LVIII.—*The Atomic Weight of Boron.*

By J. L. HOSKYNs ABRAHALL, B.A. (Oxon.), Ph.D. (Munich), late
Bishop Berkeley Fellow of the Owens College, Manchester.
(Edited by T. EWAN and P. J. HARTOG, of the Owens College.)

Preface.

[THE work recorded in the following memoir was carried out by the author during the years 1889–91 in Professor Dixon's laboratory at the Owens College. It was brought to an end by his untimely death in October, 1891*.

* See obituary notice, in the *Manchester Guardian*, Oct. 17th, 1891, and in this *Journal*, *Trans.*, 1892, p. 486.

This memoir has been drawn up mainly from the contents of five rough note-books, which contain the actual record of the author's experiments as they were performed in the laboratory. But certain missing particulars, with regard to the preparation and titrations, the editors have been obliged to fill in from their own knowledge; whilst for others they are indebted to Messrs. Harden, Ormandy, and Stanton, whom they here desire to thank. The atomic weights had in most cases only been calculated approximately from the observations; for the application of corrections, and for the calculations of which the results are now given, the editors are responsible. They feel deeply how much more imperfect must be the present exposition of the research than that which the author would have given; but, as they were better acquainted with its details than any other of his friends, they undertook the task of editing it.

It may be added that a considerable number of bulbs filled with the various fractions of boron bromide, which served for the last series of determinations, have been preserved. These were intended for additional experiments. The editors hope that, before long, this material may be utilised.—T. E., P. J. H.]

Historical Introduction.

The element boron was isolated almost simultaneously by Davy (*Phil. Trans.*, 1808, i, 43) and by Gay-Lussac and Thénard (*Annales de Chimie*, 68, 169 and *Recherches Physico-chimiques*, 1811, i, 308), who found, by oxidising boron with nitric acid, that the sesquioxide contains about one-third of its weight of oxygen. This number would give 48 as the atomic weight of boron. Almost at the same time, H. Davy (*Phil. Trans.*, 1809, i, 82) also obtained free boron, and found, by burning it in oxygen, that the oxide was composed of 1 part of boron and 1·8 parts of oxygen, from which number the atomic weight of boron is calculated to be 13·3. The first accurate determination of the atomic weight is due to Berzelius (*Ann. Phys. Chem.*, 1824, 2, 128), who estimated the amount of water of crystallisation in borax. The borax was first fused in order to destroy organic matter, and then recrystallised and dried between sheets of filter-paper for 24 hours, after which it was powdered and exposed to the air for varying lengths of time in order to get rid of mechanically enclosed water. A weighed quantity of the substance was heated carefully in a platinum crucible until it finally melted at a red heat. Three experiments which gave identical results showed that the percentage of water in borax

is 47·1.* The atomic weight recalculated from this number† is $B = 11·059$.

In 1849 (*Compt. rend.*, **29**, 7; and *J. pr. Chem.*, **47**, 415), Laurent published a further determination of the water of crystallisation of borax. He found that on throwing a piece of iron into melted borax, hydrogen was evolved, and concluded that the whole of the water was not driven off from this salt by simple fusion. He therefore mixed it with about one-tenth of its weight of powdered Iceland spar, and thus obtained the numbers 47·15 and 47·20 for the percentage of water. He did not, however, regard his experiments as very exact. The atomic weights recalculated from these results† are 10·978 and 10·857; mean = 10·917.

Finally, in 1859, Dumas (*Ann. Chim. Phys.* [3], **55**, 181, 1859) included in his well-known memoir on atomic weights the record of three experiments made by Deville, in which boron chloride and boron bromide were precipitated with silver. The atomic weights recalculated from Deville's experiments† are as follows:—

(a) from BCl_3	10·808
(b) from BBr_3	10·964

The discrepancies between the results obtained by previous observers led the author to undertake a redetermination of the atomic weight in question. For this purpose, he performed three series of experiments, depending on (1) the estimation of the water of crystallisation in borax, and (2) the estimation of the amount of silver necessary to precipitate the bromine of a given weight of boron bromide (preliminary and final series).

Determination of the Water of Crystallisation in Borax,
 $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}.$

The borax used was recrystallised once slowly, and twice suddenly, from a supersaturated solution in ordinary distilled water, and, finally, a fourth time from a supersaturated solution in redistilled water. The small crystals thus obtained were freed from the mother liquor by means of the water-pump, and allowed to stand in a vacuum of 5 mm. over anhydrous borax for a week.

Owing to the fact that on heating crystallised borax in the air it

* The weights seem only to have been determined to the centigram.

† In the following memoir, we have used throughout the following atomic weights: $\text{O} = 16$, $\text{Na} = 23·051$, $\text{Ag} = 107·923$, $\text{Br} = 79·951$, the numbers calculated by Clarke (*Constants of Nature*). We have taken $\text{H} = 1·0077$, this number being the mean of the numbers given by Stas (1·0075), Cooke and Richards (1·0083), Noyes (1·0072), Rayleigh (1·0069), and Dittmar and Henderson (1·0085). (See Ramsay in the *Year-book of Science* for 1891, p. 132.)—T. E., P. J. H.

swells up to an enormous extent, it was found extremely difficult to drive off the water in this way without incurring mechanical loss of the substance. The following process of dehydration was, therefore, used. The borax was weighed in a platinum crucible, and this was supported on a pipeclay triangle, and slipped into a wide glass tube, sealed up at one end (AB, Fig. 1). A lump of quicklime was then introduced into the tube, and the end closed with a well-fitting india-rubber stopper, through which passed a tube connected with a closed manometer, D, and, further, at E with a water-pump capable of reducing the pressure to the vapour tension of water. The end of the glass tube AB, in which the platinum crucible stood, was placed in an air-bath made from a biscuit tin. The crucible was thus heated in

FIG. 1.

various experiments for very different lengths of time (5—20 hours) to between 250° and 300° ; but practically the whole of the water that could be expelled at this temperature was found to come off in the first three or four hours. About $\frac{1}{2}$ per cent. of water still remained in the substance after the longest continued heating. To remove this residual quantity of water, the crucible was taken out of the tube and heated over the naked flame of a Bunsen burner until the weight became approximately constant; in some cases the final heating was done with a blowpipe.

The experiments recorded below were only considered by the author as preliminary, and were carried out in order to determine under what conditions they must be performed to be sufficiently accurate for atomic weight determinations.

The following experiment shows that no boracic acid or other substance is volatilised with the water of crystallisation at 265° in a vacuum. A certain quantity of borax was introduced into a tube, a plug of asbestos was then inserted, the tube exhausted, and all the water which came over on heating was condensed and collected. It did not act on turmeric paper, and left no appreciable residue when left to evaporate in the cold over sulphuric acid.

It was, however, found on heating melted borax over a blowpipe that the flame was coloured yellow, which seems to show that it volatilises, at least to some minute extent, at high temperatures.

It was observed that on prolonged heating over a Bunsen burner the weight of the crucible and contents, which diminished at first, finally began to increase. This final increase may have been due to absorption of sulphur from the flame.

The following are the results of these preliminary experiments, of which the data are sufficiently complete to allow of an atomic weight being calculated from them:—

No. of expt.	Corrected weight of $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$.	Corrected weight of residual $\text{Na}_2\text{B}_4\text{O}_7$.	Percentage of H_2O found.	Atomic weight of B.
A 85.....	7·00667	3·69587	47·2069	10·843
A 91.....	12·95936	6·82560	47·3308	10·593
A 113	4·65812	2·45248	47·3504	10·554
A 129	7·47208	3·93956	47·2763	10·703
A 131	4·94504	2·60759	47·2686	10·719

The numbers of the experiments given in Column 1 correspond to the pages of the note-book on which they are recorded. The weights of hydrated and anhydrous borax were corrected for buoyancy in air.

As has already been said, the weight of the fused borax in some cases reached a minimum value, after which it increased. This minimum value (corresponding to the highest percentage of water) has in these cases been taken as the final weight of the fused borax. The weighings (performed by the method of vibrations) were probably accurate to $\frac{1}{10}$ milligram. They have been corrected for errors in the weights used and for buoyancy in air. [For a full account of the application of these corrections see p. 661.] As the fourth place of decimals is probably correct in the actual weighings, the fifth place has been preserved in the corrected numbers.

The following remarks on the single determinations may be of value:—In A 91 and A 113, the borax was finally heated in a small Fletcher furnace capable of melting cast iron easily. In both cases the temperature was, therefore, exceptionally high, and the loss exceptionally great; the atomic weight calculated from the result is therefore low. A 129 and A 131 were the two last experiments made, and are probably more worthy of confidence than the preceding ones. In A 131, the borax was finally fused over the blowpipe. The actual weighings in a given instance are quoted to show the variations which occur on prolonged heating.

Crucible + borax fused with Bunsen burner....	27·30345
re-fused " 	27·30462
,, blowpipe.....	27·30312
,, for half an hour	27·30253

The determination of the atomic weight of boron by this method necessitates the determination of the precise range of temperature within which all the water of crystallisation of borax can be driven off, while none of the anhydrous substance is volatilised. That this is no easy matter, the above experiments clearly show. In spite of their apparent concordance,* therefore, Berzelius's results cannot be finally accepted as trustworthy.

[The method is evidently open to objection on another score, namely, that it is exceedingly rare to find bodies which crystallise with an exact number of molecules of water of crystallisation. On the one hand, the mother liquor may be included mechanically; on the other hand, the salt may be slightly deliquescent or slightly efflorescent. It is quite possible† that the compound $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$ may yield some of its water of crystallisation to anhydrous borax, both bodies tending to form a lower hydrate with a lower tension of dissociation than the decahydrate.—T. E., P. J. H.].

Preparation of Boron Bromide.

a. Preparation of Boron.—The method followed was that described by Wöhler and Deville. A considerable amount of trouble was taken in attempting to purify the borax completely. Pure boracic acid (of commerce) was first boiled with a small quantity of baryta to free it from sulphuric acid, which adheres to it very tenaciously, and was then recrystallised in small portions at one time. The boracic acid so obtained was fused over the blowpipe in a platinum dish, and poured out on to an iron plate, broken up and powdered, and passed through a sieve.

The powdered substance was then heated in an iron crucible with sodium, under a layer of sodium chloride, exactly in the way described by Wöhler and Deville (*Ann. Chim. Phys.* [3], 52, 63, 1858). The mass was poured into hydrochloric acid and filtered, and the boron mud thus obtained was transferred to a platinum dish and treated with strong hydrochloric acid and ammonium fluoride (to remove iron and silica), the liquid being warmed. It was finally washed with alcohol and hydrochloric acid, and alcohol and ether, and dried in a vacuum. It appears that this preparation was not pure, but still contained iron

* See note *, p. 652.

† This suggestion is due to Dr. Harden.

(perhaps in the form of a boride?). A second preparation of boron was made, the fused mass being poured, as before, into hydrochloric acid and then washed by decantation till free from the acid. As soon as this is the case, the boron begins partly to dissolve, partly to suspend itself in the water, and from these washings, boron free from iron was obtained, by precipitating with hydrochloric acid, re-suspending by treatment with potash, and precipitating again with hydrochloric acid. The boron thus freed from iron was then dried on a porous tile in a vacuum for a month. It was found that it was impossible, however, to free it from water in this way, for on heating it in a vacuum at 100° , water, and at a higher temperature, hydrogen, were given off.

To free the boron from water and from any oxide which might be formed in the presence of water, a portion of it was washed with alcohol and then with ether, but on heating subsequently to this operation, hydrocarbons were evolved, and the attempt to obtain boron free from oxide was therefore abandoned, and it was decided to eliminate the products due to its presence at a later stage.

b. Preparation of the Bromine.—The editors can find no details with regard to the bromine used in Preparation 1 (*infra*). The bromine used in Preparation 2 was made in the following way:—A solution of potassium bromide was treated with bromine and shaken up with pure carbon bisulphide to free it from iodine. The bromide was then crystallised and heated with pure potassium dichromate and dilute sulphuric acid, and the bromine thus obtained was finally distilled over pure, red-hot, electrolytic copper to free it from chlorine. [It is possible that other precautions to ensure its purity were also taken. —T. E., P. J. H.] It was collected in a stoppered funnel, D, Fig. 2, ground to fit the apparatus for the production of boron bromide.

FIG. 2.

c. Preparation of Boron Bromide.—Two different preparations of boron bromide were made from the boron obtained in the way described above. In the first, only 6 grams of boron were used, and the details given in the author's note-books are incomplete. This preparation was used for the preliminary set of determinations.

The second preparation was on a large scale, and the editors are able, from their own knowledge, to give somewhat fuller details with regard to it, although no notes on the subject have been preserved.

Preparation 1.—Six grams of boron were first ignited in hydrogen in a hard-glass tube placed in an ordinary combustion furnace, to free it from moisture; bromine was then distilled backwards and forwards over the substance heated to redness, the product allowed to stand over mercury till the excess of bromine was absorbed, and then distilled off from the mercuric bromide formed.

Preparation 2.—The apparatus used consisted of a hard-glass combustion tube, CC', Fig. 2, about 1200 mm. in length, to the ends of which were fused the U-tubes A and B. The stoppered funnel D, containing the bromine, was ground to fit into the tube A, and the joint well wrapped round with lead foil. The bent neck of the distilling flask E which contained mercury was similarly ground into the U-tube B.

Bromine was slowly distilled over the red-hot boron placed between C and C', and the bromide formed, together with the excess of bromine, were finally transferred to the distilling flask. This was then sealed up and the mixture allowed to remain in it until the colour of the bromine had disappeared. The substance was then redistilled into a clean dry flask of the form shown in Fig. 3, and from this flask it was finally distilled into the tube F, from which

FIG. 3.

it was transferred to the glass bulbs used in the atomic weight determinations.*

The tube AB was about 1 metre long, so that when the flask was exhausted by means of the Sprengel pump, the mercury in the trough CD did not rush back into the flask. A thermometer, E, was sealed into the neck of the flask by wrapping it tightly round with thin lead foil, which, for further security, was enveloped outside with sheet india-rubber coated with coaguline.

The apparatus being so arranged, the boron bromide was distilled in fractions of 10 to 15 c.c. at a time into the test-tube F standing in the trough CD over dry clean mercury.

The separate portions of boron bromide were then introduced into thin glass bulbs of the form shown in Fig. 4, which had been pre-

FIG. 4.

viously weighed. In order to fill each bulb, it was first filled completely with the mercury. The open end of the capillary neck was then slipped up into the boron bromide at the top of the tube F, and by alternately warming and cooling the bulb with a small flame, the whole of the mercury was replaced by boron bromide. The capillary was then sealed off as close to the bulb as possible, and the neck was preserved along with the bulb to be weighed again.

The bulbs thus prepared always contained a small bubble of gas; this, however, consisted only of the vapour of boron bromide, as on slightly warming the bulb in the hand the bubble could be made to disappear entirely. The size of the bubbles varies rapidly with the

* As the boron was not anhydrous, some hydrobromic acid must have been formed during the operation, but it is probable that by the action of the mercury and the mercuric bromide, and the repeated distillation of the boron bromide, it was finally completely eliminated.

temperature, so that boron bromide would appear to have a large coefficient of expansion.*

Preparation of the Silver.

The silver used was prepared in various ways:—

- (a) Was obtained as chemically pure from Schuchardt.
- (b) Was prepared by reducing silver nitrate with ammonium sulphite in the presence of copper, according to the method described by Stas.
- (c) Was made by reducing silver chloride with milk sugar, but the method used differed somewhat from that of Stas, and is therefore described. About 60 grams of recrystallised silver nitrate were fused till a small quantity of silver had been reduced; the melt was dis-

* *Density of Boron Bromide.*—In order to apply the buoyancy correction to the weights of boron bromide, it was necessary to know the density of the liquid. This was determined (by the editors) with one of the bulbs (6) prepared by the author. The diameter of the bubble of boron bromide vapour resting against the side of the bulb at the temperature of the experiment (16.5°) was found to be 3.3 millimetres: its volume was known to be greater than a hemisphere, and less than a sphere. As the difference between the limiting values is a small quantity compared to the others which entered into the calculation, no sensible error was committed by supposing the mean to be the true value.

The density of the boron bromide was found from the following equation:—

$$d_B = \frac{B}{V - \frac{g}{d_g} - v},$$

where d_B = density of boron bromide.

B = weight of boron bromide (corrected for buoyancy by assuming the density to be that given by previous observers, that is, 2.7) = 10.8151 grams. This weight was determined as the difference of the weights of the bulb filled and empty. Strictly speaking, the weight of boron bromide vapour in the bubble should be subtracted from this number, but this weight cannot be more than $\frac{1}{10000}$ milligram, and is therefore negligible.

V = the volume of the filled bulb, known by a determination of its loss of weight in water of known temperature = 4.37381 c.c.

g = weight of glass of the bulb = 0.56388 gram.

d_g = density of the glass of the bulb = 2.4679 .

v = volume of the bubble = 0.0137 c.c.

Whence we find—

$$d_B \text{ (at } 16.5^{\circ}) = 2.6175.$$

Wöhler and Deville gave the number 2.69 , but they do not state the temperature at which the determination was made, and which was probably 0° .

The result given above is of course affected by the uncertainty as to the exact volume of the bubble, but the limiting error in the density cannot amount to $\frac{1}{300}$ of the total value. As the density was only required to correct the weighings, greater accuracy was not attempted.—T. E., P. J. H.

solved in 250 c.c. of water, filtered, and the solution diluted up to 3 or 4 litres. It was then precipitated by means of pure, dilute hydrochloric acid, and the silver chloride formed was washed by decantation, and digested with aqua regia in the cold. It was then again washed and dissolved in 1 litre of water, saturated with ammonia, and filtered. 100 grams of twice recrystallised milk sugar were dissolved in 1 litre of water, and filtered into the silver solution. The mixture was allowed to stand for a day in the cold, then warmed, and finally boiled. The reduced silver was washed by decantation, first with cold water, and then with boiling water. The water used had been carefully redistilled from an iron can provided with a block-tin condenser. The silver obtained by the method described is in an extremely finely divided form, and the washing was very tedious. It was collected and melted on lime in the oxy-coal-gas blowpipe, care being taken to use an excess of oxygen. The silver used in the final set of determinations was then purified by electrolysis in the following way. Part of it was dissolved in nitric acid, and the solution of silver nitrate was placed in a platinum dish which formed the negative pole. The positive pole consisted of the remaining portion of the silver suspended in a linen bag, and connected to the battery by a platinum wire. The bag was hung from the top of a bell-jar which protected the solution from dust. A tangent galvanometer was included in the circuit, and the current regulated to the strength which was found by Lord Rayleigh and Mrs. Sidgwick (*Phil. Trans.*, ii, 1884, 411) to give the best results with the silver voltameter. Black crystals (of peroxide?) were formed in very small quantity, which grew in long, hair-like filaments, and sometimes reached from the dish across to the bag. They were, however, isolated, and easily removed (the silver, on melting in a vacuum, gave off no oxygen). The metal obtained was granular and brilliantly white.

The electrolytic silver was placed in a boat cut from a block of quicklime, and melted in a porcelain tube in a vacuum.

Weighings.

The weighings were all performed with a Ladd and Oertling balance provided with an optical arrangement for estimating accurately the amplitude of the swings of the pointer. [The balance has been described by Wills, *Trans.*, 1879, 35, 707.] All weighings were made by Gauss' method. The object to be weighed was first placed on the left-hand pan, four sets of vibrations (each consisting of 5 or 7 swings past the centre of the scale) were taken, and the position of the zero was calculated. This operation was repeated

with the object to be weighed in the right-hand pan, and finally again with the object in the left-hand pan. The difference between the two weighings with the object on the left-hand pan never amounted to more than $\frac{1}{20}$ milligram, and generally was less than $\frac{1}{40}$. The mean of the two weighings with the object in the left-hand pan was of course in all cases taken. The difference between them was due to a slow change of the zero point which was found to be continuous throughout the series of operations. Such variation did not therefore introduce a sensible error into the weighing.

The temperature of the air in the balance case, and the barometric pressure were noted for each weighing. The air was assumed to be dry, as fresh calcium chloride was kept in the case.

The errors of the weights were determined three times in the course of the work, before each prolonged set of weighings. As two of the 1-gram weights happened to be precisely equal in weight, they were taken as standards.

The only weights for which the corrections varied more than one or two hundredths of a milligram were the 10-gram weight and the 5-gram weight. The correction for the 10-gram weight varied 0.6 milligram, and that for the 5-gram weight 0.3 milligram, during the three years over which the work extended.

The weighings of boron bromide (A) and of silver (B) were corrected for buoyancy in air by the following formulæ:—

(A.) Corrected weight of $\text{BBr}_3 =$

$$W - w + \sigma \left[\frac{W - w}{2.617} - \frac{W_B - w_B}{8.28} - \frac{W_p - w_p}{21.23} \right],$$

(B.) Corrected weight of Ag =

$$W + \sigma \left[\frac{W}{10.5} - \frac{W_B}{8.28} - \frac{W_p}{21.23} \right],$$

where W is, in A, the apparent weight in grams of the bulb full of boron bromide in air, and in B the apparent weight of silver in air.

w is the apparent weight of the glass bulb in air.

σ is the weight of 1 c.c. of air at the temperature and pressure noted during the weighing.

W_B and w_B are the brass weights used in making up the weights W and w .

W_p and w_p are the platinum weights used in making up the weights W and w .

[The correction for the rider is negligible.]

2.617 is the density of boron bromide.

8.28 is the density of the brass weights.

21.23 is the density of platinum (Everett).

10.5 is the density of silver.

The density of the brass weights was determined by weighing the 50-gram weight in water. The error introduced by the difference between the actual density of the platinum weights used and the average of the numbers given in Everett's *C.G.S. Units*, which has been taken, could not introduce a sensible error into the experiments.

Titration of Boron Bromide.

When the weight of boron bromide in the bulb chosen for an experiment had been determined, a lump of silver was cut off from the mass, and reduced very nearly to the proper amount by means of a sharp, hard-steel chisel. It was next washed with dilute hydrochloric acid, ammonia, and water, and heated before the final weighing. It was then dissolved in nitric acid in a stoppered bottle. The bottle had walls about $\frac{1}{4}$ inch thick, and the stopper was ground in with care. When the silver was all dissolved, the bulb of boron bromide was introduced, the stopper inserted, and the bottle shaken so as to break the bulb. The sudden pressure, due to the evolution of gaseous hydrogen bromide, which did not immediately dissolve, was so great as to burst the bottle in some cases, a number of determinations being thus lost. Some bottles specially made for the purpose were used in the final determinations, of which one or two alone proved satisfactory.

The titrations were carried out by a method which in its essentials is that of Stas. A solution of silver nitrate was made up so that 1 gram of solution contained exactly 1.09 milligram of silver, and a potassium bromide solution was prepared which was exactly equivalent to it (by weight). These solutions were introduced into pipettes of the form shown in Fig. 5. The small glass cap A was ground on

FIG. 5.

to the end of the siphon tube, so as to prevent loss of liquid when the pipette was not in use. The pipettes were weighed (to the milligram) before and after each addition of solution.

The bottle was placed in a wooden box, blackened internally, and could be illuminated by the rays of a lamp, which were spread out into a flat pencil by means of a glass cylinder, placed with its axis horizontal. The slightest turbidity in the liquid could thus be detected after the addition of silver or bromide solution. Before repeating the addition of either solution, it was found advantageous to filter the supernatant liquid through a small filter into a test-glass, leaving the curdy mass of silver bromide at the bottom of the bottle. The filtered liquid was then poured back into the bottle, and tested afresh with bromide or silver solution, as the case might be. Towards the end of the reaction, a considerable time was allowed to elapse between the successive additions of these solutions; often only two or three drops were added in a day, so that each titration required a week or more for its completion.

It is well known that some excess of one (say, the silver) solution may be added before an additional drop ceases to produce a visible cloud; and after this point has been reached, a not inconsiderable amount of the other (say, the bromide) solution must be added before an additional drop of this solution ceases to produce a cloud. The silver solution was therefore first added, until the no-turbidity point was attained; the process was repeated with the bromide solution, and again with each solution alternately several times. It was assumed that half of the bromide solution added after silver had ceased to produce a visible reaction was equivalent to the excess of silver present at the beginning of this operation, and that the other half was itself present at the end of the operation as excess. Then, on adding the silver solution again, half the amount added was regarded as equivalent to the excess of bromide in the liquid, while the second half as before remained in excess at the end of the operation. In this way, the excess existing at the previous stage could be calculated from each addition of bromide or silver solution after the first. The mean of all the numbers thus obtained was taken to be the true excess present after the first addition of silver or bromide solution. In this way, the exact weight of silver necessary to precipitate the bromine in a known weight of boron bromide could be determined.

The atomic weight of boron was calculated from the experimental numbers by the formula

$$B = 3AgX - 3Br,$$

where B, Ag, and Br are the atomic weights of boron, silver, and

bromine respectively, and X is the ratio of the weight of boron bromide taken to the weight of silver necessary to precipitate the bromine it contains.

Ag was taken = 107.923, Br = 79.951 (see note †, p. 652).

The following table gives the experimental data and atomic weights calculated from them:—

TABLE II.*—*Preliminary Series of Determinations.*

Frac- tion.	No. of bulb.	Weight of boron bromide.	Weight of silver weighed out.	Deficiency or excess deter- mined by titration.	Total silver.	Ratio X = boron bromide silver.	Atomic weight of boron.
—	10	1.31203	2.84299 —1.15058	+0.00165	1.69406	0.774489	10.902
—	7	4.39944	5.67589	+0.00240	5.67829	0.774783	10.998
—	4	5.04022	6.50785	+0.00035	6.50820	0.774441	10.887
—	1	6.51597	8.38890	+0.00029	8.38919	0.774326	10.850
—	9	7.75343	10.01369	—0.00134	10.01235	0.774388	10.870

It must be borne in mind that a given percentage error in the determination of X will produce a relative error 23 times as great in the value of B , a result which may easily be deduced from the equation given above, $B = 323.769X - 239.853$, if we replace X by its value 0.774. The author was, of course, aware of this, but the method described was chosen, nevertheless, as the most accurate one available.

The close agreement of determinations made with the various fractions of boron bromide of preparation ii (Table III) affords strong evidence that the substance was in a state of all but absolute purity. It must, however, be noticed that—

(1.) The pairs of experiments made with the same fractions, namely, 23 and 25, and 32 and 34, yield results which differ only by the 1/60,000th part of their value, and that this may probably be considered as the experimental error to which determinations made with the same fraction were liable.

(2.) The two results deduced from experiments made with the first fraction differ in a relatively marked way from the other five results.

* The editors hesitated to insert this table, as the numbers are without comparison less concordant and trustworthy than those of Table III, but have decided to do so for the sake of completeness.

They have purposely omitted to calculate a mean atomic weight from the observations, as the author regarded them as purely preliminary.

TABLE III.—*Final Series of Determinations with Boron Bromide.*

Fraction.	Number of bulb.	Weight of boron bromide.	Weight of silver weighed out.	Deficiency or excess of silver determined by titration.	Total silver.	Ratio X boron bromide = $\frac{\text{silver}}{\text{boron bromide}}$.	B = atomic weight of boron.
i	23	4.467835	5.769480	+ 0.001788	5.771268	0.774152	10.794
i	25	8.428151	10.880752	- 0.000104	10.880648	0.774143	10.792
ii	19	1.655111	2.136486	+ 0.001107	2.137593	0.774288	10.838
iii	10	8.032352	10.373182	+ 0.001019	10.374201	0.774262	10.829
vi	32	4.092743	5.286621	- 0.000672	5.285949	0.774268	10.831
vi	34	2.389993	3.086793	+ 0.000049	3.086842	0.774254	10.826
xi (?)	11	7.721944	9.974278	- 0.000224	9.974054	0.774203	10.811

Mean of all the determinations. 10.817

Mean error ± 0.016

Probable error ± 0.0047

Atomic weight determined from the ratio of the total quantity of boron bromide to the total quantity of silver employed in all the determinations = 10.812.

Mean of the last 5 determinations (excluding those made with the first fraction) ± 0.007

Mean error ± 0.003

Probable error ± 0.003

Atomic weight determined from the ratio of the total quantity of boron bromide to the total quantity of silver employed in the last 5 determinations = 10.823.

(3.) Boron chloride has a lower boiling point than boron bromide, and if any of this substance were present as an impurity in the bromide, the major portion of it would distil over with the first fraction, and the atomic weight calculated from the determinations made with this fraction would, therefore, be too low.

Hence it would seem preferable to neglect the first two results, and to consider as the atomic weight yielded by these determinations the number calculated from the last five results.

The number thus obtained, $B = 10.825$, is, it will be seen, lower than that given by previous observers, and, moreover, differs considerably from the nearest whole number.