On the Fineness of the One Yen Silver Coin.

by

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1. Introduction.

The experiments recorded in the following pages have for their object the study of the nature of segregation of silver in the one yen coin, and of the mode of taking portions for assay from the coin in such a manner that portions so taken shall represent the exact composition of the whole piece.

The subject is of considerable importance in the technical operations of the mint, and also with regard to the provisions of the law which governs the issue of national coinage.

It is comparatively easy to determine with exactness the average fineness of a mass of silver coins, for they may be melted together in a crucible, and a small portion dipped out of the melted mass after a thorough stirring may then be granulated in water. The granules thus obtained will exactly represent the average composition of the mass, provided that the coins have been melted in sufficient quantity and with certain precautions in order to prevent oxidation in the process of fusion.

The exact determination of the fineness of any individual coin is not so easy, since the silver-copper alloy usually employed in coinage shows the property of segregation to a considerable degree, the silver being concentrated towards the centre of the ingot made from this alloy. A small portion cut from the coin in a haphazard manner will not therefore be the true representative sample of the coin taken as a whole.

Although the experiments strictly refer to the silver yen coin, yet the conclusions drawn from them may be applied equally well to many other coins, when the conditions of manufacture are similar.

In order to obtain a clear understanding of such conditions, it may be perhaps useful to give a brief account of the process of silver minting in the Imperial Mint.

The process of minting begins with the melting of refined silver with the right proportion of copper in a crucible, the metal being covered with a layer of powdered charcoal. When in perfect fusion, the bath is stirred up thoroughly; a small portion is dipped out and immediately let fall into cold water. The small shots, or granules of the alloy thus obtained are dried and reserved for assay, which determines the exact proportion of silver in that melt. The metal is then poured into cast iron moulds and transformed into long flat strips or "bars," which are taken out of the moulds and cooled in water. The bars are next rolled out by a pair of rollers, until they are reduced to the thickness of the coin to be manufactured. In the course of lamination, these bars, now known as "fillets," usually require to be annealed, an operation which is performed in a sort of reverberatory furnace, where they are heated to a low redness; they are then taken out and immediately cooled in water, so as to reduce the oxidation of the metal to a minimum.

The finished fillets are taken to the cutting machine, by which circular discs or " blanks " are punched out of them. A single row of blanks are cut from each fillet in the case of large coins, such as the silver yen. The blanks are next adjusted in weight, usually by means of an automaton balance.

After being " marked " or compressed on the edges, they are annealed in iron pans, introduced into a furnace similar to that just mentioned. When taken out they are cooled in water and washed in very dilute sulphuric acid, by which the superficial layer of copper oxide is dissolved out, leaving the blanks with a clean white surface. After washing and drying, the blanks are ready for the coining press, where they are transformed into coins. Finally the coins thus prepared must be tested as to the sound, and the correctness of weight and fineness, before they are allowed to be issued to the public.

The dimensions of the silver yen coinage bar and of the finished fillet are :

	Bar.	Fillet
Length.	60.00 cm	
Breadth.	4.30 ,,	5.00 cm
Thickness.	1.25 ,,	0.23 ,,

The dimensions, &c., of blank and coin are :

	One Yen Blank.	One Yen Coin.
Diameter.	...............38.0 mm	38 mm
Thickness.	.... 2.3 mm	—
Legal weight.	....	416 grains, (26.957 Gram.).
Legal tolerance in weight.	....	1.5 ,, above or below legal weight.
Legal fineness.	....	900 per mille.
Legal tolerance in fineness.	......	2.0 above or below 900.

It will be seen from the preceeding account, that many other causes than mere segregation of silver have more or less influence on the actual fineness of the finished coin, for some stages of the process tend to lower the fineness by the oxidation of the metal, while other stages act in an opposite way by taking away a part of the oxide formed.

II. Distribution of Silver on the Coin.

The first series of experiments consisted in the endeavour to discover the average fineness of the One Yen coin produced from bars, of which the assay of granulation was known, and to examine extent the of segregation by which different portions of the same coin differed in composition.

We selected four bars from four different melts named A, B, C, and D, the granulation assays of which were carefully made. These were rolled down to the required thickness as usual. Three blanks were cut out from each of the fillets, one from the middle and one from each end. These were marked respectively, A_2, A_1, A_3 ; B_2, B_1, B_3, &c. &c., the direction of lamination of the bar being carefully marked on each blank. These blanks were then treated exactly the same as the blanks for regular coinage. Care was taken in annealing to place each of them among separate lots of ordinary blanks, so as not to allow the effect of any accidental irregularity to fall simultaneously on all of them. The loss of their weight in grains in annealing and pickling is shown in Table I.

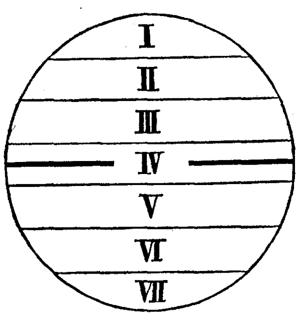
Table I.

Showing Loss in Annealing.

Mark of Blank.	Weight before Annealing.	Weight after Annealing and Pickling.	Loss in the Operation.
A_1.	415.74	415.65	.09
A_2.	415.98	415.89	.09
A_3.	415.87	415.78	.09
B_1.	416.51	416.39	.12
B_2.	415.80	415.70	.10
B_3.	415.83	415.73	.10
C_1.	415.61	415.52	.09
C_2.	416.06	415.97	.09
C_3.	415.63	415.53	.10
D_1.	415.92	415.84	.08
D_2.	415.76	415.69	.07
D_3.	416.21	416.13	.08

Each blank was then marked with six lines parallel to the direction of rolling, and cut into seven strips of equal breadth which were named as in Figure 1.

Fig. 1.



middle line of original bar.

The narrow strips thus obtained were cut into smaller pieces and assayed. The results of the assays are incorporated in Table II. Assaying was conducted by the usual volumetric method. The proportion of silver was estimated to $\frac{1}{10}$ of 1 per mille. When it is given to the second place of decimal, the number is the mean of several experiments.

Table II.

Showing Fineness at Different Portions of Blanks.

Name of melt.	*A.*			*B.*			*C.*			*D.*			Average or Composite Finenesss.
Granulation assay of the melt.	899·10			898·75			899·35			898·75			
Section of blank. / Mark of blank.	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3	
I.	898·50	898·55	898·62	898·45	898·57	898·20	898·80	898·43	898·53	898·50	898·07	808·90	898·508
II.	899·15	899·72	899·07	899·48	899·68	889·08	899·94	899·05	899·62	899·15	899·00	899·66	899·383
III.	900·95	901·27	900·07	900·83	901·68	900·71	901·20	900·57	900·98	901·05	900·50	900·85	900·888
IV.	903·10	902·77	901·42	901·07	902·03	901·80	902·55	902·26	902·02	902·90	903·06	901·66	902·222
V.	901·97	900·85	902 67	899·85	900·03	899·94	901·15	902·88	900·57	901·18	901·76	900·45	901·109
VI.	899·55	899·15	900·62	898·76	898 70	898·70	899·51	900·78	899·60	899·34	899·78	899·27	899·480
VII.	898·70	898·40	899·25	888·12	897·67	898·15	898·83	899·10	899·06	898·52	898·57	898·50	898·573
Mean of all assays made on Blanks.	900·487	900·397	900·397	899·750	900·117	899.826	900·617	900·787	900·331	900·341	900·504	900·129	General Average
Average Fineness of Blanks.	900·427			899·899			900·578			900·352			900·307

In order to show the distribution of silver on the coin, we produce below the details of assay of the blanks C_1, C_2 and C_3, the figures which denote the fineness indicating as nearly as possible the relative positions of the respective portions.

Fig. 2.

Brank C_1.

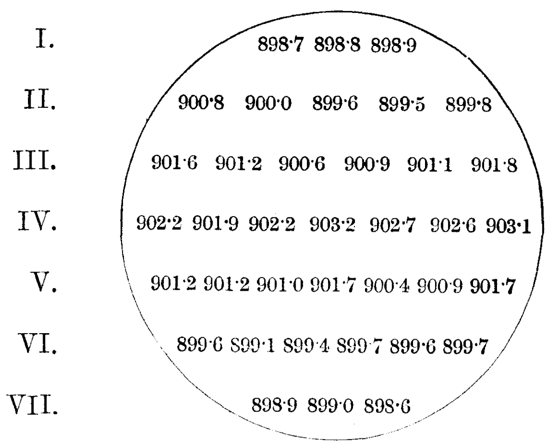


Fig. 3.

Blank C_2.

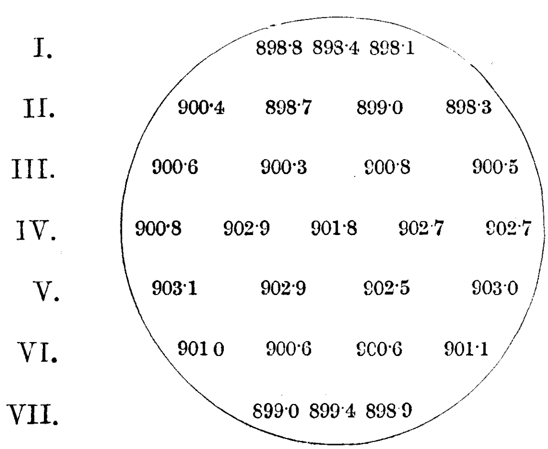
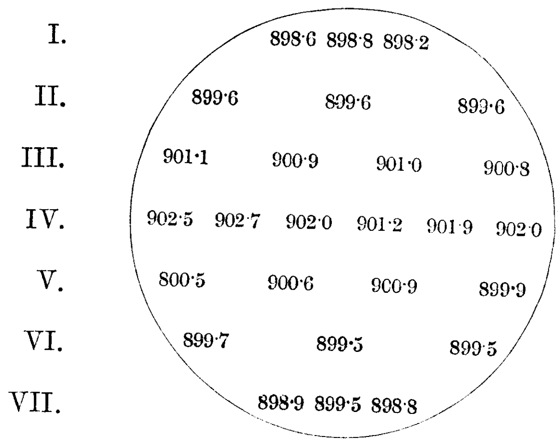


Fig. 4.

Blank C_3.



	C_1.	C_2.	C_3.
Average of all assays.	900·617	900·787	900·331
Highest assay.	903·2	903·0	902·7
Lowest assay.	898·6	898·1	898·2
Difference between highest and lowest assays.	4·6	4·9	4·5

The preceeding results furnish fresh illustrations of the well known fact, that, in an ingot made of the alloy containing 900 per mille of silver and 100 of copper, there is a segregation or concentration of silver towards the central line of the ingot. The middle portions in such an ingot contain the highest proportions of silver, while copper predominates along the edges. We observe in the blanks under examination that this difference may be as much as 4·9 per mille, as in blank C_2. It is also to be observed that even adjacent parts lying in the same line may show a considerable difference in composition, which is probably due to several causes. We may, however, regard each of the strips which we have prepared as of one fineness by taking the mean of all the assays made from it. Taking the strip IV as the middle, the strips I, II and III, lie on one side of the central line at the same distances as VII, VI, and V, respectively on the other.

Comparing the numbers corresponding to each of these strips, we obtain the results shown in the following table.

Table III.

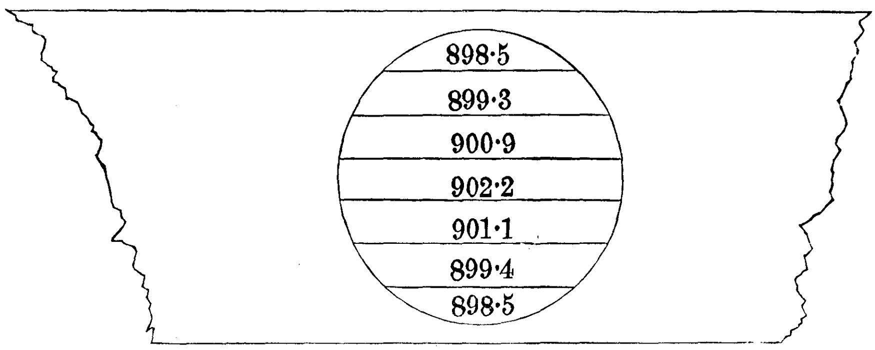
Showing the difference of fineness between two similar portions of blanks.

Mark of Blank.	Difference in fineness between strips.		
	I—VII.	II—VI.	III—V.
A_1.	0·20	0·40	1·02
A_2.	0·15	0·57	0·42
A_3.	0·63	1·55	2·60
B_1.	0·33	0·72	0·98
B_2.	0·90	0·98	1·65
B_3.	0·05	0·38	0·77
C_1.	0·03	0·43	0·05
C_2.	0·67	1·73	2·31
C_3.	1·53	0·02	0·41
D_1.	0·02	0·19	0·13
D_2.	0·50	0·78	1·26
D_3.	0·40	0·39	0·40

We may conclude then that the metal lying in the central line of the original bar shows the highest average fineness, while on both sides of this line, the fineness gradually decreases towards the edges, and the strips which lie parallel to and equidistant from the middle line have nearly the same fineness. The correspondence is not strictly exact as may be seen in Table III. The small divergences may be due, apart from slight irregularities occurring in the metal itself, to the fact that the strips, into which the blanks were cut, were not, from instrumental causes, mathematically corresponding divisions of the original bar.

In order to eliminate, as far as possible, the effect of such irregularities, we have taken the mean of the several blanks as given in the last column of Table II. Thus we obtain, so to speak, an ideal composite blank or coin the fineness of the several parts of which is represented in Fig. 5.

Fig. 5.



The fineness of the entire blank=900·3.

We also see that on an average the coins produced from a melt are about 1·3 per mil higher in fineness than the assay of granulations of that melt, as shown in the following statement :—

	A.	*B.*	*C.*	*D.*	Mean difference.
Assay of granulation of melt	899·10	898·75	899·35	898·75	
Average fineness of blanks	900·427	899·899	900·578	900·325	
Difference.	1·327	1·149	1·228	1·575	1·319

III. Methods of Cutting Portions for Assay from the Coin.

If the figures given in the preceeding section be taken as representing the general distribution of silver in the One Yen Coin, what would be the best mode of cutting portions for assay from it in order to ascertain the exact fineness of the piece?

It is almost superfluous to mention that the assay of the entire piece of such a large coin as the Silver Yen, being rather cumbersome, it is usually convenient to take about one gram of it for an assay.

It would be comparatively easy to cut out an exact representative sample from the coin, if the direction of rolling were apparent on its surface, for we should then know which was the central or richest part. Such is the case with blanks before they are treated with dilute acid. But in the coin, marks are obliterated, and portions must be cut from such positions that they represent the entire piece as nearly as possible, in whatever relation they may stand with regard to the direction of rolling of the bar, from which the particular coin has been prepared.

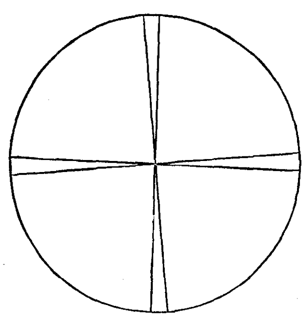
Four methods of cutting a coin for assay, besides our own, are known to us, and we will proceed to examine each of them.

Method *a*. A small portion is cut off from the rim of a coin, which, in some cases, is partly laminated by means of a pair of rollers previous to cutting. Since we know that the fineness at different parts differ so greatly, this method of single cutting must be at once rejected, as being unsuitable for large silver coins.

Method *b*. In the assay laboratory of the Bureau of the Mint at Washington the standard silver dollar is first rolled out into a very thin ribbon by means of a pair of small rollers ; an innumerable number of small discs is then punched out of all parts of this ribbon, a miniature cutting machine similar in construction to that used in minting operations being provided for the purpose. The discs are then well mixed and a number of them is weighed into a single assay. This method involves a considerable amount of labour in rolling and cutting, especially when a large number of coins is to be daily assayed. It may perhaps be difficult to guard the small and thin discs belonging to a particular coin against contamination with very minute scraps of silver detached from another coin operated in the same machine. Besides we are inclined to think that a number of such discs, unless indeed they be very minute, taken together for an assay does not always represent the average sample of the whole coin. Some experiments made by us in this connection show that the results of many assays made on a single coin are not sufficiently concordant.

Method *c*. A method formerly employed in the Imperial Mint consists in cutting four equal isosceles triangles from diagonal positions as shown in Fig. 6., the sharp angles of the triangles meeting at the centre of the coin, and the four portions when put together weighing almost exactly the weight required for an assay.

Fig. 6.



As may be understood from the nature of segregation already explained, this method does not provide the true representative sample of the coin, and is far from affording concordant results when several assays are made of the same coin. If any pair of the diagonally cut triangles should happen to fall on the middle line of the original bar, represented by the central strip in Fig. 5, they would be of an excessively high fineness, while the other pair of triangles, although lower in fineness, would not be sufficiently low to counterbalance the excess of fineness of the first pair. The result would be the indication of too high a fineness for the coin. This assay being evidently too high, the assayer would now cut two other pairs of triangles from portions of the coin which lie between the first cuttings and assay them. The result would be as a rule to give too low a fineness, equally evident, the mean of the two assays being probably nearer the truth. In the case of the first assay being too low, the second assay would be similarly too high. Hence in the double assays, which were necessitated from this cause, made on 121 coins between January and September, 1887, the percentage of differences in fineness between two assays of the same coin were as follows:

Difference nil	... ...	1·7 %
Difference of between 0·1 and 0·5 per mille	...	4·9 ,,
,, ,, 0·6 and 1·0	... ...	4·9 ,,
,, ,, 1·1 and 1·5	... ...	28·1 ,,
,, ,, 1·6 and 2·0	... ...	34·7 ,,
,, ,, 2·1 and 2·5	... ...	17·4 ,,
,, ,, 2·6 and 2·7	... ...	8·2 ,,

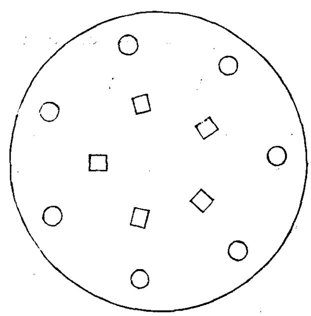
Besides, there is always a difficulty in cutting the thick silver coin in the required form by means of a pair of shears, so that the weight of the cut portions is sometimes wide away from the mark.

Although the assays of individual coins are thus considerably vitiated in correctness, the mean of a sufficient large number of coins individually assayed may agree closely with the assay of all these coins melted together. But this agreement, it is needless to remark, does not sufficiently prove the correctness of the individual assays. The remark however applies equally well to any other method. We refer to this, because the said agreement has been put forward as an argument in favour of this method.

Method *d*. This method, due to M. Stas of Belgium and in use in the mints at Brussels and at Paris, consists in punching out small pieces from certain portions of a coin by the single action of a special machine. These pieces put together make up an assay. The number, positions and forms of the punchings differ in different denominations of coins and have been determined by experiment and calculation.

In the case of the 5 Franc Silver coin, similar in size to the Silver Yen, they are as represented in Figure 7.

Fig. 7.



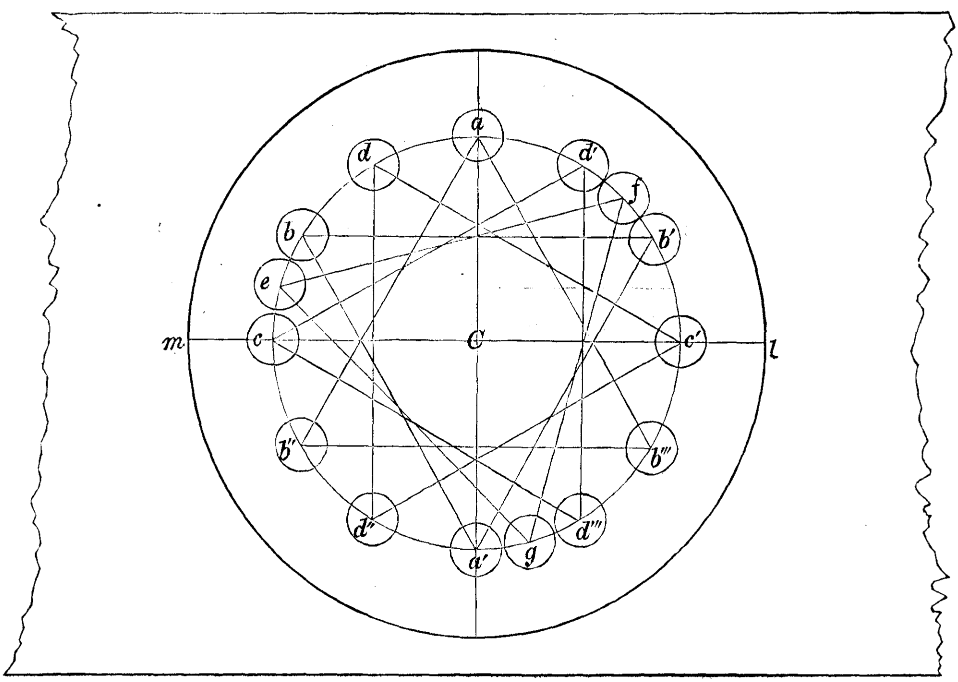
The punchings taken from inner parts are distinguished by a square form.

This method as applied to the Silver Yen coin appears to give remarkably exact results. We discovered however that the cutters being necessarily of a slender form frequently meet with serious accidents, so that after trying the machine for a considerable time, we were obliged to give it up and substitute for it another and simpler form described in the next paragraph.

New Method. A careful study of the distribution of silver in the coin has induced us to choose for our assay of the Silver Yen, three circular punchings of equal weight taken from the angles of an equilateral triangle, which may be supposed to be described on the coin, the distance of the centre of each punching from the circumference of the coin being made equal to one-seventh of the diameter. Portions of metal taken from any set of such positions when put together, give almost exactly the average fineness of the entire coin, of which therefore they are the true representative sample.

Thus in Figure 8, let *c* be centre of the coin, *ml* be its diameter and the middle line of the bar. Let *cc′*, diameter of the inner circle, be equal to $\frac{5}{7}$ *ml*, and let equilateral triangles be described in this circle as shown.

Fig. 8.



Then from the nature of segregation in the coin, it will be readily seen that, $c=c'$; $a=a'$; $b=b'=b''=b'''$; and $d=d'=d''=d'''$. Therefore the small punched out circles at $a, b,'' b'''$ = the same at $a,' b, b'$; and the circles at c', d, d'' = the same at c', d, d''. In the same way it may be shown that the circles at e, g, f, have their equivalent set.

Now by interpolation from a curve based on the numbers in Figure 5, we get the fineness of the parts marked a, b, c &c. on the ideal composite coin as follows :

$a = a'$ .... = 899·0
$b = b' = b'' = b'''$ .... = 900·8
$c = c'$ .... = 902·3
$d = d' = d'' = d'''$ .... = 899·3
e .... = 901·7
f .... = 899·9
g .... = 899·1

The three punchings may be any one of the sets above indicated or those lying between them ; the resulting fineness of the sample will be nearly identical with each other and with the exact fineness of the composite coin, as shown in Table IV.

Table IV.

Showing the Fineness of three portions in the ideal composite Coin of fineness 900·3.

Position of Punching.	Fineness.	Average Fineness of the three Portions.
c or c'	902·3	
d''' or d''	899·3	900·3
d' or d	899·3	
e	901·7	
g	899·1	900·23
f	899·9	
b or b''	900·8	
a' or a	899·0	900·2
b' or b'''	900·8	

Numerous double assays of individual coins by this method have been made. The results do not indeed show absolute coincidence, but the agreement has been in most cases quite close.

Thus double assays made by this method on 105 coins gave the following percentage occurrences of differences :

Difference nil				=	19·1 %
Difference of between	0·1 and 0.5	per mille		=	59·0 ,,
,, ,, ,,	0·6 and 1·0	,,		=	18·1 ,,
,, ,, ,,	1·1 and 1·5	,,		=	2·8 ,,
,, ,,	1·6			=	1·0 ,,

The correctness of the results obtained by this method has been verified by us in many instances by the direct assay of the whole coin, after taking the portions for assay by punching, the coin being cut up into small parts and divided into as many assays as there are pieces of metal. In other instances the entire coin, after the removal of the punchings for assay, has been dissolved in nitric acid and made up with water to a certain known volume, an accurately calibrated bottle of about 2½ litres capacity being used for this purpose. An aliquot part of this liquid was taken up in a Stas pipette. The liquid was then transferred to a shaking bottle and assayed after having been evaporated on the water-bath to the same degree of concentration as in ordinary assays. The results have shown in all cases a close agreement between the assay on the punchings and the exact fineness of the coin ascertained in this way.

Table. V.

Showing the results of assays by the new method on coins whose compositions have been accurately determined.

No. of Experiment.	Assay on Coin.	Exact known fineness of coin.	No. of Experiment.	Assay on Coin.	Exact known fineness of coin.
1	899·8	899·75	14	899·7	899·82
2	900·8	900·67	15	899·9	900·61
3	900.3	900·62	16	900·7	900·78
4	899·8	900.37	17	899·8	900·33
5	900·1	900·47	18	899·7	900·34
6	900·1	900·25	19	900·3	900·12
7	899·6	900·15	20	900·5	900·50
8	900·0	900·30	21	900·4	900·59
9	900·3	900·20	22	900·6	900·59
10	899·6	899·80	23	900·4	900·81
11	900·6	900·58	24	900·5	900·39
12	899·6	899·75	25	900·2	900·48
13	900·0	900·11	26	900·0	900·39

The assays of granulated dips taken from the melted mass of a large number of coins, which had been individually assayed by this method, also shew a close approach to the average of the individual assays. In melting, special care was taken to cover the metal with powdered charcoal.

Table VI.

Showing Assays of Mass compared with Average of individual Assays.

No. of Experiment.	Number of Coins melted together.	Assay of Granulated Dip.	Mean of individual Assays of all the Coins.
1.	130	899·90	899·90
2.	50	900·10	900·04
3.	64	900·00	900·08

A small screw press worked by hand is used by us for cutting out the small circles from the coin (Fig. 9.), one circle being punched out at a time. A steel punch of the required diameter is attached to the screw. The coin is introduced by means of a brass sliding guide. The constant position which the guide is caused to take brings the coin to the exact relative position with regard to the punch. The latter descends by the action of the screw and cuts out a circular piece from the required position. The coin is then turned round through an arc of 120° in the guide by bringing the hole made by the first punching opposite a mark on the guide. A second action of the screw punches out another circle. The coin is turned round another 120° and the third circle is cut out. The process is simple and may be performed in less than half a minute. The somewhat large size of the cutter, or punch, and the very simplicity of the apparatus make any accidents extremely rare.

In this apparatus, the punch strikes out circular pieces of almost exactly the same weight. In default of the punch, we recommend the following method of cutting which may be performed with a pair of shears. It consists in cutting three equilateral triangles as shown in Figure 9.

Fig. 9.

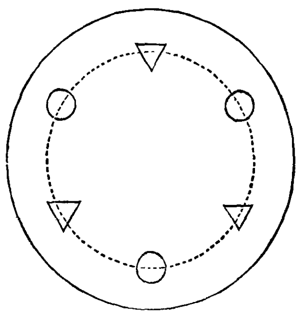
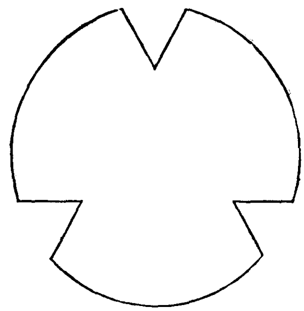


Fig. 10.



The centre of gravity of the triangles should be upon the circumference of the inner circle whose diameter is equal to $\frac{5}{7}$ of that of the coin.

In order to facilitate the cutting of such triangles of equal weight, it is advisable to use a pattern of tin plate cut as shown in Figure 10.

APPENDIX.

Note on the Stas Pipette.

The Stas pipette used by the writers in the assaying of silver delivers a nearly constant volume of liquid as shown in the following rtatement:—

Weight of water at 70° F. delivered by the Stas Pipette.
Time occupied in delivery = 13 seconds.

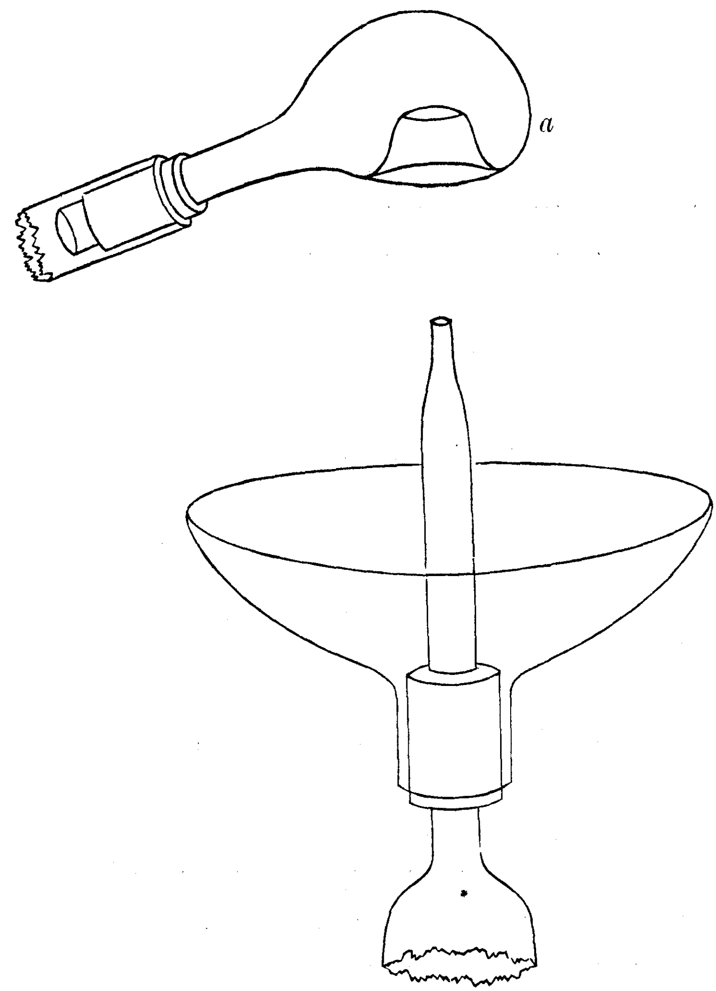
Experiment	I.	1000·140	grains
,,	II.	1000·146	,,
,,	III.	1000·129	,,
	Mean	1000·1383	,,

In the arrangement of common forms of the pipette, a shallow bell-shaped glass is suspended over the top of it. Any excess of the liquid, which is introduced from below and is projected upwards, strikes against the glass and is caused to drop down into the glass dish adapted to the neck of the apparatus. There is in this arrangement a constant danger of the dish overflowing, and even of the liquid being splashed out on the table.

The arrangement employed by us consists of an overflow tube instead of the bell-shaped glass. It is said to have been first devised by the late Mr. W. E. Dubois, assayer in Philadelphia Mint, and has been adopted in that mint and also in the Royal Mint in London. In the form used in those institutions it is constructed of gutta-percha. But as made by us it is of glass, and with a little manipulation in the blow-pipe, may be easily constructed in the laboratory from a piece of bulb-tubing.

The apparatus consists of a glass bulb *a*, Fig. 11, blown on one end of a tube. The under side of the bulb is made into a cavity the top of which is cut open into a hole, thus forming a circular groove inside the bulb. The head of the Stas pipette comes just below the cavity.

Fig. 11.



The liquid is filled into the pipette from below as usual; any excess of liquid is projected by its own force into the bulb above, and thence round the inner groove, quietly flowing away by the inclined tube to any suitable receiver placed at the end of the tube, without fear of spilling or splashing.

The Imperial Mint, Osaka.
April, 1890.