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by

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Determining Weight Standards of Debased Ancient Silver-Copper Alloy Coinages

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In numismatics a standard method for calculating the weight standard of an ancient coinage is to collect the weights of as many specimens as possible and then to take the average of these.[1] Alternatives to the average may be preferred: median weights, or distribution curves, or combinations of these and other measures, together with a calculation of the deviation.[2] The condition of the coins may also be taken into account, excluding worn, damaged or corroded specimens, or coins with earth or mineralised deposits and concretions on their surfaces; and statistical methods may be undertaken to compensate for potential biases.[3] All of these approaches can be critiqued but there is a general feeling that combinations are probably better than reliance on a single method and that if the different methods produce similar results these are likely to be broadly accurate.[4]

The methods rely on the assumption that each coin weighed is composed of solid metal, in a form more or less identical to that when it was originally made. Given that many surviving ancient coins, particularly those composed of copper alloys, have heavily tarnished, corroded or mineralised surfaces ('patinas') that are less dense than the metal beneath, this assumption is likely to be incorrect for a significant number of surviving specimens. The mineralised areas and corroded deposits may be of varying depth, sometimes penetrating the entire coin. The problem is particularly acute for silver-copper alloy coins, where the surfaces were deliberately treated at the time of manufacture to corrode out the copper portion of the alloy in order to give the surfaces the appearance of fine silver.[5] This process left voids and corrosion products within the subsurface body of the coin. Further corrosion and leaching of copper, and the formation of additional corrosion products of both silver and copper, are likely to have occurred during the centuries in which the coins remained buried in the ground, and cleaning of the coins with corrosive chemicals after discovery will produce yet more changes to the composition.[6]

All of these changes will have an impact on the weight and density of the coin. To some extent the degree to which these are affected will depend on the amount of copper in the alloy, although the burial environment may also cause the silver

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[1] Grierson 1975, pp. 146–9 (with caveats); Göbl 1987, p. 49; Burnett 1991, p. 19.

[2] Naster 1975; Duncan-Jones 1994, p. 219 n. 28; Butcher and Ponting 2014.

[3] Hoyer 2013, pp. 248–52.

[4] See, e.g., the remarks in Hoyer 2013, p. 252 and Butcher and Ponting 2014, pp. 90–6.

[5] On the technique of depletion silvering, see Ponting 2012; Butcher and Ponting 2014, pp. 107–8.

[6] The various processes of tarnishing and mineralisation of silver-copper alloys are explored in Costa 2001, pp. 21–4.

to deteriorate. While we use the term ‘silver’ to describe a variety of silver-copper alloys, it is worth bearing in mind that many ancient coinages we describe in this way are in fact argentiferous coppers – that is, they contain more base metal than noble, and they were thus more susceptible to corrosion and loss of weight than finer coins. The extent to which corrosion processes will affect estimates of the weight standards of silver-copper alloy coins has not been explored in any systematic way, but it probably deserves more consideration than it has hitherto received.

Some indication of the extent of the problem can be observed by studying these effects on very base coinages. The coinages of late Ptolemaic and Roman Egypt are well known for base tetradrachms that were made predominantly of copper.[7] In 1910 J. G. Milne published a study of a group of Egyptian tetradrachms of the emperor Tiberius that had been acquired by the Ashmolean Museum through the agency of Giovanni Dattari.[8] These formed part of a hoard that included a group of late Ptolemaic tetradrachms and one of Ptolemy II. Milne was surprised by the ‘remarkable variation in weight’ of the Tiberian coins, which ranged from 5.54g to 13.32g (Fig. 1).[9] They all belonged to a single regnal year, seven (AD 20/21). He arranged for four of the coins to be analysed using wet chemical analysis by Professor Edmund Letts of Queen’s College, Belfast, and found that ‘the proportion of silver in these coins varied almost as widely as their weight’.[10] This he attributed to extreme carelessness at the Alexandrian mint; what he did not remark on, however, was the inverse correlation between weight and fineness. The lighter the coin, the higher the proportion of silver it contained, and vice versa (Fig. 2).

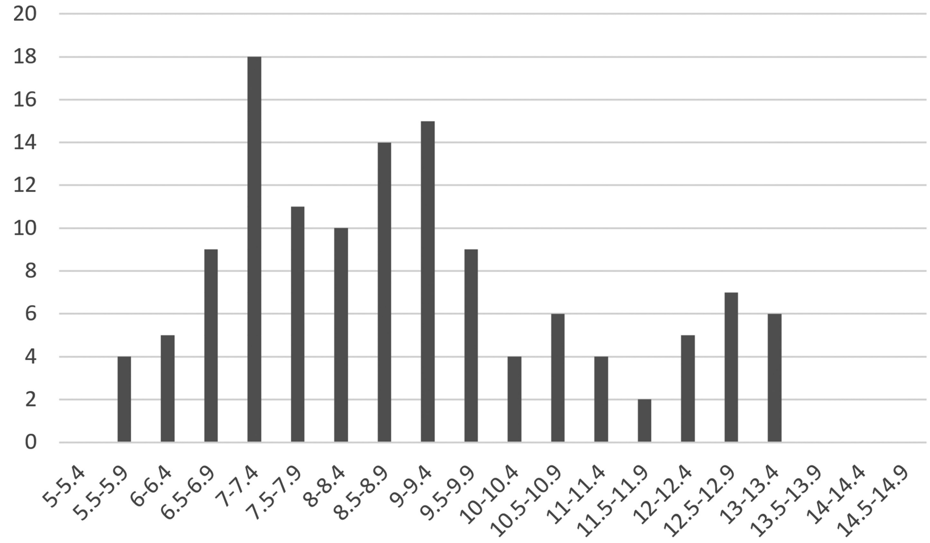

Fig. 1. Number of specimens (y axis) per weight interval (x axis) in the sample of Alexandrian tetradrachms of Tiberius year 7 published by J.G. Milne (1910).

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[7] Butcher and Ponting 2014, pp. 606–64; Faucher and Olivier 2020, p. 97.

[8] Milne 1910.

[9] Milne 1910, p. 335.

[10] Milne 1910, p. 336.

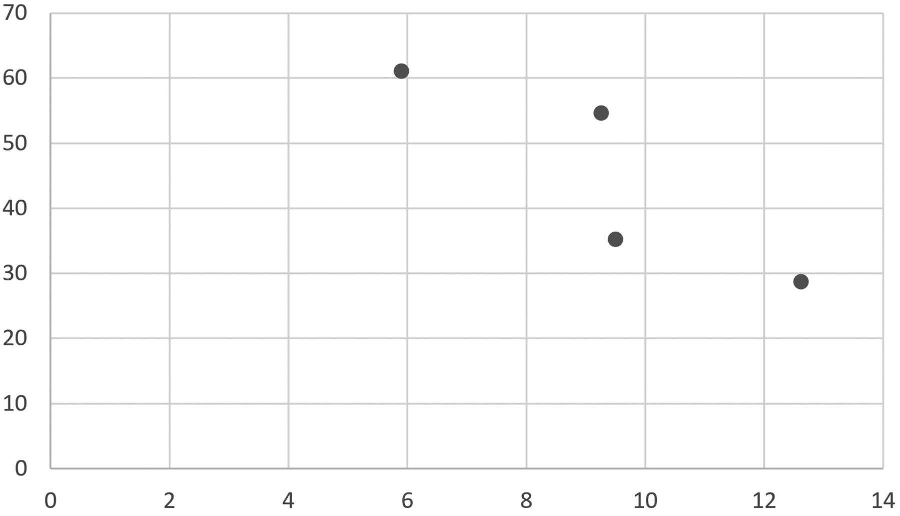

Fig. 2. Correlation of weight in grammes (x axis) and percentage fineness (y axis) of the four Alexandrian tetradrachms of Tiberius year 7 analysed by the chemist Prof. E.A. Letts of Queen's College, Belfast, the results of which were published in Milne 1910 as evidence of the 'gross carelessness of the mint officials at this time' (Milne 1910, p. 337).

A similar inverse correlation between fineness and weight was observed by Richard Duncan-Jones for Roman denarii of Trajan issued between AD 112 and 117, using data derived from David Walker's *Metrology of the Roman Silver Coinage* (1977). Heavier denarii had a tendency to be baser, and lighter denarii to be finer. Duncan-Jones could not find a satisfactory explanation for this, but he was partly correct in guessing that 'the effect appears to be a by-product of specific metallurgical procedures, which was not necessarily intended'.[11]

The most likely explanation for these kinds of inverse correlations can be found in very thorough work performed on specific gravities of ancient silver-copper alloy coins by Earle Caley in the 1940s and 50s. The bulk of it appeared in his *Chemical Composition of Parthian Coins* (1955), which, in spite of its title, presents the results of Caley's own wet chemical analyses of a variety of Greek and Roman coins as well as Parthian. He found that it was not uncommon for the specific gravity of individual coins to fall well below that of any silver-copper alloy, or even that of pure copper. Taken at face value this would mean that the coins concerned contained no silver at all, even though his chemical analyses showed that they did.[12] For example, an Egyptian tetradrachm of Vespasian had a specific gravity of only 5.6, a measurement that fell well below the specific gravities of both copper and silver. The chemical analysis of this coin had determined a fineness of 22.53% silver, which should produce a specific gravity of 9.22. He found a clear correlation between the fineness of each coin analysed and the degree of discrepancy between its expected and

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[11] Duncan-Jones 1994, pp. 242–3 and fig. 16.2.

[12] Caley 1952, p. 680; 1955, pp. 59–60.

current specific gravity: the greater the level of debasement, the larger the difference between the specific gravity recorded and that which would be anticipated for such an alloy.[13] Whereas fine coins were often identical or close to the specific gravity expected, debased coins nearly always fell below the expected figure. They were much less dense than they should have been.

Caley concluded that the discrepancy was likely to be due to the fact that a large proportion of the baser coins was now composed of something other than silver and copper – most likely a combination of corrosion products (e.g. silver chloride and cuprous oxide) and empty voids containing air.[14] That voids were in part responsible, and that these voids could be present deep within the cores of heavily debased and corroded coins, he demonstrated by taking a Ptolemaic tetradrachm with a very low specific gravity of 5.68, shaving away the outer, more corroded surfaces, and determining the specific gravity in the usual way, but leaving the coin core suspended in water for more than 24 hours and taking it out, drying it and weighing it at intervals. The coin core gradually gained weight, reaching an equilibrium after a day – an increase of 0.215g. Clearly the core of the coin contained voids, and these voids were absorbing the water. In this case corrosion had penetrated to the very centre of the coin. He determined that 'ancient billon coins have often undergone extensive internal corrosion with the formation of cavities and pores that have greatly reduced their original weight and specific gravity'.[15]

If one follows Caley's reasoning, the likely reason for the inverse correlation between weight and silver fineness is that corrosion, particularly of any copper portion of an alloy, is responsible for the divergences – the individual specimens being weighed have all been corroded to differing degrees. In the case of baser alloys this is partly due to the processes employed at the mint to deliberately corrode the blanks in order to produce a silvery surface; and partly due to corrosion during centuries of burial and any subsequent cleaning following discovery. As a result, many have lost a significant proportion of their copper, and therefore weight and density, and they have each lost these to different degrees. What was originally a relatively consistent product has become a very inconsistent one, owing to various random factors that encouraged or discouraged internal corrosion: flaws in the individual flans; the length of time they were blanched at the mint; the amount of heat applied during the process; any subsequent cold-working and striking; the environments they were exposed to during use and the microenvironments surrounding them after they were buried, and so on. Those that are more corroded have usually lost more of the copper portion of the alloy relative to the silver portion, so that when a wet chemical analysis is undertaken of the entire coin, as in the case of Milne's Egyptian tetradrachms of Tiberius, the corroded coins will appear to be finer because there is less copper to measure. Rather than a reflection of the original proportions of silver to copper used to make the alloy, the silver content recorded for the light-weight coins is a reflection of the amount of copper that has been corroded out of the coin as a whole.

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[13] Caley 1955, pp. 50–3. He observed the same problem for gold-silver alloys: 1949, pp. 75–6.

[14] Caley 1952, p. 681; 1955, pp. 60, 62.

[15] Caley 1955, p. 66.

The process of production of silver-copper alloy coins resulted in objects that were not entirely uniform either in weight or fineness at the point of issue. Corrosion during centuries of burial have further altered the objects as they have come down to us, even if the surfaces of the coins appear to be intact and fine detail is preserved. How, then, to determine the original weights of the surviving coins? Caley offered a potential solution, though this could be used only where the correct fineness for an issue was known. Since the volume of each coin was not very different from what it was originally, it should be possible to calculate an approximation of the original weight using its present weight, its present specific gravity and an estimation of the theoretical specific gravity as determined by analysis.[16] He suggested a simple formula:

$$\text{Original weight} = \frac{\text{Present weight x Theoretical specific gravity}}{\text{Present specific gravity}}$$

This, he thought, would produce a tolerably accurate estimate of the original weights of even heavily corroded coins. At the time that he was writing it was impossible to apply the formula systematically to larger groups of silver coinages simply because there were too few compositional analyses of them available to allow an estimation of the theoretical specific gravity. Even after better sets of analyses became available in the 1960s and 1970s there seems to have been little interest in applying the formula in metrological studies. If used at all, specific gravity was more commonly employed in determinations of fineness, particularly of gold-silver alloys.[17]

Fortunately we are now in a position where we can use the results of recent compositional analyses together with Caley's formula to see whether it yields meaningful estimates of original weights. We begin with the Egyptian tetradrachms of Tiberius, using coins that are probably specimens from the hoard recorded by Milne in 1910 (see below). The present weight of each coin was determined with an electronic balance,[18] as was the weight of water displaced.[19] The theoretical specific gravity was determined using the average fineness of an issue, derived from Butcher and Ponting, *The Metallurgy of Roman Silver Coinage* (2014). As Caley noted, the method cannot pretend to absolute accuracy, because it assumes the coin is made of silver and copper only, whereas in reality it may contain minor impurities such as lead or gold at levels sufficient to have some effect on the specific gravity.[20] The specific gravities of the copper and silver may also vary depending on thermal and

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[16] Caley 1955, pp. 66–7.

[17] E.g. Oddy 1980; Oddy and Munro-Hay 1980 (gold and gold alloys); Debernadi et al. 2017 (an innovative use of neutron diffraction combined with specific gravity on silver alloys).

[18] It is conventional to record coin weights to two decimal places, but here they have been recorded to three. However, recording them to three decimal places makes little difference to the estimation of the specific gravity of each of the coins discussed here.

[19] This is measured to three decimal places. Caley (1955, pp. 48–50) observed that beyond a third decimal place the sensitivity of the balance often presents issues that make determining the weight displaced difficult to measure with certainty. For large coins such as those discussed here, small discrepancies make little difference to the estimate of original weight. However, it makes the measurement of small coins problematic.

[20] Caley 1955, pp. 41–50, for this and what follows.

mechanical treatments – e.g. the heating, re-heating, casting and working of the blanks during production.[21] Some small inaccuracies in the measurement of specific gravity are likely to arise from the presence of air trapped in the voids or in tiny fissures on the edges of the coins. Finally, modern analytical results show us that small variations in fineness were tolerated by ancient mints, meaning that the average fineness applied here may not be strictly accurate for individual specimens. In spite of these drawbacks the method appears to give a better impression of the original weights of the individual coins than would be achieved merely by recording their weights with a balance.

The Ashmolean Museum collection contains a number of tetradrachms of Tiberius of his regnal year 7 that came to the Museum via Milne in 1925 and these presumably derived from the hoard, since they exhibit a similarly unusual range of weights to those he reported in his 1910 article and all have the same dull, grainy surfaces that suggest they come from the same source. Another ex Milne coin of year 7 has a ticket marked 'Hoard E '09'. This has a slightly different surface appearance, and, since a coin of Tiberius' year 14 in the same collection has the same notation on its respective ticket, 'Hoard E' would appear to be a separate source (no year 14 coins were recorded by Milne as coming from the hoard he published in 1910). This 'Hoard E' year 7 coin has, however, been included as the first coin in the table below, which gives the specific gravities of these coins (Table 1).

Table 1. Weights and specific gravities of Milne's Tiberius tetradrachms of year 7. 'Milne catalogue' refers to the numbered entries for individual coins in Milne 1933.

Source	**Milne catalogue**	**Current weight (g)**	**Specific gravity**
Hoard E '09	38	6.357	4.26930826
Milne 1925	39	6.647	4.42838108
Milne 1925	40	8.180	5.3151397
Milne 1925	41	12.333	8.32748143
Milne 1925	42	9.030	5.79961464
Milne 1925	43	9.745	6.81468531
Milne 1925	44	5.946	4.16970547
Milne 1925	45	8.127	5.21295702
Milne 1925	46	13.140	8.86639676
Milne 1925	47	12.470	8.68384401
Milne 1925	48	6.672	4.44207723
Milne 1925	49	13.365	8.82760898
Milne 1925	50	8.585	5.78114478
Milne 1925	51	5.717	3.91039672
Milne 1925	52	6.481	4.30631229

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[21] Caley 1949, p. 73.

The average weight of the tetradrachm, according to this sample, is 8.853g. Not a single specimen has a specific gravity as high as pure copper (8.93), let alone one that matches a silver-copper alloy: even 1% silver would produce a specific gravity of 8.94. There is, however, a general pattern observable: the heavier coins have the highest specific gravities, approaching that of copper; whereas the lighter coins have specific gravities that are much lower. The lightest specimen in the sample also has the lowest specific gravity (3.91).

Milne's hoard is an extreme case, and it is unlikely that anyone would attempt to use their raw weights when undertaking a metrological study. It is obvious enough when one handles these coins that there is something wrong with the light ones; the discrepancy between their size and expected weight is readily apparent. For the very lightest, the experience is similar to picking up a piece of pumice stone: one does not expect a metallic-looking object to feel so insubstantial. David Walker clearly suspected something was amiss when analysing the Ashmolean tetradrachms of Tiberius for his 1976 volume *The Metrology of the Roman Silver Coinage*. Of the 15 coins listed here, seven of the lighter ones were not analysed by Walker at all; of the remaining eight, all were apparently analysed but results were published for the four heaviest specimens only.[22] None of them were analysed for Butcher and Ponting's *The Metallurgy of Roman Silver Coinage* of 2014, precisely because it was suspected that the coins were heavily corroded internally and the heart metal was unlikely to survive.[23]

In the latter study a larger sample of weights of Tiberius' tetradrachms, avoiding corroded, worn and very light-weight specimens, produced an average weight of 13.33g.[24] The range, though narrower than for the Milne sample, was nonetheless quite broad (11.14g – 14.33g), with an uneven distribution, and it was concluded that the original average weight of the coinage may have been higher than 13.33g and that the lighter weights recorded were probably the result of corrosion.[25]

While the average of the raw weights of Milne's tetradrachms is unsuitable for the study of standards, Caley's formula does allow us to use the weights in combination with their current specific gravities and theoretical specific gravity for metrological analysis. Butcher and Ponting noted that the average silver fineness of Tiberius' Egyptian tetradrachms was about 25%, and thus the theoretical specific gravity of the coins would be 9.2748.[26] If one applies Caley's formula to calculate the original weights of the individual coins, Milne's 'remarkable variation in weight', derived from simply recording the raw weights of the coins, disappears (Table 2 and Fig. 3). Instead of a wide spread of individual weights, the coins cluster tightly in a narrow range (13.226g – 14.459g). The average weight is 13.831g, and the majority of the coins fall within the 13.5g – 13.9g interval.

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[22] Walker 1976, p. 143, nos. 61–4 (Milne 41, 46, 47 and 49); the results for an additional coin that was not part of Milne's material was also published (1976: no. 65). In these cases Walker recorded the fineness on the tickets housed with the coins. Tickets accompanying Milne nos. 40, 50, 51 and 52 imply that these too were analysed (the tell-tale scraping on the edges of the coins are witness to preparation for his XRF analysis), but no results are given either on the tickets or in the 1976 publication.

[23] Butcher and Ponting 2014, pp. 616–17.

[24] Butcher and Ponting 2014, p. 616 and fig. 20.1.

[25] Butcher and Ponting 2014, pp. 616–17.

[26] Butcher and Ponting 2014, p. 618.

Table 2. Estimated original weights of the coins listed in Table 1 using Caley's formula. The fineness is assumed to be 25% silver, 75% copper (SG 9.27482207).

Milne catalogue	Estimated original weight (g)
38	13.8102101
39	13.9215079
40	14.2739512
41	13.7360115
42	14.4408980
43	13.2629956
44	13.2258963
45	14.4594476
46	13.7452863
47	13.3186445
48	13.9307827
49	14.0420806
50	13.7731108
51	13.5597899
52	13.9586072

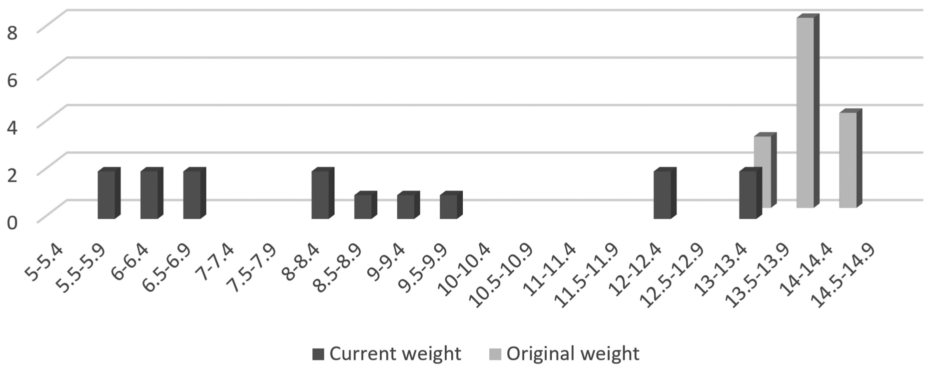

Fig. 3. Comparison of the current weights of the 15 tetradrachms of Tiberius of year 7 listed in Table 1 with their estimated original weight. The y axis = number of specimens; the x axis the weight intervals.

The original hoard recorded by Milne contained 136 year 7 tetradrachms of Tiberius. Milne noted the weights of 129 of these; seven that were chipped or broken were excluded from his list. Tabulating the weights of these 129 coins shows that there remains very little overlap with the estimated original weights of the 15 in the Ashmolean, and the irregular distribution for the current weight is even more pronounced (Fig. 4).

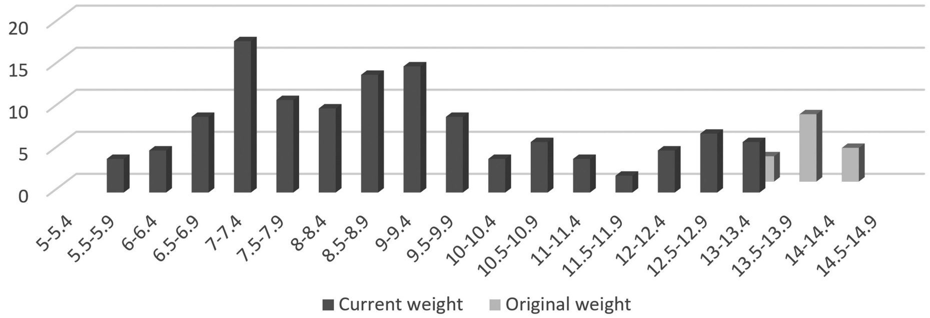

Fig. 4. Comparison of the weights of the 129 tetradrachms of Tiberius of year 7 in Fig. 1, originally recorded in Milne 1910, with the estimated original weight of the 15 tetradrachms in Fig. 3.

Although the sample of 15 coins is quite small, the results suggest that the Tiberian tetradrachms were originally produced within quite a narrow weight range, and that the broad tolerance of weights revealed by a simple weighing of the coins does not reflect mint practice, any more than the results of the global wet chemical analyses conducted for Milne's 1910 publication reflect lax standards of fineness.

The coinage of Tiberius is hardly a special case. Many other coinages in antiquity were heavily debased and these can also benefit from the application of this method in order to determine approximate standards. For example, the late Ptolemaic tetradrachms of Alexandria were produced to a slightly higher standard of fineness than the succeeding tetradrachms of Tiberius, but the surviving specimens exhibit similarly erratic weights, leading to uncertainty about the standards employed.[27] These are specimens of the coinage of Ptolemy XII and Cleopatra VII issued following a debasement under Ptolemy XII in 55/54 BC, which are distinguished from previous issues by a change of style and flan shape and by the presence of an Isis crown located in the reverse field before the eagle.[28] Analyses of samples taken from the cores of some of the coins of Cleopatra VII indicate a fineness for this coinage of about 33%, though a case has been made for more than one standard being employed.[29]

A sample of 36 tetradrachms of Cleopatra VII, taken from the Ashmolean Museum and some other sources, ranges in weight from 7.92g to 14.697g (the 'current weight' column in Table 3). The lightest specimen is nearly half the weight of the heaviest in the sample. The overall average weight is 12.173g, but the distribution has two peaks quite far apart, one at about 10.7g and another at about 13.7g ('current weight' in Fig. 5). This might hint at more than one weight standard in use; at least, that would be a reasonable conclusion to draw from the fact that the average does not coincide with the peaks in distribution.[30] However, it is worth noting that the specific gravity

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[27] See the remarks in Faucher and Olivier 2020, pp. 101–2.

[28] Hazzard and Brown 1984; Hazzard 1990; Faucher and Olivier 2020, p. 101.

[29] Hazzard 1990; Gölitzer 2004; Butcher and Ponting 2014, pp. 613–14; Faucher and Olivier 2020, pp. 101–3.

[30] Faucher and Olivier 2020, p. 102, fig. 6.3.

of the lightest coin weighing 7.92g is 5.42, which is below the specific gravity of any metals that we would expect to find as a major component of an ancient coinage, being comparable to the specific gravity of silver chloride.[31] It would suggest that a significant portion of the metal originally present in this coin has been transformed into corrosion products or leached out, and what remains does not represent the weight of the coin as originally issued.

The other lighter coins also have very low specific gravities (Table 3). Those under 10g have specific gravities of less than 7 – well below that of copper (about 8.93), and even that of tin (about 7.28). In fact, a significant number of the coins in the sample, even those above 10g, fall below the specific gravity of copper. If one were to use the specific gravity of these coins to try to estimate fineness, one would have to conclude that most were not composed of a silver-copper alloy at all. They are simply not heavy enough compared with their volume.

Applying Caley's formula to these figures, assuming an average fineness of 33% (specific gravity 9.39), changes the weight distribution dramatically ('original weight' in Table 3 and Fig. 5). For a start, the range is narrowed to 12.34g – 15.18g. The average weight is now 13.94g, and the distribution peak matches this, falling within the 13.5–13.99 interval (Fig. 5), the same as the tetradrachms of Tiberius. All of this suggests we are looking at a more realistic estimate of the original weights of this sample of late Ptolemaic coinage than we would have possessed had we simply relied on the current weights alone. It further suggests that, while the fineness of the coins was lowered between the late Ptolemaic and first Roman issues under Tiberius in regnal year 7, the weight standard remained the same.

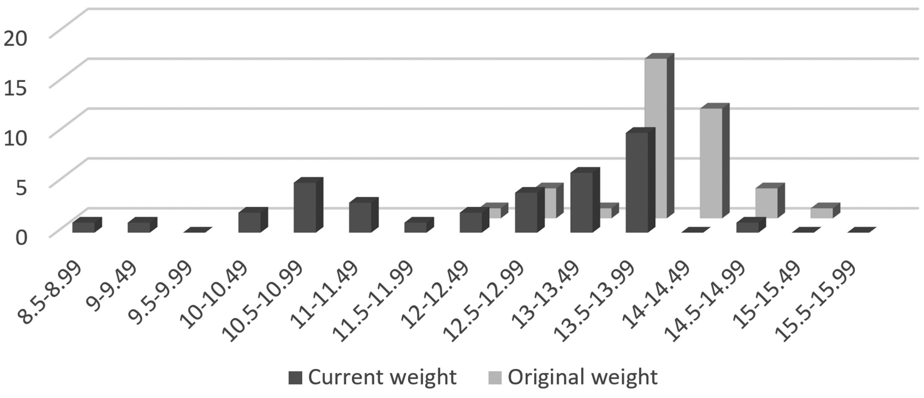

Fig. 5. Comparison of the current weights of 36 late Ptolemaic tetradrachms of Cleopatra VII listed in Table 3 with their estimated original weight.

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[31] About 5.5: Caley 1955, p. 50.

Table 3. Current weight, specific gravity and estimated original weight of 36 late Ptolemaic tetradrachms of Cleopatra VII in the Ashmolean Museum. ‘Svoronos number’ refers to the catalogue of Svoronos 1904.
The fineness is assumed to be 33% silver, 67% copper (SG 9.390867).

Source	**Ruler**	**Regnal date**	**Svoronos no.**	**Current weight (g)**	**Specific gravity**	**Original weight (g)**
Keble	Cleopatra	Year 2	1817	12.156	9.00444444	12.6776705
Egypt Expl Fund	Cleopatra	Year 4	1819	9.466	6.68975265	13.2880768
Egypt Expl Fund	Cleopatra	Year 8	1822	13.588	9.15633423	13.9360466
Keble	Cleopatra	Year 9	1823	13.367	9.24412172	13.5791937
Milne 1920	Cleopatra	Year 9	1823	8.692	5.68476128	14.3586356
Milne 1923	Cleopatra	Year 9	1823	13.649	9.24728997	13.8609197
Cole 1971	Cleopatra	Year 10	1824	13.576	9.27956254	13.7388384
Milne 1920	Cleopatra	Year 10	1824	12.972	8.45632334	14.4055900
Egypt Expl Fund	Cleopatra	Year 10	1824	13.988	8.89256198	14.7718338
Milne 1920	Cleopatra	Year 11	1825	12.828	8.31367466	14.4901078
Egypt Expl Fund	Cleopatra	Year 12	1826	11.238	7.45719973	14.1520366
Milne 1920	Cleopatra	Year 12	1826	13.688	8.98162730	14.3116813
Egypt Expl Fund	Cleopatra	Year 13	1827	10.912	8.30441400	12.3395992
Milne 1920	Cleopatra	Year 13	1827	13.267	8.66557805	14.3774174
Milne 1923	Cleopatra	Year 14	1828	13.744	9.22416107	13.9923918
Egypt Expl Fund	Cleopatra	Year 14	1828	10.504	7.10209601	13.8890923
Milne 1920	Cleopatra	Year 15	1829	13.073	8.78561828	13.9736101
Egypt Expl Fund	Cleopatra	Year 15	1829	10.743	7.24898785	13.9172649
Milne 1920	Cleopatra	Year 16	1830	13.293	8.97569210	13.9078740
Egypt Expl Fund	Cleopatra	Year 16	1830	12.949	8.69644056	13.9830010
Egypt Expl Fund	Cleopatra	Year 17	1831	12.333	8.52904564	13.5791937
Milne 1928	Cleopatra	Year 17	1831	13.509	9.10309973	13.9360466
Egypt Expl Fund	Cleopatra	Year 18	1832	10.665	7.03496042	14.2365544
Milne 1920	Cleopatra	Year 18	1832	13.385	9.08073270	13.8421380
Private coll	Cleopatra	Year 18	1832	13.500	9.14634146	13.8609197
Milne 1920	Cleopatra	Year 19	1833	13.108	8.40256410	14.6497525
Egypt Expl Fund	Cleopatra	Year 19	1833	11.121	7.01640379	14.8845242
Egypt Expl Fund	Cleopatra	Year 20	1834	11.075	7.41795044	14.0205644
Milne 1920	Cleopatra	Year 20	1834	12.542	9.10820625	12.9312239
Milne 1923	Cleopatra	Year 20	1834	14.697	9.09467822	15.1756411
No source given	Cleopatra	Year 20	1834	13.681	9.15117057	14.0393462
Private coll	Cleopatra	Year 20	1834	7.920	5.42094456	13.7200567
Egypt Expl Fund	Cleopatra	Year 22	1835	11.899	7.95919732	14.0393462
Milne 1920	Cleopatra	Year 22	1835	10.055	7.33941606	12.8654878
Egypt Expl Fund	Cleopatra/ Caesarion	Year 1	1815	10.679	7.23019634	13.8703106
No source given	Cleopatra/ Caesarion	Year 1/16	1816	10.357	6.74723127	14.4149808

The implications of these observations go beyond the debased coinages of Egypt. Other silver-copper alloy coinages seem to show a decline in the weight standard as the coinage became progressively more debased, not least the Roman imperial denarius.[32] By the later Severan period the denarius was just as debased as the Egyptian coinages considered here, and the recorded weights are very variable.[33] While undertaking specific gravity studies of large numbers of small coins is not very practical,[34] it seems clear that those coinages exhibiting broad and erratic distributions of weights need to be investigated to determine whether their specific gravity is consistent and conforms to the expected measure for that particular alloy. The impact of corrosion on the weights of individual silver-copper alloy coins, and therefore on the calculation of weight standards, is likely to increase with the level of debasement: the greater the debasement, the more likely it is that the weights of the surviving coins will deviate from their original weights. This has obvious relevance when tracking changes to weight standards over time. Successive debasements may give the impression of a decline in average weight, but this could be an artefact arising from greater levels of corrosion in a progressively-debased alloy, and not the result of any ancient fiscal policy. If a standard appears to fall following the debasement of a coinage, Caley's formula would be a useful method to determine whether the apparent weight reduction is real or not. Furthermore, since it is common for numismatists and historians of the Roman economy to discuss the average silver content of a coinage in terms of the grammes of silver,[35] an illusory weight decline in a coinage following a debasement would generate the false impression of an even greater reduction in average weight of silver in that coinage than was really the case.

The above exercises are offered as proof of principle rather than as an attempt to calculate exactly the weight standards of the coinages concerned, but it shows us how even material that exhibits extreme variation in weight and density might still contribute to the study of metrology. Larger samples, using heavier, better-preserved, specimens of a coinage would probably provide a more accurate estimate of standards. Nor are these exercises an argument against the use of average weights derived from a simple weighing of the coins, as long as one is aware of the problems

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[32] Duncan-Jones 1994, pp. 219–28.

[33] See, for example, the weights recorded for denarii of Elagabalus and Severus Alexander in Walker 1978, pp. 24–32, which range from 1.98g (no. 4143) to 4.29g (no. 4288).

[34] The material itself is often less than ideal: for example, it is not uncommon to encounter coins in collections that have been coated with water-repellent waxes or lacquers as a preservative.

[35] The practice is helpful in that it allows coinages of different weights and finenesses to be compared, and has been widely used as a way of describing silver content ever since the pioneering studies of David Walker, e.g. Walker 1976, pp. 18, 25: 'the pre-reform denarius of Nero contains only 3.47g of silver', 35: 'the weight of silver in three denarii would have been 10.95g', 50: 'a drachma with a mean silver content of 1.98g'; 1977, p. 57: 'the denarius during the period 107-148 contains a mean weight of silver in the denarius of about 2.85g of silver, compared with 3.00g of silver or slightly above for the standard of Nero'; 1978, p. 139: 'the antoninianus contained about 1.10g of silver'. It is used in tabulations of debasement, e.g. Harl 1996, p.127, table 6.1, where changing silver content over time is presented in terms of both fineness and grammes of silver, the latter allowing the reader to see what appears to be a gradual decline; and it forms the basis of other calculations, e.g. Duncan-Jones 1994, p. 227, estimating the number of denarii struck from a pound of silver.

posed by the corrosion of silver-copper alloys; indeed, weighing coins is an essential first step in identifying coin issues that would benefit from the kind of analysis presented here.

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