THE BRONZE ALLOYS OF THE COINAGE OF THE LATER ROMAN EMPIRE

A summary study of the secondary numismatic literature relating to the bronze coinage of the fourth century demonstrates clearly the importance of the alloys which were used in the coin metal. The specific question of whether or not there was a silver wash on the coins of the period following the first tetrarchy that was meant to increase their intrinsic value still remains open. If one holds erroneously, as Mickwitz and the earlier writers apparently did,[1] that the bronze coins were not fiduciary, then this silver coating, if present, would have played a very important role in determining the intrinsic value of the currency and its face value.

In truth, however, it is most probable that the bronze coinage was fiduciary. Most recent opinion with regard to these coins has tended towards the belief that their monetary value rested upon other factors than their intrinsic value. The metallic content of the coinage played a very small part indeed as compared with such factors as whether or not the fiduciary coins could be readily exchanged for ones with full bullion value and whether or not they were acceptable to the government in satisfaction of tax debts at full face value. Nevertheless it is clear that a silver wash on a bronze coin may well have been intended to indicate that it was to be considered as more valuable than a simple bronze piece, as would normally be the case if a silver

[1] Mickwitz, "Geld und Wirtschaft im römischen Reich des IV Jahrhundert n. Christus," *Societas Scientiarum Fennica* (*Finska Vetenskaps Societeten, Helsingfors*), *Commentationes Humanarum Litterarum*, IV, 2, p. 62, calculated the value of the coins and established the denominations on the basis of the intrinsic value of the metal. P. Strauss, "Remarques sur la monnaie de cuivre au IVe siècle," *Revue numismatique*, Ser. 5, Vol. VIII (1944–45), pp. 4–5, felt that the diminution of the weight of the bronze coinage as well as the debasement of the alloy by reducing the silver content from four to two per cent was a sufficient explanation for the rising price of a pound of gold. Mattingly, *Roman Coins*, pp. 232–3, attributed the instability of the value of these *aes* coins to the same factors.

washed coin were to come into conditions of perfect competition in circulation with a plain bronze one. A smaller silvered piece might well represent a higher denomination than a heavy all bronze coin. Exact information on the nature of the coin metal would therefore be invaluable in the identification of the individual denominations.

The fact that a certain number of coins from the fourth century appear to have a silver wash was recognized very early. These coins are relatively few in number as compared with the sum total of extant fourth century bronzes, but the appearance of some of them would clearly lead one to the conclusion that silver was present on the surface to an appreciable degree. Many of the reports of hoards or excavations make specific mention of the presence of the so-called silver wash on some of the pieces,[2] and the standard secondary works, as mentioned before, are replete with references to the "silver-washed" currency of the fourth century.[3] Such references, however, are really based upon a comparatively few coins and even fewer analyses, so that it is quite clear that the entire problem must be re-examined.

The Romans were capable of obtaining refined copper and lead which were virtually pure.[4] In the production of alloys for use in coinage they could, if they chose, either include or exclude any appreciable amounts of the common or precious metals. They could refine the copper and lead ores used in the coin alloys so as to remove

[2] C. H. V. Sutherland, "A Roman Hoard from Lincolnshire," *Numismatic Chronicle*, Ser. 6, Vol. II (1942), p. 108, and Mattingly, "A Small Roman Hoard from Winchester," *Numismatic Chronicle*, Ser. 6, Vol. IV (1946), pp. 152–7, may be taken as examples of such reports.

[3] To cite only a few of these references see Mommsen, *Histoire de la monnaie romaine*, trans. Duc de Blacas, III, pp. 97–8; Maurice, *Numismatique constantinienne*, I, p. 427; Segrè, *Metrologia e circolazione monetaria degli antichi*, p. 436; "Inflation and Its Implication in Early Byzantine Times," *Byzantion*, XV (1940–41), p. 255, note 24; Mattingly, "The Monetary Systems of the Roman Empire from Diocletian to Theodosius I," *Numismatic Chronicle*, Ser. 6, Vol. IV (1946), pp. 112–3; Giesecke, *Antikes Geldwesen*, p. 189. Many more citations of this order can be given.

[4] On the extraction and purification of copper in antiquity see J. and L. Sabatier, *Production de l'or et de l'argent et du cuivre chez les anciens et hôtels monétaires des empires romain et byzantin*, pp. 50–3; J. Hammer, "Der Feingehalt der griechischen und römischen Münzen," *Zeitschrift für Numismatik, neue Folge* XXVI (1926), p. 12. Cf. R. J. Forbes, *Metallurgy in Antiquity. A Notebook for Archaeologists and Technologists*, pp. 231–377. Forbes, *op. cit.*, pp. 169–230 deals with the production of silver and lead in antiquity.

the silver which is normally present in those ores as an impurity. The analysis of the coinage in the period following the reign of Valentinian I supports this contention, as does a passage from Cassiodorus in which that sixth century author indicates that the currency of his day was supposedly of pure metals, and that the precious and base metals were kept separate.[5] Leyden Papyrus X demonstrates clearly that by the third century mans' knowledge of the metallurgical arts was so far advanced that the separation of silver from lead or copper ores did not present any insurmountable problems. Conclusive evidence, however, that the Romans were capable of separating the various metals found together in the ores of the fourth century is to be found in the text of *Codex Theodosianus*, IX, 21, 6 (Feb. 13, 349 A.D.), which will be discussed in detail at a later point.

A quantitative analysis of a series of late Roman bronzes should therefore furnish clear proof of whether or not the Romans did refine the constituent elements of the bronze to a high degree at all times and whether or not they applied a silver coating to the surface. If the percentage of silver in the coin alloy is two per cent or better, it can be safely assumed that silver has been added to the metal with a definite purpose in mind. If the silver content lies below two per cent, the explanation for its presence must lie elsewhere. The amount of two per cent has been chosen arbitrarily, but it is reasonable. If the silver content were less it would hardly impart a lasting sheen to the coins, and if it were applied solely to the surface it would be rapidly worn away leaving only the bare bronze.

The analysis of late Roman bronzes should yield still more information of value. If the series of coins is extensive enough, it should be possible to determine how strictly the Romans sought to maintain a specific alloy and also at what periods changes were made in the metallic content of the coins. This, of course, rests upon the presumption that discipline at the various mints was strict, and that the orders transmitted to the mintmasters by the imperial government received unquestioned and absolute obedience.

A record of a number of such quantitative analyses exists in the various numismatic publications. In the Appendix to this article 104

[5] Cassiodorus, *Variae*, VII, 32: *Auri flamma nulla injuria permixta albescat, argenti color gratia candoris arrideat, aeris rubor in nativa qualitate permaneat.*

such analyses involving a total of 319 coins extending from the reign of Diocletian to that of Heraclius have been collected. Unfortunately the pieces that have been analyzed have not in all cases been adequately described. This presents a problem because of the large number of ancient counterfeits of fourth century bronzes. Nearly half of the coins found in the rubbish heaps at Oxyrhynchus were cast and therefore of illegal origin.[6] The early fourth century really shows extraordinary activity on the part of the counterfeiters.[7] This, as is to be expected, was immediately reflected in a rash of laws designed to put an end to the practice of forging currency by setting forth increasingly severe punishments for that crime.[8]

The problem of such counterfeits coming from antiquity is a real one even in our time, and it has troubled the modern numismatists in the preparation of their catalogues. The French scholar Maurice, who wrote the standard work on the coinage of Constantine, encountered this difficulty in its most serious form. A series of pieces is known which have the same type in silver and in silvered bronze.[9] There are other bronze coins which, according to Maurice, occur with a visible silver wash and without it in the same type.[10] It seems obvious that the first series just cited, *i.e.*, that including coins occurring in silver and in silvered bronze, is composed of true silver pieces and counterfeit bronzes which were meant to circulate as silver.[11] The second group, however, presents a more difficult problem. It may be that originally the entire series of coins was silver coated, but that in the course of time the thin covering layer of silver was worn off completely on some of the pieces. It is even possible that the silvery appearance of some of the coins may be the result of salts or oxides not containing silver, or perhaps some of the bronze coins were

[6] J. G. Milne, "Report on the Coins found at Antinoe in 1914," *Numismatic Chronicle*, Ser. 6, Vol. VII (1947), p. 112.

[7] Maurice, *Numismatique constantinienne*, I, pp. 229–30, and 435. For the concave bronze coins from cities which are not known to have had mints see Blanchet and Dieudonné, *Manuel de numismatique française*, I, p. 151.

[8] *Codex Theodosianus*, XI, 21, 1; *Ibid.*, IX, 21, 2 = *Codex Iustinianus*, IX, 24, 1; *Ibid.*, VII, 13, 2. Cf. Maurice, *Numismatique constantinienne*, I, pp. xxiv and cxix. Many more laws may be cited.

[9] Maurice, *Numismatique constantinienne*, I, pp. 397–8.

[10] *Ibid.*, I, p. 427.

[11] *Ibid.*, I, pp. 397–8.

silver-washed or zinced by counterfeiters since antiquity or even during the fourth century. The many possibilities present a problem in themselves, but a careful chemical analysis of these coins would eliminate some of these hypotheses. Such an analysis would only be of use, however, if a full description of the type were given for each specimen, so that it would be possible to establish the relationships, if any, between the percentage of silver, the mint, and the coin type.

With these difficulties in mind it is still possible to make some general statements regarding the alloys of the coins listed in the Appendix. These analyses, as can be seen from the notations in the column for losses or the totals of the percentages given where no notation of loss was made by the original authors, have been carried out rather carefully, and as a group they represent a fairly accurate picture of the metallic content of late Roman bronzes. The silver content of individual coins only rises above two per cent exceptionally. Approximately $9^1/_2$ per cent of the total number of analyses show silver in excess of two per cent. Since these analyses, however, include coins struck as late as the reign of Heraclius, at which time there is no question of a silver coating, a more accurate calculation would limit the number of analyses involved to the period before the reign of Theodosius I. Of the 73 analyses which fall into that category only about $13^1/_2$ per cent show more than two per cent of silver. A total of ten coins, all dated in the reign of Valentinian I or earlier, show upon analysis what may be considered appreciable amounts of silver. Five of these ten coins have weights above eight grams and five of them have weights below $5^1/_2$ grams. All of the heavier coins are attributed to Diocletian and Maximian while the lighter ones are attributed to Galerius, Magnentius, Constantine II, and Valentinian I.[12] In the case of Magnentius only two coins were analyzed, and both showed silver in excess of two per cent. In all other cases the number of coins showing only small amounts of silver or none at all exceeded the number of pieces with a possible silver coating.

[12] Hammer, "Der Feingehalt der griechischen und römischen Münzen," *Zeitschrift für Numismatik, neue Folge* XXVI (1926), p. 143, maintained that from Diocletian on the larger bronzes contained some silver, but that silver was only added to the smaller bronzes from the reign of Constantine onwards.

This wide variation in the silver content of the alloy is further reflected in the composition of the major constituents of the coins. The base metal content of the *aes*, as can be seen, varied considerably. The mint authorities do not seem to have striven for uniformity of composition in the coinage. In many cases no zinc at all was found in the coins, while the percentage of lead was often quite high. The actual coin weights and types for those pieces showing high lead content are unknown. The general picture, however, does not show any rational order in which the composition was varied. This would seem to indicate that the agency for the preparation of the blank discs from which the coins were struck did not mix highly refined metallic elements in exactly prescribed proportions, but rather that raw metals, which had been refined to varying degrees, were mixed. It must be remembered that the metallic content of the bronze would be relatively unimportant because it merely served as a base for a fiduciary coin of low face value.

Probably the most important analysis of late Roman bronzes was that carried out by Brambach on 216 coins of the reign of Constantine the Great. Tests showed the presence of 1.98 per cent of silver and 0.02 per cent of gold. The weight of the metal involved in this analysis was about two Roman pounds, so that the weight of the silver was only some 13 grams out of a total of approximately 646 grams of metal. Even this is a fairly high percentage as compared with the majority of the analyses. Unfortunately these tests can only be considered as uncontrolled because there are no descriptions of the coins involved. Since the total amount of silver was so small, the presence of only a single coin that was silvered in antiquity might negate the validity of the entire analysis. Still the amount of silver is so small that these results may be interpreted as indicating that the bronze coinage of that period was not silver coated, but that small amounts of silver were left in the metals used in the coin alloy.

Prior to the analysis of nine large *folles* of the western half of the Empire which had been part of the Seltz hoard, it was customary to rely on the work done by Hammer and to say that fourth century bronzes had a silver wash which formed from two to four per cent of the mass of the coin, but that since most of the silver was applied on

the surface it had worn off to a large degree.[13] The very accurate and painstaking analysis carried out by Lewis on the nine large bronzes from the western half of the Empire revealed no silver whatsoever. Those coins which seemed to have a "white" or silvery coating were found upon analysis to have a thin layer of copper salt deposited on the surface. On very close examination it was further revealed that this copper salt was actually green in color.

In the preparation of the coins for this analysis a great degree of care was evident, for in some cases the surface layers were removed until bright metal was exposed, but in others the fragments were analyzed as received. This would appear to be definite proof that during the period of the first tetrarchy the bronze coinage of at least the western half of the Empire was not silver washed. There may have been a difference in the metallic composition of the coins from the eastern half of the Empire, but the fact that only a very few authors have noted the mints in conjunction with the analyses negates any possibility of determining whether or not such was the case. It should be noted, however, that four of the ten coins showing silver in excess of two per cent are attributed to Maximian who ruled in the West. The coins which are derived from the rulers in the East do not show quite as much silver. It is therefore most likely that in the East, as well as in the West, silver was not one of the elements added to the coin alloy.

On the basis of his research Lewis maintained that the coins of the first tetrarchy were not silvered. He was, however, faced by the fact that a law in the Theodosian Code, which has already been mentioned and which we shall re-interpret at a later point, seemed to indicate that in 349 A.D. there was silver in the coinage. Earlier writers had consistently explained that the edict of 349 was evidence of a silver wash on the bronze coins.[14] Therefore, following Mattingly and Mickwitz, Lewis pointed out that not long after 340 A.D. there was a

[13] *Idem.* Cf. Mickwitz, "Geld und Wirtschaft im römischen Reich des IV Jahrhundert n. Christus," *Societas Scientiarum Fennica* (*Finska Vetenskaps Societeten, Helsingfors*), *Commentationes Humanarum Litterarum*, IV, 2, *op. cit.*, pp. 83–4.

[14] See Babelon, *Traité des monnaies grecques et romaines*, I, pt. I, cols. 608–9, for one of the most far-reaching of such interpretations.

change in the coinage with the issuance of a new piece of greater weight. The most probable date for this change was 348 A.D. Lewis contended that the edict of 349 referred to these new coins which he called the *maiorina pecunia,* since they were larger and the term occurred in the edict of 349. He attempted to support this further by pointing out "that even in 356 A.D. after a second rise in weight to ca. 6 grams, not all *folles* were of this "somewhat larger coinage" is shown by the summary of Codex Theodosianus IX. 23. 1 in the Vatican MS.... *ut nulli viatori liceat amplius a mille follibus portare neque centenionales* (small coins) *vel maiorinas,* if as seems almost unquestionable, *follis* here signifies the coin and not the coin-filled container..."[15]

In refutation of this last point it may be said that it is by no means as unquestionable as Lewis infers that the *folles* mentioned in *Codex Theodosianus,* IX, 23, 1, are the coins and not the coin-filled containers. There is more than adequate proof that such coin-filled containers existed in antiquity. The actual remains of such rolls of coins in leather strips with the ends twisted have been recovered. One such roll was preserved intact, and the traces of others as well as the "spilled piles" of coins matted together by corrosion are known.[16] Etymological and literary proof exists for such rolls of coins,[17] and one early sixth century papyrus gives the price of a suckling pig as one solidus and three *dermata.* It is most probable that the leather container with a specific number of coins is referred to here.[18] It is also true that at least some earlier scholars have interpreted the text in a fashion that Lewis feels is impossible. Finlay, in a short note, specifically takes it to be the sack filled with coins and points to the example

[15] N. Lewis, *A Hoard of Folles from Seltz (Alsace),* NNM 79, pp. 17–21.
[16] *Ibid.,* pp. 3–4. He points to the modern usage in which coins are often wrapped in paper in a similar manner.
[17] Babelon, *Traité des monnaies greques et romaines,* I, pt. I, col. 761. Cf. Isidore of Seville, *Etymologiarum,* XVI, xviii, 11 (ed. Lindsay, 1911): *Folles dicuntur a saculo quo conduntur, a continente id quod continetur appelatum.* Also see Hultsch, *Metrologicorum Scriptorum Reliquiae,* I, pp. 144, note 4; 267; 303; 308; 342–3; II, pp. 105; 151–2. *CIL.,* V, 1880 (late fifth or early sixth century) contains the expression *"denariorum folex sescentos"* probably in the sense of a bag of coins worth 600 denarii. Cf. *Ibid.,* VIII, 5333.
[18] *P. Oxyrhynchus,* 1917; West and Johnson, *Currency in Roman and Byzantine Egypt,* p. 137.

of the modern Turks who used the expression "a purse" for the sum of 200 piastres.[19]

Even more important the analyses listed in the Appendix to this article show fewer coins dated after 349 containing appreciable amounts of silver. Elmer in his study of the coinage of Julian, it is true, refers to the silver-wash (*Silbersud*) which is noticeable on some coins of this reign, but he points out that it is lacking on most pieces. He attributed this lack to the action of the moist earth and said, without giving any reference or detailed evidence, that analyses show that the larger coin of Julian had from 1.20 to two per cent of silver.[20] The list of analyses compiled for this paper is in direct contradiction of Elmer's statement. Only one coin after 355 A.D. shows more than 0.35 per cent of silver, and that coin is attributed to Valentinian. Any silvery appearance on these mid-fourth century pieces would seem to be the result of copper salts.

A new explanation must be found for the fact that ten of the analyses show silver in some quantity as well as for the edict of 349. These two bits of evidence must be connected. The solution, however, is readily attainable if it is remembered that even today the largest part of the silver produced each year is a by-product of copper and lead refining, and that copper and lead are two of the major constituents of bronze. Native copper always contains some dissolved silver, and *galenite*, the usual lead ore, very commonly contains silver sulphide in addition to lead sulphide. In metals which were not highly refined some of this silver would remain. The analyses show quite conclusively that highly refined components were not mixed to prepare the coin alloy, and that the formula for that bronze was not strictly adhered to by the various mints. Therefore some silver would remain in the coins.

How is the law of 349 A.D., which specifically refers to silver in the *maiorina pecunia*, to be understood in the light of this new view? According to the *Lex Julia*, as commented upon by Ulpian, it was

[19] Finlay, *Greece Under the Romans* (London, n. d.), p. 127, note 1.

[20] Elmer, "Die Kupfergeldform unter Julianus Philosophus," *Numismatische Zeitschrift, neue Folge* XXX (1937), p. 31. He also maintained that the smaller coins were of pure copper, and that only individual ones showed as much as 1/1000th part of silver. The examples of this coin which were silvery in appearance, he concluded, had been either silvered or zinced since antiquity.

forbidden at an early date to insert or to mix anything into the alloy of the public currency, and it was also forbidden to extract anything therefrom.[21] This important law was still in force in the fourth century. The text of the edict of 349 A.D. reinforces this provision with reference to a specific set of circumstances. The exact instance in question becomes evident from a careful review of the wording of the law.

Imp. Constantius A. Limenio P(raefecto) P(raetori)o Comperimus nonnullos flaturarios maiorinam pecuniam non minus criminose quam crebre separato argento ab aere purgare. Si quis igitur post haec fuerit in hac machinatione deprehensus, capitaliter se fecisse cognoscet, verum et eos, qui domum agrumque praebuerint, relatis in largitionibus facultatibus esse plectendos: nostra scilicet super eorum nominibus edocenda clementia. *P(ro)p(osita) prid. id. Feb. Limenio et Catullino conss.*[22]

This is a constitution addressed to the Praetorian Prefect Limenius, designed against the *flaturarii* who frequently cleanse (*purgare*) the *maiorina pecunia* by separating the silver from the bronze. There is no need at this point to determine what is meant by the *maiorina pecunia* other than to indicate that it was obviously a form of bronze currency. The text of *Codex Theodosianus*, IX, 23, 1, makes this abundantly clear. The *flaturarii* are easily recognizable as some of the mint workers. It was their function to cast and to prepare the coin flan or blank discs of metal which were later struck by other workmen at the mint.[23] It must therefore be borne in mind that the fraudulent practice which this constitution is directed against was definitely perpetrated prior to the striking of the coin and the possible application of any silver wash on the surface. It was a crime carried out prior to or during the casting and preparation of the flan or blank from which the coin itself was to be struck. What had happened to cause the issuance of this new edict reinforcing the substance of the

[21] *Digest*, XLVIII, 13, 1. This law refers to gold, silver and bronze. *Basilika*, LX, 45, 2, prohibits only the adulteration of gold and silver, but it does not mention bronze.

[22] *Codex Theodosianus*, IX, 21, 6 (Feb. 13, 349 A.D.).

[23] F. Lenormant [E. Babelon] in Daremberg-Saglio, *Dictionnaire des antiquités grecques et romaines*, III, pt. II, p. 1984. For this meaning in words related to *flaturarius* see Vitruvius, II, 7, 5, and Pliny, *Naturalis Historiae*, VII, 56, 57, 197. Cf. Mommsen, *Historie de la monnaie romaine*, trans. Duc. de Blacas, III, p. 15. It was Mommsen's view that the phrase *conflare pecunias* meant to separate precious metal from the base metal coin.

Lex Julia? Possibly it was reported to the Emperor Constantius II that some of the *flaturarii* were further refining the metal sent to them so as to remove the last vestiges of silver from the copper and lead ores before making the blanks. Since there would be virtually no change in the appearance of the coins they could do this successfully and secure a profit, if the silver content of the metallic ores was sufficiently high.

This edict therefore does not indicate that the bronze coinage was silver-washed, as has been supposed in the past, but rather the contrary, that the coins were meant to look like bronzes. If the coins were meant to be silver-washed, the fraudulent practice of the *flaturarii* would be immediately obvious to all. The newly issued coins would not present a silvery appearance, and the piece that had been tampered with would never have been received into circulation for fear that the government would not honor it when it collected taxes. Also the fact that this criminal act was apparently restricted to the mint officials indicates that the removal of a silver wash from coins that had already been struck was not at issue. If it were a mere removal of silver wash it cannot be doubted that others than mint workers would be involved in the fraudulent practice. Such easy profits would not be permitted to slip by. The metal workers of the Empire and other members of the ordinary population would also have plied this trade with vigor.

In summation it would appear on the basis of the chemical tests and the actual text of the one pertinent law that the coin alloy of the first half of the fourth century was relatively uncontrolled and that the various ingredients were not highly refined. As the coinage of silver coins fell off, however, and as the use of such silver coins came to be more and more restricted to areas such as Britain, the imperial government took sharper measures to recover all of the silver contained in the ores used for the bronze coin alloy. After the mid-fourth century it seems almost certain that no silver was permitted to remain in the coin alloy.

The migration of the silver coinage to Britain, sections of Gaul, and the lower Danube region is very noticeable during the fourth century. The changes in the weights of the silver coins some time after 355 A.D. indicate a changed mint ratio. Without diverging too widely

from the subject of this article into the controversial field of the intrinsic value and the variations in the supply of silver during the fourth century it can be said that the real reason for the increased care in the recovery of silver in the latter half of the fourth century lies in the changing value of that metal and its restricted use within the borders of the Empire. A study dealing primarily with the silver coinage of that period should yield the final answer.

HOWARD L. ADELSON

APPENDIX I[1]

Emperor	*No.*	*Weight*	*Copper*	*Tin*	*Zinc*	*Lead*	*Silver*	*Iron*	*Nickel*	*Gold*	*Copper Oxide*	*Loss*	*Total*	*Source*
Diocletian	1	3.77	94.92	3.05	0.90	0.12	0.25	0.23	0.40				100.00	Bibra[2]
	1	?	88.93	1.20	8.28		1.50					0.09	100.00	Sabatier
	1	2.65	95.84	2.23		1.93							100.00	Bibra[3]
	1	?	91.38	3.85	2.89	traces	1.81	potin	of Alex-andria			+Pb 0.07	100.00	Sabatier
	1	3.41	98.60	0.90			0.20						99.70	Maurice
	1	±3.00	88.84	1.00		2.28					7.88		100.00	Webb
	1	9.50	91.08	3.03	2.15	1.38	1.00	1.13	0.23				100.00	Bibra[4]
	1	10.75	92.78	1.85		1.20	4.18						100.01	Maurice
	1	8.55	92.70	7.30		traces							100.00	Schaeffer[5]
	1	?	87.00	13.00		traces							100.00	Schaeffer[6]
Maximian	1	4.70	85.66	6.28		7.79		0.52	0.05				100.30	Lewis
	1	9.50	94.91	1.10		0.07	2.65	0.77	0.50				100.00	Bibra
	1	9.15	97.57	4.61		1.74		0.47	0.04				104.43	Lewis
	1	8.15	92.67	5.07	0.63	0.30	0.40	0.30	0.30				100.00	Bibra[7]
	1	8.50	91.85	3.63		4.46		0.10	0.04				100.08	Lewis
	1	9.30	91.96	3.80		1.34	2.60	0.07	0.23				100.00	Bibra[8]
	1	13.70	89.67	5.52		4.22		0.98	0.04				100.43	Lewis
	1	8.33	97.97	traces		traces	2.03	traces	traces				100.00	Bibra
	1	9.65	86.25	6.41		7.27		0.13	0.03				100.09	Lewis
	1	9.55	94.59	2.00		0.14	3.27	traces	traces				100.00	Bibra[9]
	1	?	96.95	0.87	0.24	1.09		0.20					99.35	Brazener
Const. Chlor.	1	3.75	94.42	1.04	2.00	1.36	0.22	0.26	0.70				100.00	Bibra[10]
Galerius	1	10.25	85.80	5.33		8.55			0.04				99.72	Lewis

Emperor	*No.*	*Weight*	*Copper*	*Tin*	*Zinc*	*Lead*	*Silver*	*Iron*	*Nickel*	*Gold*	*Copper Oxide*	*Loss*	*Total*	*Source*
	1	5.22	96.09	0.98			2.55						100.43	Maurice
	1	2.52	98.87			1.03							99.90	Bibra[11]
Maxentius	1	?	86.50	13.50			traces						100.00	Schaeffer[12]
	1	?	82.03	5.03	1.30	11.40						0.24	100.00	Sabatier[13]
	1	6.35	88.72	5.85		5.43							100.00	Bibra[14]
Max. Daza	1	7.10	87.98	4.00		6.16		1.38	0.05				99.57	Lewis
	1	8.45	87.89	4.49		6.55		0.92	0.04				99.89	Lewis
Licinius I	1	?	83.75	7.77	0.66	7.82	Also in Sabatier from Göbel						100.00	Bibra[15]
	1	4.05	89.59	5.00		3.35	1.86						99.80	Maurice
	1	?	89.50	10.50			traces						100.00	Schaeffer[16]
317–323	1	?	97.30	0.11	0.14	0.34	Nil	1.54	Nil				99.43	Brazener
Const. Mag.	1	2.30	90.27	6.81		2.27	0.14	0.20	0.31				100.00	Bibra[17]
	1	3.13	94.07	2.00		2.37	1.04	0.08	0.44				100.08	Bibra[18]
	1	?	92.34	1.34	2.30	1.01	0.83	1.00	0.21				100.00	Bibra[19]
	1	?	95.93	0.35	1.46	0.53	0.25	0.76	0.42				100.00	Bibra[20]
	1	4.10	91.19	3.33	2.70	1.10	0.93		0.75				100.00	Bibra
	1	2.50	94.64	1.56		3.80							100.00	Bibra[21]
	1	?	87.50	7.14	0.91	4.26	Also in Sabatier from Göbel					0.19	100.00	Bibra[22]
	1	?	91.39	3.78	0.06	2.81	1.01	0.13	0.10				99.28	Brazener
	1	4.20	68.87	22.89	1.86	5.85	0.30	0.03	0.20				100.00	Bibra[23]
	1	?	90.60	9.40			traces						100.00	Schaeffer[24]
	1	5.33	75.50	14.00	1.70	7.33	1.03	0.14	0.30				100.00	Bibra[25]
	1	5.75	90.27	4.43		5.30		0.37					99.37	Lewis
	216	ca. 646.90	86.03	3.90		8.05	1.98			0.02		0.02	100.00	Brambach

(Average weight of the 216 coins was 3+ grams.)

Emperor	*No.*	*Weight*	*Copper*	*Tin*	*Zinc*	*Lead*	*Silver*	*Iron*	*Nickel*	*Gold*	*Copper Oxide*	*Loss*	*Total*	*Source*
Const. I or II	1	1.32	87.96	4.35	7.69								100.00	Bibra[26]
	1	2.00	83.55	1.42	14.76			0.27					100.00	Bibra[27]
337–361	1	?	77.18	1.57	0.08	19.91	0.36	0.07					99.17	Brazener
Constantine II	1	1.60	93.82	2.46		2.19	1.75						100.00	Maurice
	1	1.40	84.68	2.80		7.80	3.22	1.40	0.10				100.00	Bibra[28]
	1	2.20	89.68	4.36		4.27	1.03	0.66					100.00	Bibra[29]
	1	2.40	96.01		2.07	1.72		1.00	0.20				100.00	Bibra[30]
	1	1.78	90.01	1.13	1.44	7.00		0.42	traces				100.00	Bibra[31]
	1	2.07	92.75	2.37		3.08	0.90	0.53	0.17				100.00	Bibra[32]
	1	3.95	91.65	4.71		1.72	1.01	0.13	0.66				100.00	Bibra[33]
	1	3.20	93.93	1.83	1.76	0.70	1.00	0.55	0.23				100.00	Bibra
Constans I	1	2.05	87.77	1.90	1.60	8.20		0.13	0.40				100.00	Bibra[34]
	1	2.01	91.82	1.40		6.15	traces	0.13	0.30				99.80	Bibra[35]
	1	?	90.99	0.42	1.92	5.25	0.97	0.12	0.33				100.00	Bibra
Constantius II	1	4.44	91.25	2.38	4.44	0.52	0.80	0.20	0.41				100.02	Bibra[36]
	1	?	88.01	4.08	3.74	3.95						0.22	100.00	Sabatier[37]
Magnentius	1	3.70	89.08	2.63	2.00	2.27	3.40	0.27	0.25				99.90	Bibra[38]
	1	4.00	85.43	2.11	1.38	8.08	2.70	0.30	traces				100.00	Bibra[39]
Gallus	1	3.38	95.05	1.97	1.90	0.80	traces	0.08	0.20				100.00	Bibra[40]
355–363	1	?	83.68	1.24	0.50	13.98	Nil	0.20					99.60	Brazener
363–364	1	?	83.92	1.10	0.06	13.64	0.35	0.07	0.10				99.24	Brazener
366–376	1	?	86.71	0.78	0.05	11.98	0.26	0.10	0.11				99.78	Brazener
Valentinian I	1	4.20	87.08		0.61	9.99	2.02	0.20	0.10				100.00	Bibra
	1	?	92.94	0.70	2.23	2.11						2.02	100.00	Sabatier[41]
,, and Valens	1	2.52	94.66	1.04	1.33	1.82		0.71	0.44				98.85	Bibra[42]

Emperor	*No.*	*Weight*	*Copper*	*Tin*	*Zinc*	*Lead*	*Silver*	*Iron*	*Nickel*	*Gold*	*Copper Oxide*	*Loss*	*Total*	*Source*
379–395	1	?	98.16	0.20	0.16	0.41	Nil	0.17	Nil				99.10	Brazener
Theodosius I	1	1.17	98.30			1.76							100.06	Bibra[43]
	1	3.75	96.62	3.38		traces							100.00	Bibra[44]
	1	?	90.04	1.25	2.60	6.11	traces						100.00	Sabatier[45]
Arcadius	1	4.50	95.97	1.22	1.31	1.00							99.50	Bibra[46]
	1	4.30	96.29	0.93	1.50	0.90							99.62	Bibra[46]
	1	3.70	96.68	1.00	0.80	1.02							99.50	Bibra[46]
IV or V cent.	1	?	62.40	0.80		36.80							100.00	Mattingly
	1	?	66.60	0.70		32.70							100.00	Mattingly
	1	?	68.70	1.60		29.70							100.00	Mattingly
	1	?	64.50	1.60		33.60	0.30						100.00	Mattingly
Zeno	1	12.13	96.29	1.11	2.43								99.83	Bibra[46]
	1	6.00	96.20	1.80	0.50	1.30							99.80	Bibra[46]
Anastasius	1	15.31	97.51	1.01	0.93								99.45	Bibra[46]
	1	15.41	97.48	0.50	1.30	0.07							99.81	Bibra[46]
	1	6.01	97.04	0.88	1.03	0.42							99.37	Bibra[46]
	1	?	97.41		2.31							0.28	100.00	Sabatier[47]
Justin I	1	1.90	87.84	4.40	0.70	5.73							98.67	Bibra[46]
	1	1.96	96.91	1.20	0.76		0.33						99.20	Bibra[46]
	1	17.50	98.26	0.51	0.92								99.69	Bibra[46]
Justin I and So-	1	12.10	97.76	0.24	1.60	0.70							100.30	Bibra[46]
[phia	1	11.10	97.26	0.84	1.43								99.53	Bibra[46]
	1	?	96.75	0.80	2.45	traces							100.00	Sabatier[48]
Justinian	1	2.20	93.06	4.80	0.40	1.64							99.90	Bibra[46]

Emperor	*No.*	*Weight*	*Copper*	*Tin*	*Zinc*	*Lead*	*Silver*	*Iron*	*Nickel*	*Gold*	*Copper Oxide*	*Loss*	*Total*	*Source*
	1	3.16	84.53	6.82		8.65							100.00	Bibra[49]
	1	?	100.00		The source cited is Göbel, but the result is unusual								100.00	Mommsen[50]
Justin II	1	?	96.75	0.80	3.42	The source quoted is Sabatier, but it does not seem to be correct							100.97	Mommsen
Maurice	1	4.00	79.94	6.50	6.89	6.12							99.45	Bibra[46]
	1	4.10	79.63	5.33	7.50	7.00							96.46	Bibra[46]
Phocas	1	6.23	96.70	1.00	2.00								99.70	Bibra[46]
	1	5.50	94.93	2.93	1.00	0.50							99.36	Bibra[46]
Heraclius	1	5.91	98.30	0.88		0.37							99.55	Bibra[46]

[1] The number of analyses is very limited, and only a very few of these analyses are reported in conjunction with detailed information regarding the coin type or the mint attribution of the coins. It is, therefore, necessary that a study containing such information should be done. The sources of metal for the individual mints must have differed from province to province, and as a result the impurities in the metals would have varied from mint to mint. In the table the coins have merely been attributed to a ruler or a date period according to the scheme of attribution used in the source. The totals have been calculated in some cases by the original analysts, but in many others it was found necessary to supply them. Since these totals give us the amount of material lost in the analysis, they can, in some measure, be used to judge the exactness of the testing, and it may also be seen whether the result might have been materially changed by a closer analysis. In cases where the losses were calculated by the original analyst they have been included. The table itself is self-explanatory. In the columns to the right of the coin weights are the percentages of the various metals included in the alloy.

The principal source of the chemical analyses listed in the table is J. Hammer, "Der Feingehalt der griechischen und römischen Münzen, "*Zeitschrift für Numismatik, neue Folge* XXVI (1926), pp. 1–145, which is summarized in a chart on pages 137–144 of that work insofar as it pertains to the period of the Later Roman Empire. Hammer's study is largely dependent on an earlier work by E. Bibra, *Die Bronzen und Kupferlegierungen der alten und ältesten Völker* (Erlangen, 1869). In addition some of the analyses contained in this Appendix were derived from F. A. Schaeffer, "Deux trésors de monnaies romaines découvertes en Alsace," *Bulletin de la Société pour la Conservation des Monuments historiques d'Alsace*, 1926, pp. 93–128; W. Brambach, "Centenionalis," *Mitteilungen für Münzensammler*, I (1924), p. 84; J. and L. Sabatier, *Production de l'or et de l'argent et du cuivre chez les anciens et hôtels monétaires des empires romain et byzantin*, pp. 80–2; Maurice, *Numismatique constantinienne*, III, pp. xxxiv–xxxix; P. H. Webb, "The Pre-Reform Coinage of Diocletian and his Colleagues," *Numismatic Chronicle*, Ser. 5, Vol. IX, (1929), pp. 192–3; Mommsen, *Histoire de la monnaie romaine*, trans. Duc de Blacas, III, pp. 102–3; and p. 103, notes 1 and 2; N. Lewis, "A Hoard of Folles from Seltz (Alsace)," *Numismatic Notes and Monographs*, LXXIX, pp. 76–81; H. Mattingly, "The Bermondsey Hoard, Analysis," *Numismatic Chronicle*, Ser. 6, Vol. VII (1947), p. 91; W. F. Brazener, "Analysis," in R. Mond and O. H. Myers, *The Bucheum*, I, pp. 119–120, and Babelon, *Traité des monnaies grecques et romaines*, I, pt. I, col. 370.

It is worthy of note that the more recent analyses, in general, seem to show less silver content than the earlier ones, but it would be improper to speculate about the cause for this phenomenon. Only in the analyses given by Bibra and Maurice are appreciable amounts of silver to be found.

[2] Antimony 0.10% and sulphur 0.03%.

[3] The analyst is given as Commaille.

[4] Traces of cobalt.

[5] The analyst is given as Mahler.

[6] The coin is one of a group of eight with an average weight of 9.97 grams. The analyst is given as Mahler.

[7] Antimony 0.13%, cobalt 0.11% and sulphur 0.09%.

[8] Traces of antimony.

[9] Traces of antimony and sulphur.
[10] Traces of antimony and arsenic.
[11] The analyst is given as Commaille. Hammer mistakenly lists this as a coin of Maximianus.
[12] The coin is one of a group of thirteen with an average weight of 7.68 grams. The analyst is given as Mahler.
[13] Cited by Mommsen-Blacas, Babelon and Hammer from Sabatier.
[14] The analyst is given as Commaille.
[15] The analyst is given as Göbel. It is cited by Mommsen-Blacas from Göbel.
[16] The coin is one of a group of thirty-nine with an average weight of 4.47 grams. The analyst is given as Mahler.
[17] Traces of cobalt and sulphur.
[18] Antimony 0.08%.
[19] Antimony 0.97% and traces of cobalt.
[20] Antimony 0.30% and traces of arsenic, cobalt and sulphur.
[21] The analyst is given as Commaille.
[22] The analyst is given as Göbel. Cited by Mommsen-Blacas from Göbel.
[23] Traces of sulphur.
[24] The coin is one of a group of ninety-six with an average weight of 4.49 grams. The analyst is given as Mahler.
[25] Traces of antimony.
[26] The analyst is given as Commaille.
[27] Traces of cobalt. The analyst is given as Commaille.
[28] Traces of antimony.
[29] Traces of antimony.
[30] Traces of sulphur.
[31] Traces of antimony.
[32] Antimony 0.20%, traces of arsenic and cobalt.
[33] Antimony 0.12%, traces of arsenic and cobalt.
[34] Traces of antimony and sulphur.
[35] Traces of antimony and cobalt.
[36] Listed as Constantinus, but with the dates 337–361 A. D., indicating that it must be Constantius II. Hammer lists it correctly as Constantius II. Antimony 0.02% and traces of arsenic and cobalt.
[37] Cited by Mommsen-Blacas and Hammer from Sabatier.
[38] Traces of antimony.
[39] Traces of antimony.
[40] Traces of sulphur.
[41] Cited by Mommsen-Blacas and Hammer from Sabatier.
[42] Traces of antimony. Listed by Hammer under Valentinian I alone.
[43] The analyst is given as Commaille.
[44] The analyst is given as Commaille.
[45] Cited by Mommsen-Blacas, Babelon and Hammer from Sabatier.
[46] Cited from Hammer's listing of the analyses given by Bibra.
[47] Cited by Mommsen-Blacas, Babelon and Hammer from Sabatier.
[48] Cited by Mommsen-Blacas and Hammer from Sabatier. Mommsen-Blacas attributes it to Justinian I alone and does not mention the traces of lead.
[49] The analyst is given as Commaille.
[50] Cited by Babelon from Mommsen-Blacas.