–105; M. Beagon, 'Burning the brambles: rhetoric and ideology in Pliny, *Natural History* 18 (1–24)', in D. Innes, H. Hine, and C. Pelling (edd.), *Ethics and Rhetoric* (Oxford, 1995), 117–32.

intended to say 'the silver melts before the tin'. The fact that no such reference to tin is made indicates that *prius liquescat argentum* is to be compared *directly and only* to the soldering process (*plumbatur*); in other words, I believe that a more appropriate translation of the phrase should run as 'before any silver soldering can be brought about'. The fact that silver is explicitly specified in the sentence *prius liquescat argentum* has probably made most translators think of tin as the most obvious comparison term but, in view of the preceding considerations, such a hypothesis appears to be unwarranted.

2. There are several representative examples of *celerius*, namely an adverb with a meaning very close to that of *prius*, which occur in other metallurgical passages of the same Book 34, such as: §99 (bronze) *aera extersa robiginem celerius trahunt*; §143 (iron) *aliud robiginem celerius sentit*, and §146 (iron) *eo celerius robiginem trahit*. In all cases, Pliny is only concerned with describing *how fast* the physico-chemical properties of a certain metal manifest themselves as a function of the environment or external treatments, whereas a comparison with other metals is never involved.

Also, other passages throughout the *Naturalis Historia* involve *liquesco* combined with temporal adverbs, and—again—all these passages lack any comparisons with other materials, the emphasis being exclusively placed upon recording *how fast* the material considered by itself manifests the *liquescere* action.[6] All this evidence is consistent with my interpretation that *prius liquescat argentum* is not related to the tin.

3. There are examples of *erodi* being used in combination with *ignis* by some Latin authors, for example Sen. *Ep.* 91.11: *vasta vis ignium colles per quos relucebat erosit*. Noteworthy in the *Naturalis Historia* is the passage at 31.98: *salis natura per se ignea est et inimica ignibus, fugiens eos, omnia erodens, corpora vero astringens*, in which fire and 'erosion' are unmistakably associated with each other via a cause–effect relationship. Closely related to our purposes, as it occurs in a metallurgical context, is the passage at 35.182, extolling the attributes of bitumen as a protective agent for bronze objects against the damaging action of fire: *aeramentis inlinitur firmatque ea contra ignes*; this clearly states the notion that fire (heat) may damage metals. All these passages lend support to an interpretation of *erodi ab eo* (tin) *argentum* as the silver being corroded by heat[7] whenever the soldering process is performed *si minus albo nigri, quam satis, misceatur*. In particular, such an interpretation is consistent with both thermodynamics and Pliny's terminology. It should be noted that the metallurgy of tin–lead–silver systems is very complex, as are the attendant soldering

[6] See, for example: Plin. *HN* 19.46 *gutta quaeque saliva celerrime liquescit*; 26.60 *fungosum tenuissimis fistulis, cito liquescens virus redolens*; and 32.73 *laudatur pontica candida et carens venis squamisque et quae celerrime liquescit*.

[7] In this paper I shall discuss how and to what extent heat can affect silver. It should be noted that any soldering process involves exposure of the metallic parts to be joined to hot molten solders, although heat is never explicitly referred to in the passage under study. On the other hand, *liquesco* and words bearing the root *liqu-* are very often used by Pliny in metallurgical contexts involving high temperatures. For instance: 33.100 *cum aera inaurentur . . . ovi liquore candido usum*; 33.123 *dein sub patinis accenso follibus continuis igni atque ita calici sudore deterso, qui fit argenti colore et aquae liquore*; 34.95 *namque (aes) Capuae liquatur non carbonis ignibus, sed ligni, purgaturque roboreo cribro perfusum*; 34.130 *liquescentibus cadmea et aerario lapide. levissimum hoc est flaturae totius evolatque e fornacibus*; 34.159 *fuit in fornacibus liquor stagnum appellatur*; 34.170 *uritur autem (plumbum nigrum) in patinis per lamnas minutas . . . donec liquor mutetur in cinerem*.

properties, which depend on the alloying proportions of the metals.[8] Indeed, a 'low amount' of lead (*non satis*) in the alloy would be inadequate for soldering purposes, and would cause the silver to be exposed to the atmosphere at temperatures higher than that of the melting point of the (missing) eutectic tin–lead alloy.[9] These conditions would produce a sizeable amount of silver oxide, a black-brownish compound.[10] I therefore speculate that Pliny is simply referring to the blackening of silver, due to this oxide, when he says *erodi ab eo*, as though he considered such a blackening as a 'burning' mark left on the silver surface by the tin.[11] Although it is the heat that actually damages the silver, Pliny is in fact not much in error since, while he relates silver corrosion to the tin (*ab eo*), to describe these 'corrosive' effects, he uses *erodi*, a term by which he means the action of fire (heat).[12] On the other hand, it appears

[8] Lynch (n. 1), 299, 312. I should like to thank the anonymous *CQ* referee for calling my attention to this issue.

[9] Exposure of silver to heat could, for instance, be the case with the method known as 'sweating together', a procedure adopted in antiquity to join metals with soft solders, see Maryon (n. 1), 113.

[10] Usually, the formation and growth of metal oxides increases both with exposure time to air and with temperature: see e.g. R. K. Wild, 'Metallurgy', in J. C. Rivière and S. Myhra (edd.), *Handbook of Surface and Interface Analysis* (New York, 1998), 478. Thermochemical data show that this is also the case with silver metal exposed to oxygen within a certain temperature range: D. R. Gaskell, 'Metallurgical thermodynamics', in R. W. Cahn and P. Hasen (edd.), *Physical Metallurgy* (Amsterdam, 1983), 275- 8. Specifically, while silver is not oxidized by air or oxygen at room temperature, a film of the oxide Ag_2O forms on its surface when the metal is heated in air to about 200°C: see e.g. M. C. Sneed, J. L. Maynard, and R.C. Brasted *Comprehensive Inorganic Chemistry*, 2: *Copper, Silver and Gold* (Princeton, 1966), 141. In particular, this temperature would not be reached if the *tertiarium* were used as a solder (this alloy is in a pasty, i.e. working, condition at *c.* 185°C: see E. Paparazzo, 'Surface and interface analysis of a Roman lead pipe 'fistula': microchemistry of the soldering at the joint, as seen by scanning auger microscopy and X ray photoelectron spectroscopy', *Applied Surface Science*, 74 [1994], 69), and thus no silver oxide would ever form. By way of contrast, attempts at soldering silver with a tin–lead alloy low (*non satis*) in lead would involve temperatures comparable to or even higher than that sufficient for the formation of silver oxide, which would therefore manifest itself by a characteristic dark colouring.

[11] Since lead–tin solders were employed to attach smaller pieces to the body of silver objects, see Hughes (n. 1), 83, one can reasonably assume that the oxide-related darkening effect must be particularly noticeable because it spreads out over a proportionally large area of these small attachments. One can also surmise that, when the attachments were particularly small and thin, the silver oxidation might eventually result in their complete 'demetallization', i.e. actual corrosion: see L. Robbiola, J.-M. Blengino and C. Fiaud, 'Morphology and mechanisms of formation of natural patinas on archaeological Cu–Sn alloys', *Corrosion Science* 40 (1998) 2083–111.

[12] It is the 'low' lead amounts *non satis*, i.e. below the amount needed for the lead–tin alloy to feature soldering capabilities, which makes the (unsoldered) silver oxidize, whereas tin in itself has no corrosive effects: see Sneed and Brasted (n. 3). It should be remembered that, although the temperatures involved in the soldering of silver objects with tin–lead alloys mixed in the 'useful' (i.e. eutectic) proportion, namely 180°C, are *c.* 20°C lower than the temperature needed for air-oxidation of the silver (see n. 10), oxidation of minor amounts of the latter metal might occur at the interface as a result of local temperature gradients or imperfect mixing. While the occurrence of such localized corrosion is virtually unavoidable, its extent is quite negligible relative to the formation of the 'metallic' joint produced at the interface via incorporation of silver metal into the tin–lead alloy: see Maryon (n. 1), 112–14. Indeed, occurrence of this (minor) silver corrosion can only be revealed by detailed investigation of the joint via surface- and interface-sensitive analytical methods (see Paparazzo [n. 1], 837–52), and certainly not with the naked eye. By way of contrast, attempts at soldering silver at temperatures higher than that characteristic of air-oxidation of this metal would exclusively result in the formation of large, and thus clearly perceivable, amounts of silver oxide.

quite hard to believe that by *erodi* Pliny means a true corrosive action of the tin. Indeed, Pliny's awareness of tin actually being an anti-corrosive agent, and as such of its being plated on to metallic objects, and of these protective attributes being quite comparable to those of silver, is revealed by a passage at 34.162: *album incoquitur aereis operibus . . . et argentum incoquere simili modo*.

To Pliny's eyes, the darkening of precious, and in itself shiny, a metal as silver must be something worth noting, as he himself remarks at 33.98: *lineas ex argento nigras praeduci plerique mirantur*. To ascribe *ab eo erodi* to mercury metal or mercury-bearing substances, as proposed by some commentators,[13] seems totally unjustified, since in this passage there is reference neither to the terminology of these materials, nor to the contexts that qualify their attributes elsewhere in the *Naturalis Historia*.[14]

Conversely, if one wished to solder the silver with tin alone, one would not succeed *neque argentum ex eo plumbatur*, since the temperature would increase more and more up to the melting point of the silver (*liquescat*), whereas no soldering would be accomplished (*neque . . . plumbatur*). It is worth noting the fact that no silver darkening, due to formation of silver oxide (which I implied in *ab eo erodi*), is recorded here. Non-admixed tin produces no meaningful soldering, and any attempt using such material would involve prolonged exposure to more and more heat, and the attendant temperatures would rise higher and higher, well above the decomposition temperature of silver oxide. This implies that, on its way from room temperature up to the melting point of silver, the heating during (attempted) soldering would first cause growth of silver oxide, then decomposition of the same oxide, but to Pliny's eyes these two latter steps remain unnoticed.[15] In other words, he probably deems the melting, namely the disfiguring, of an object made of such a precious material as silver a much worse effect, and one deserving more urgent attention, than staining.[16] It should be noted that the purity test for silver described at 33.127 (also commented upon by Greenaway[17]), *vatillis ferreis candentibus ramento inposito, quod candidum permaneat, probatur. Proxima bonitas rufo, nulla nigro*, is consistent with my interpretation. Indeed, the temperature involved with white-hot (*candentibus*) iron (*c.* 1000°C) is much higher than the decomposition temperature of silver oxide (*c.* 230°C), the presence of which would thereby not be detected in such a test.

The interpretation put forward by some commentators that both *prius liquescat argentum* and *ab eo erodi* are to be related to the formation of a silver–tin alloy[18] seems

[13] See Bailey (n. 2); Corso, Mugellesi, and Rosati (n. 2). It is worth stressing that the use of lead–tin soft solders (involving no mercury amalgams) has been documented in Roman silver objects: see Hughes (n. 1), 83.

[14] 33.99: *argentum vivum appellatur. venenum rerum omnium est perrumpitque vasa permanans tabe dira*; 33.125: *hydrargyro argentum inauratur solum nunc prope, cum et in aerea simili modo*. It should be noted that the first of these passages bears no specific relation to soldering processes, as well as that increasing the amount of lead in the solder would not certainly limit the *venenum* and *perrumpitque* actions of *argentum vivum*. On the other hand, the second passage is about gilding.

[15] Silver oxide decomposes at 230°C (see West [n. 3], B-137), i.e. very close to the melting point of tin (ibid. B-150), and about 50°C higher than the melting point of lead–tin eutectic alloys (Lynch [n. 1]). It should be remembered that silver oxide decomposition, $Ag_2O \Rightarrow 2Ag$ (met) + $\frac{1}{2}O_2$ (gas), brings the silver back to the metallic state.

[16] Although he often expresses himself with moralizing, even deprecating, tones against *luxuria* items (see Wallace-Hadrill [n. 4], 85–91), Pliny is well aware of silver's value being inferior only to gold's, 33.95: *Ab his* [gold ores] *argenti metalla dicantur, quae sequens insania est*.

[17] F. Greenaway, 'Chemical tests in Pliny', in R. French and F. Greenaway (edd.), *Science in the Early Roman Empire: Pliny the Elder, His Sources and Influence* (London, 1986), 154.

[18] Bailey (n. 2), 197; Rackham (n. 2), 244; Le Bonniec (n. 2), 312; Rottländer (n. 2), 96.

unwarranted for the following reasons. Firstly, it seems unlikely that Pliny could record the 'eutectic' effects in alloys involving comparatively low proportions of silver (*c.* 2–4 per cent).[19] Secondly, the extensive and thereby perceivable occurrence of a silver-bearing alloy would somehow imply that 'successful' soldering had been accomplished, but this would obviously be against *neque argentum ex eo plumbatur*. Thirdly, if a silver–tin alloy were implied in *prius liquescat argentum*, the same alloy would again involve that some soldering occurs via the two metals melting *together at the same time*, but this is against *prius* .

4. Apropos *plumbum album*, the passage at 34.163 is noteworthy: *Ut liquefactum pondere videatur, non calore, rupisse*, which—I believe—gives a decisive proof that Pliny is well aware of tin having a strikingly low melting point, as appears in the vivid way in which he highlights such a characteristic of this metal. Such awareness, so clearly and unmistakably apparent in this passage, is virtually impossible to reconcile with the same author's implying that silver melts at a lower temperature than does tin. On the other hand, neither in Books 33 or 34, nor in any other book throughout the *Naturalis Historia*, does any passage occur stating that silver features an unusually low melting point.[20] Several other passages bear witness to Pliny's awareness of metallurgical processes. For instance, at 33.95 he describes thermal cycles *eodem opere ignium discedit*, where the plural *ignium* probably emphasizes the importance of selecting appropriate temperatures in view of the particular process; or, at 34.94: *omne enim diligentius purgatis igni vitiis excoctisque*, where *diligentius* seemingly betrays a careful concern with the parameters required in a given thermal treatment. His awareness of metallurgical matters is further witnessed by a passage at 34.159: *huius qui primus fuit in fornacibus liquor stagnum appellatur; qui secundus, argentum; quod remansit in fornacibus, galena, quae fit tertia portio additae venae; haec rursus conflata dat nigrum plumbum deductis partibus nonis II.* As can be seen, Pliny gives a great deal of rather thorough detail to describe a process aimed at separating metals, alloys, and by-products (*stagnum*, *argentum*, *galena*, *plumbum nigrum*) from each other by virtue of their differing melting points, and he manages to record the stages of the process in chronological order (*primus*, *secundus*, *remansit*) as a function of heat involved (*fornacibus*, *conflata*). Again, such a detailed account of the benefits

[19] see Lynch (n. 8).

[20] In fact, there are several pieces of evidence that suggest that Pliny was aware of silver having a comparatively high melting point. For instance, 36.200: *accipit harenas ex quibus aliubi vitrum, aliubi argentum, aliubi minium, aliubi plumbi genera, aliubi pigmenta, aliubi medicamenta fundit.* This passage appears in a context extolling the attributes of fire, and it is worth noting that the first four articles mentioned therein (all inorganic materials or metals) are listed in order of decreasing melting point, and in particular silver is mentioned before *plumbi genera*, i.e lead and tin (cf. 34.156). Moreover a passage at 34.157: *postea caminis separantur conflatique in plumbum album resolvuntur* shows Pliny's awareness that the separation of tin from gold is made possible by the great difference between the melting points of the two metals. Since gold has a melting point comparatively similar to that of silver (1040 and 960°C, respectively), this passage contributes a further hint of Pliny being aware of a similar difference between silver and tin: again, this is against that *argentum liquescat prius* implies *quam plumbum album.*

Also, in his account of white lightning (*fulmen clarum*), 2.137: *aurum et aes et argentum liquatur intus*, Pliny reports the melting of silver (*liquatur*), as well as of two other high-melting-point metals, as a paradigmatic manifestation of the heating violence of such lightning. The melting of silver objects as a dramatic witness to the violence of lightning is also reported in Sen. *QNat.* 2.31: *ceterum mira fulminis . . . opera sunt . . . divina . . . potentia: loculis integris . . . conflatur argentum.* Further references to this and analogous phenomenona are given in D. Vottero, *Questioni Naturali, Lucio Anneo Seneca* (Turin, 1989), 330, n. 2.

(and possible harm) involved in the heat treatment of a great variety of metals is hard to reconcile with such great errors in the melting points of silver and tin.

Also, could Pliny ever think it possible to solder a metal (silver) with another metal (tin) featuring an allegedly higher melting point, while he himself is aware that silver has a much higher melting point than tin?[21] In other words, I believe that the main issue for Pliny is not the melting points of the silver or of the tin, but the phenomena associated with the latter metal being admixed with varying proportions of lead.

Not only does my interpretation provide a better interpretation of the passage, it also allows one fully to understand and explain the key role played by the passage itself within the context of Pliny's treatment of tin. Indeed, the passage comes just after: [tin] *nulli rei sine mixtura utile est* (§161). This latter sentence proves to be the premise, the main message that justifies the entire passage studied in the present article, as it has the following three consequences: (i) *neque argentum plumbatur*, (ii) *prius liquescat argentum*, and (iii) *ab eo erodi argento*. Specifically, while the first is a more *general* consequence, the second and the third are *particular* consequences, which emphasize the implications involved in the premise in dramatic, even paradoxical terms, and my interpretation helps to highlight such implications. Indeed, tin by itself is so useless that it would cause the silver to melt (*liquescere*), however high the melting point of the latter metal may be, and can even prove so harmful as to *erodi* so valued a metal as silver.

Just as paradoxical is the fact that 'pure' tin cannot be soldered to itself because, although no difference in the melting point or value is involved, again it needs *mixtura*, as stated at 34.158: *ne (potest) album quidem secum sine nigro*. Thus, silver and tin are the two opposite, extreme *exempla* marking the route along which Pliny's rhetorical strategy makes the readers proceed, acquainting them with the message he wishes to convey.

In conclusion, I propose the following new translation of the passage studied in this article:

Silver cannot be soldered with tin, because the silver melts before being soldered. And it is directly verified that, when the amount of lead admixed with tin is less than needed, the silver is damaged by the tin.

This translation, which in my opinion has philological justifications within the context both of the passage itself and of several other passages throughout the *Naturalis Historia*, shows that Pliny's treatment of the metallurgical topics therein is fully understandable in the light of both thermodynamics and chemistry.

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[21] See the passage at 34.163, discussed before, and n. 19.