On the Atomic Weight of Chlorine

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PHILOSOPHICAL TRANSACTIONS.

I. *On the Atomic Weight of Chlorine.*

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Communicated by Prof. H. B. DIXON, *F.R.S.*

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PART I.—GENERAL.

SIX years ago Prof. DIXON and I began a research with the object of determining directly the weight of chlorine which combines with the unit weight of hydrogen. Our method was to burn a jet of hydrogen in an atmosphere of chlorine; hydrogen being stored and weighed in palladium, the chlorine being condensed and weighed as liquid. The figure we obtained for the combining weight of chlorine was appreciably higher than that found indirectly by STAS, and still higher than that approved by the International Committee on Atomic Weights.

While this research was in progress, other determinations had been made bearing on the relative weights of silver, chlorine and nitrogen, so that some modification in the accepted values of one or more of these elements appeared inevitable. The direct "joining up" of the two ends of the chain connecting hydrogen with chlorine thus became a matter of immediate importance. Since the method of burning one gas in an atmosphere of the other had been proved to be accurate within fairly narrow limits, I was encouraged to continue the investigation, and to modify the apparatus with a view to eliminate some of the possible sources of error in the former series of experiments.

The most important source of error lies in the weighing of the hydrogen. To diminish this error the weight of hydrogen employed was doubled; and since Prof. DIXON and I found, when water was used to condense the hydrogen chloride formed in the flame, that some of the water vapour was decomposed by the free chlorine, I avoided this by burning a jet of chlorine in dry hydrogen, condensing the hydrogen chloride as it was formed in a tube dipped into liquid air. In some of the experiments the hydrogen chloride has been weighed. My experiments (concluded in 1907) agree closely with the results previously obtained in 1905.

The method employed was briefly as follows:—

Hydrogen, made by the electrolysis of barium hydrate solution and dried by potash and phosphorus pentoxide, was occluded and weighed in palladium contained in a boro-silicate glass bulb: the chlorine, prepared by electrolysing fused silver chloride in a Jena glass vessel, was weighed as a liquid in a thick-walled boro-silicate glass bulb. These bulbs were attached to a quartz combustion vessel, which was also connected with a quartz tube and with a steel bomb and a pump. After a thorough evacuation of the whole apparatus, the combustion vessel was filled with hydrogen from the heated palladium bulb, and the chlorine was ignited by a spark at the tip of a quartz jet and continued to burn in the atmosphere of hydrogen, with a fine needle-shaped flame, until nearly all the chlorine weighed had been burnt. The hydrogen chloride, immediately after its formation in the flame, was condensed as a snow-white solid by liquid air surrounding a limb of the combustion vessel; and a little chlorine, which had escaped burning, was also solidified. At the end of the combustion, the residual gas in the combustion vessel was extracted by the pump and subsequently analysed; it proved to be practically pure hydrogen.

Then the snow-white hydrogen chloride was allowed to pass through a quartz tube filled with mercury vapour, and the purified gas was condensed in a steel bomb immersed in liquid air. It was successfully weighed in three experiments; in two other experiments the gas was absorbed by water and weighed as aqueous acid.

The balance was made specially for this work by Oertling. Each piece of apparatus weighed was tared with another of the same material and of very nearly equal volume and weight, and the small weights used in the weighings were reduced to a vacuum standard.

Below are set out the corrected weights of hydrogen and chlorine burnt in eight experiments and the weights of hydrogen chloride caught in five.

TABLE I.

	Hydrogen burnt, in grammes.	Chlorine burnt, in grammes.	Hydrogen chloride caught, in grammes.	$\frac{\text{Chlorine burnt}}{\text{Hydrogen burnt}}$.	$\frac{\text{Hydrogen chloride caught} - \text{hydrogen burnt}}{\text{Hydrogen burnt}}$.
1	2·1452	75·5026	77·6469	35·196	35·196
2	2·0387	71·7504	73·7880	35·194	35·194
3	1·7762	62·5004		35·188	
4	1·9935	70·1638	72·1565	35·196	35·196
5	1·6469	57·9671		35·198	
6	2·1016	73·9662		35·195	
7	1·7254	60·7162	62·4401	35·190	35·189
8	2·0885	73·4991	75·5859	35·192	35·191
			Mean . .	35·194 ± 0·0008	35·193 ± 0·0009

If the atomic weight of hydrogen be taken as 1·00762, the mean values for the atomic weight of chlorine calculated from the numbers in the table above are 35·462 ± 0·0008 and 35·461 ± 0·0009.

Dixon and Edgar, burning hydrogen in chlorine, found the equivalent of chlorine to be 35·463±0·0019 from their nine experiments.

The concordance of the two sets of experiments is thus exceedingly close, and the number 35·462 may be taken as representing the result of the whole work.

On the other hand, Noyes and Weber* have recently effected a complete quantitative synthesis of hydrogen chloride by passing a known weight of hydrogen over weighed potassium chlorplatinate, noting the loss in weight of the salt, and condensing and weighing in water the hydrogen chloride formed. The mean number they have thus obtained for the atomic weight of chlorine is 35·452±0·0008 (H = 1·00762).

In view of the promised recalculation of the Atomic Weights by the International Committee, I have not attempted to correlate my results with the recent determinations of silver, nitrogen and chlorine.

The inception of this work is due to Prof. Dixon, and I gladly take this opportunity of thanking him for the searching, yet kindly, criticism to which he has subjected these experiments.

To the Government Grant Committee I am indebted for two grants, which have largely covered the cost of the apparatus employed.

Part II.—Details of Experiments.

1. *Preparation of Hydrogen.*—The preparation of hydrogen and its occlusion in palladium have been fully described in the previous paper.† The only alterations I introduced in the arrangement of the apparatus were these:—Four phosphorus pentoxide drying tubes instead of three were used, and a water reservoir was attached to one arm of the electrolysis vessel. The whole apparatus, including the bulb containing palladium, was made of boro-silicate glass.

In the preparation of the hydrogen, the gas passed through two U tubes containing platinised pumice, kept at 400° C., instead of 220° C., to remove any oxygen diffusing from the + electrode.

The purity of the hydrogen is evidenced by the fact that the residual gases from the combustion of all the hydrogen—about 15½ grammes—burnt in my eight experiments and of the corresponding weight of chlorine yielded less than half a cubic centimetre of nitrogen. If it be assumed that all this nitrogen came from the hydrogenised palladium bulb (which is not likely), the maximum weight of nitrogen present in the hydrogen was 1 part in 25,000.

2. *The Palladium Bulb.*—The palladium bulb, of which a sketch is given in fig. 1, differed little from that described in the former paper. It was made of boro-silicate glass, and terminated, not in a jet, but in the inner portion of a ground joint.

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* 'Jour. Amer. Chem. Soc.,' 30, 13, 1908.

† 'Phil. Trans.,' 1906, vol. 205, p. 172.

The bulb contained over 600 grammes of palladium, in which about 2½ grammes of hydrogen were stored in each experiment.

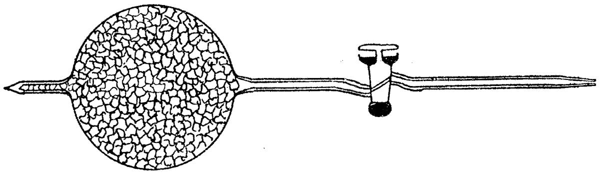

Fig. 1.

To Messrs. Johnson and Matthey my thanks are due for lending me 400 grammes of palladium.

3. *Preparation of Chlorine.*—The details of the preparation of chlorine by electrolysing fused silver chloride are given fully on pp. 177–180 of DIXON and EDGAR'S paper.* The only alteration I made in these experiments was to substitute boro-silicate glass for soft glass as the material for the various connecting tubes.

As before, the purity of the gas was shown by its complete absorption by pure, dry mercury.

4. *The Chlorine Bulb.*—The bulb, in which chlorine was condensed as a solid by liquid air, was made of boro-silicate glass; a sketch of the apparatus is given in fig. 2.

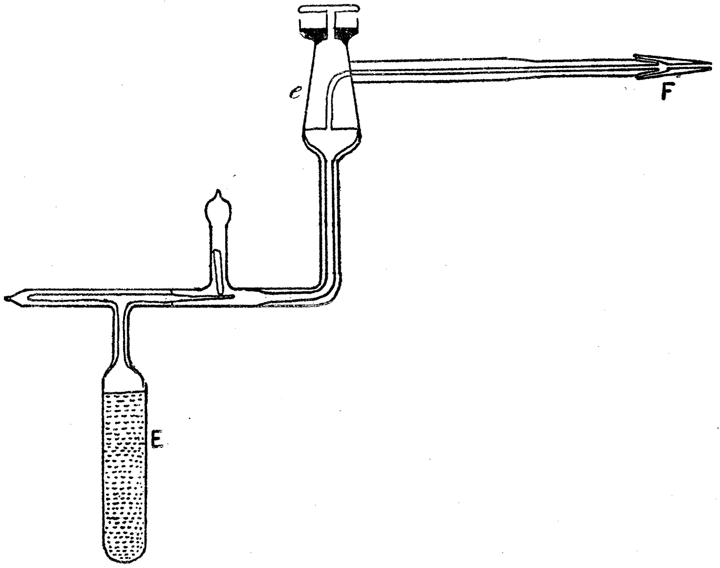

Fig. 2.

The only difference to be noted between the apparatus I used and that described in the former paper is that mine terminated in a quartz jet F connected by a ground joint with the delivery tube.

The "reversed" tap (*e*, fig. 2) had proved so trustworthy in controlling the exit of

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* 'Phil. Trans.,' 1906, vol. 205, p. 177.

chlorine under pressure in the former experiments that it was employed unhesitatingly in these.

The weights of chlorine condensed in each experiment varied between 70 and 80 grammes.

5. *The Method of Weighing.*—For the various weighings I used a short-armed balance made specially for this work by Oertling. Even in weighing the steel bomb (weighing considerably over 1000 grammes) the concordance of individual weighings showed that their mean could be relied on to 0·0001 gramme.

Each piece of apparatus weighed was counterpoised by another of the same material, and of very nearly the same volume and weight. The weights employed, though they had been standardised for the previous work, were carefully re-standardised for this; but the variations found were too insignificant to affect results calculated from the older values.

The details of the method of weighing are given in full in the former paper. It may be noted here that the variations in volume of the palladium bulb, caused by the differences in sealing off the thick-walled capillary tube, were small. In all the experiments the bulb and its counterpoise differed so little in volume that, though the density of the air in some of the determinations altered appreciably between the first and second weighings of the bulb, in no case was it found necessary to apply a correction to the apparent weight.

6. *The Combustion Apparatus.*—The chlorine was burnt in the quartz combustion vessel A (shown in fig. 3, and, on a larger scale, in fig. 4), a prominent feature of which was the dependent vertical limb B in which hydrogen chloride could be condensed. The vessel had a capacity of 350 c.c. and was fitted with five ground

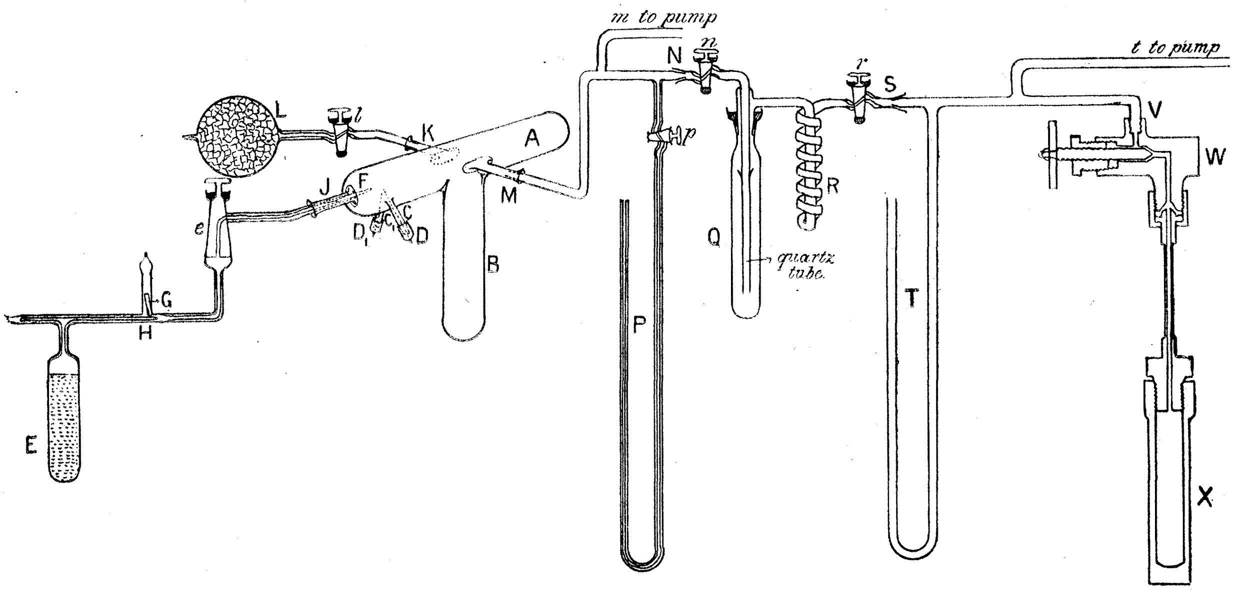

Fig. 3.

quartz tubulures. Into the two small tubulures C and C_1 (shown both in fig. 3 and fig. 4) were fitted two platinum wires D and D_1, sheathed in glass except for their extreme tips; these sheaths were ground into the tubulures and the joints protected

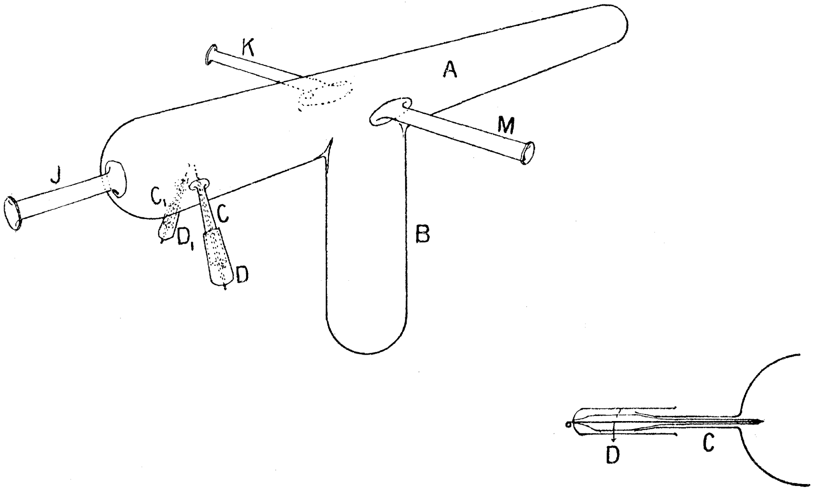

Fig. 4.

by caps containing mercury. By passing sparks between the tips of the wires, the chlorine, from the chlorine condensation bulb E (fig. 3), could be ignited easily at the tip of the quartz jet F. The bulb E and the palladium bulb L were connected with A by the ground tubulures J and K respectively.

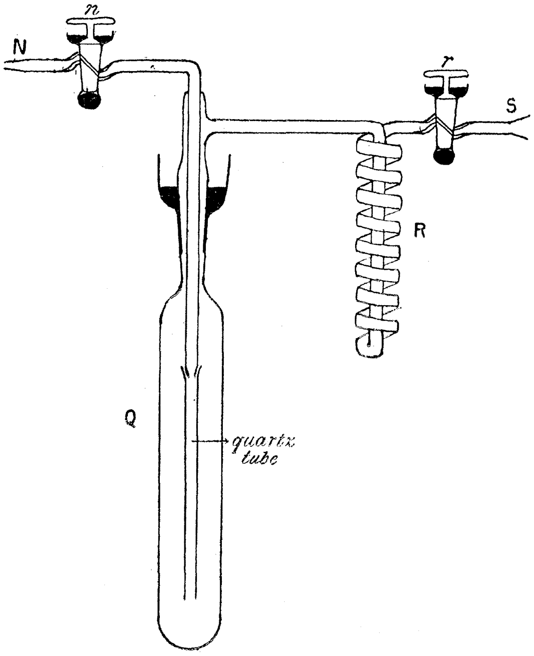

Fig. 5.

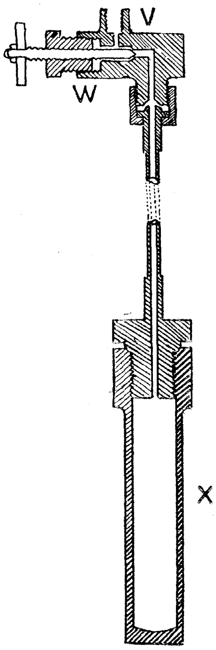

Fig. 6.

7. *The Evacuation Apparatus.*—To the tubulure M was attached, by a ground joint, the evacuation apparatus. This consisted of a quartz tube Q (shown in fig. 3

and, on a larger scale, in fig. 5) in which mercury could be heated to absorb chlorine, R, a small spiral condenser, X, a nickel-plated steel tube in which to condense the hydrogen chloride, and side tubes leading to two manometers, P and T, and to two Sprengel pumps.

In order to weigh the chlorine condenser separately, two taps, *n* and *r*, were inserted, and ground-glass joints fitted at N and S. The ground-glass joint S led to the apparatus in which hydrogen chloride was condensed and weighed.

In six experiments this was a weighed nickel-plated steel bomb, consisting of a cylindrical steel tube X (fig. 6), connected by a length of flexible copper tubing with a screw valve W. The bomb was connected to the rest of the apparatus by the joint V—a joint between glass and steel cemented by solid phosphoric acid.

In two other experiments the hydrogen chloride was absorbed and weighed in water. Fig. 7 is a sketch of the apparatus used. Y was a boro-silicate glass bulb (over 200 c.c. in capacity), fused to which was a tap *y* and a phosphorus pentoxide tube to absorb water vapour. Z was a thick-walled capillary tube in which hydrogen chloride could be condensed by liquid air. A tap *z* closed the apparatus.

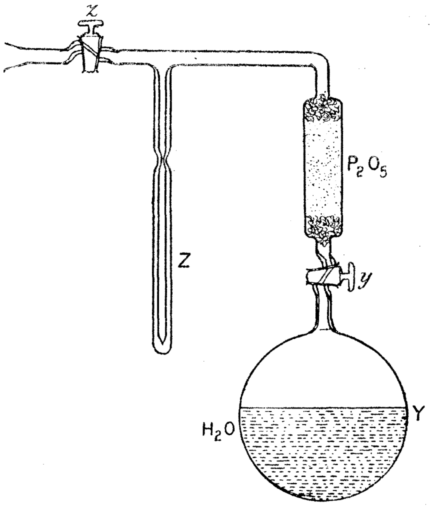

Fig. 7.

Metaphosphoric acid was used as a lubricant on all the taps and ground joints. It is somewhat troublesome to spread evenly on a glass surface, but it has none of the disadvantages of organic lubricants.

8. *Method of carrying out the Combustion and Condensation.*—When the palladium bulb, the liquid chlorine bulb, the chlorine condenser, and the hydrogen chloride condenser had been weighed, the different parts of the combustion and condensation apparatus were fitted together. Then the pumps, fitted with McLeod gauges, were set working so as to evacuate the combustion vessel A (fig. 3) through the connecting tube *m* and the rest of the apparatus through *t*. Since the quartz tube Q and the steel bomb X had been previously evacuated prior to weighing, it was only necessary to evacuate the small portion between V and *r*. So as to facilitate the removal of traces of nitrogen, most of the glass apparatus was heated by the flame of a Bunsen burner.

When the pressure had fallen as low as some thousandths of a millimetre of mercury, the now vacuous combustion vessel was isolated from the pump by closing a tap, and the lower end of the vertical limb B was immersed in liquid air.

The liquid chlorine bulb E was packed into a freezing mixture of calcium chloride and ice, in which it was kept during the combustion.

The palladium bulb L, enclosed in an asbestos-lined copper box, was gradually raised to 250° C. Then hydrogen was cautiously admitted through the tap l until the pressure shown by the manometer P was nearly atmospheric, at which point l was temporarily closed.

The glass cul-de-sac H was broken by lifting the small piece of steel rod G, imbedded in glass, by means of an electromagnet, and allowing it to drop. Since the temperature of the liquid chlorine was about $-25°$ C., the pressure on the reversed tap e was rather more than atmospheric. The ignition of chlorine at the tip of the quartz jet F was brought about by cautiously turning the tap e so as to admit chlorine to F, at the same time rapidly passing sparks between the platinum tips until the gas had lit. Chlorine burns in dry hydrogen with a fine needle-shaped flame. In daylight this cannot easily be seen; the combustion therefore was carried out in a dark room. The only part of the combustion vessel A heated by the burnt gases was the end immediately opposite the flame; during the combustion this was continuously cooled by a rapid stream of water. The atmosphere of hydrogen was continually renewed from L, while the tap e controlled the admission of chlorine to the jet. The elongation of the chlorine flame showed when the atmosphere was failing, but the readings of the manometer P were chiefly relied on in following the changes of pressure of the hydrogen.

During the combustion the endeavour was made so to regulate the admission of hydrogen as to keep it at a pressure just below atmospheric, but more often than not the attempt failed, owing to the rapid rate at which the gases burnt and the small size of the combustion vessel. If the flame went out, the hydrogen atmosphere had to be restored and the chlorine re-lit by a spark, but this seldom occurred during the experiments.

The hydrogen chloride, immediately after its formation in the flame, was condensed as a pure white solid by the liquid air surrounding the lower end of the vertical limb B; some chlorine, too, which had escaped burning in the flame, was condensed along with the hydrogen chloride. As the solid accumulated, the liquid-air vessel was gradually raised so that, at the end of the combustion, nearly the whole of B was immersed in liquid air.

The combustion was continued until only a few grammes of liquid chlorine were left in E, when the tap l of the palladium bulb was finally closed and L allowed to cool. The flame was now made very small. As the atmosphere became rarefied, the flame became more and more attenuated until, just before it went out, e was finally closed. The combustion, the average duration of which was over four hours, was then at an end.

Then the residual gases in the vessel were sucked out by the pump through m, collected and subsequently analysed. The vapour pressures of solid hydrogen chloride and solid chlorine at the temperature of liquid air were so exceedingly small that none could be detected in the gases pumped out. In the gas analysis it was assumed that both these gases were absent. Even in the highest vacuum obtainable under the prevailing conditions, some hydrogen must still have adhered to the walls of the quartz vessel A; but preliminary experiments showed the amount could not have been greater than 1 part in 55,000 of the hydrogen used. If a correction could be applied for this small weight of gas, it would have the effect of raising slightly the atomic weight of chlorine.

The Sprengel pump fastened to *m* was now separated by fusion from the apparatus, and the tap *p* was closed so as to isolate the mercury in the manometer from subsequent contact with hydrogen chloride and chlorine.

The next series of operations was to evaporate the snow-white hydrogen chloride in B and to condense it in the bomb immersed in liquid air. The successful accomplishment of this required very careful manipulation, the details of which were only learnt in the light of many failures.

The first step was to warm gently the mercury in the quartz test tube Q so as to fill the chlorine condenser with mercury vapour. To prevent its diffusion into the bomb the coil R was surrounded by a freezing mixture of solid carbon dioxide and ether. The steel tube X was now partially immersed in liquid air; the taps *n* and *r* and the screw valve W were opened; and the evaporation of the solid hydrogen chloride was commenced by slowly lowering the liquid air surrounding the limb B. The solid gradually evaporated into the combustion vessel, whence the gas passed on to the chlorine absorption apparatus. Here all traces of chlorine combined with mercury vapour and condensed as mercuric chloride. That the absorption of chlorine was complete was shown conclusively by the bright surface of mercury in the broad manometer tube T remaining untarnished at the end of the condensation. It was found, in preliminary experiments under similar conditions, that no weighable amount of mercury vapour could diffuse backwards out of Q.

The purified hydrogen chloride, after its passage through Q, passed on to the steel tube X and there condensed. By repeated trials it was found possible so to lower the bomb into liquid air as to effect the condensation at a pressure never exceeding two-thirds of an atmosphere.

The condensation took over four hours. When it was complete, the taps *n* and *r* and the screw valve W were closed; and the whole apparatus was taken to pieces. Then the palladium bulb, the liquid chlorine bulb, the chlorine condenser, and the bomb were cleaned and weighed.

In six experiments, then, the hydrogen chloride formed in the combustion was condensed in a steel bomb by liquid air. In two other experiments Y (fig. 7) was substituted for the bomb and the gas was condensed and weighed in water. In this case the manipulation varied a little from that adopted in condensing the gas by liquid air. Y was placed in a salt-ice mixture so as to freeze slowly the 100 c.c. of water it contained. This done, Y was attached to a pump and rapidly evacuated. At the end of the evacuation the phosphorus pentoxide showed no signs of harmful deliquescence. The taps *z* and *y* having been closed, Y was disconnected from the pump and weighed. It was then attached to the rest of the apparatus by a ground-glass joint.

The evaporation of the solid hydrogen chloride in B and its passage through Q was conducted as before, though at a lower pressure.

The purified hydrogen chloride passed through the taps *z* and *y* into the bulb Y, surrounded at first by cold water, later by a calcium-chloride-and-ice freezing mixture. Here the gas was absorbed; occasional shaking of Y kept down the pressure. Towards the end of the absorption, when only a very little solid hydrogen chloride was left in B (fig. 3), the tap *y* was closed and the end of the thick-walled capillary tube Z was immersed in liquid air. The last traces of hydrogen chloride condensed here. Preliminary experiments showed that in a high vacuum no measurable amount of hydrogen chloride could cling to the walls of the quartz combustion vessel. As an extra precaution, however, the walls of A were always warmed by hot water during the last stages of the condensation of hydrogen chloride.

Z was separated by fusion from Y, but was afterwards weighed along with it. Finally, the different parts of the whole apparatus were disconnected as before.

9. *Analysis of Residual Gases.*—The analysis of the residual gases was carried out as follows:—

Fig. 8 is a sketch of the apparatus in which the gases were collected. It consisted of a graduated glass reservoir A furnished with two taps, B and C, and connected with a graduated tube D. The weight of the apparatus, filled with mercury between the taps B and C, having been determined, D was filled with mercury and the whole placed in a mercury trough. The gases were collected in D and passed into A; it was assumed they were hydrogen and nitrogen.

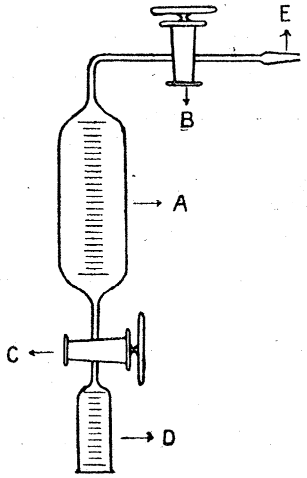

Fig. 8.

The gas apparatus, standing in the trough, was then taken to the balance room. The tap C was opened and the whole allowed to reach the temperature of the room. By noting the difference in level of the mercury in A and of the mercury in the trough, with the aid of the etched scales on A and D, the divisions of which were 1 mm. apart, and by subtracting this difference from the barometric height the pressure of the gases was found. The tap C was closed, the tube D emptied, and the gas apparatus was again weighed. The difference in the weights of the apparatus before and after the collection of the residual gases (corrected for the weight of these residual gases) gave their volume under the ascertained conditions of temperature and pressure.

D having been refilled with mercury, the gas apparatus was replaced in the trough, C was opened, and successive small volumes of pure, dry oxygen added to the gases. Between each addition C was closed and the platinum spiral in A was cautiously heated by an electric current so as to bring about the combination without explosion of all the oxygen with the hydrogen. When the volume of oxygen added was just below half the volume of the residual gases, the tap C was temporarily closed. The gas apparatus, still standing in the trough, was then attached by the inner portion E of a ground-glass joint to a Sprengel pump. After the pump had been thoroughly evacuated, the tap B was opened and the small remaining volume of wet hydrogen and nitrogen (in no experiment exceeding 4 c.c. in volume) was sucked out of A. At the same time the tap C was cautiously opened so as to allow mercury to rise slowly in A and fill the whole apparatus, thus removing the last traces of gas from the apparatus.

The wet nitrogen and hydrogen passed through a coil, immersed in a freezing mixture of solid carbon dioxide and ether. Most of the water vapour in the gases condensed in the coil. The dried gases then passed through the pump and were collected in another gas apparatus, a sketch of which is to be found on p. 193 of DIXON and EDGAR'S paper. The details of the subsequent gas analysis are given in full on the same page.

The composition of the residual gases of the combustion, assuming they were hydrogen and nitrogen, was thus arrived at by subtracting from the total volume collected in the first gas apparatus (fig. 8) the volume of nitrogen found in the second.

10. *Results of the Experiments.*—In the tables set out below are given the results of eight experiments. Table II. contains the volumes of residual gases, in each experiment, reduced to normal temperature and pressure.

TABLE II.—Volumes of Residual Gases (Cubic Centimetres at N.T.P.).

Experiment . .	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Volume of hydrogen unburnt	38·14	45·81	36·46	40·72	45·09	39·58	43·17	38·42
Volume of nitrogen found	0·10	0·09	0·07	0·04	0·05	0·07	0·02	0·03

In Table III. are placed the weights of chlorine which escaped burning in the flame and were caught by mercury in the chlorine absorption apparatus.

TABLE III.—The Weights of Chlorine Uncombined with the Weighed Hydrogen (in Grammes).

Experiment . .	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Unburnt chlorine. . .	0·0645	0·1338	0·1032	0·0979	0·0612	0·1158	0·0761	0·1087

Table IV. gives the weights of the palladium bulb and the liquid chlorine bulb, in each experiment, before and after the combustion, together with the corrections for buoyancy and for the unburnt gases. The corrected weights of hydrogen chloride, caught in the steel bomb in Experiments 1, 2, and 4, and condensed in water in Experiments 7 and 8, are also given. In Experiments 3, 5, and 6 the individual weighings of the bomb were so discordant that it was obvious the screw valve had not been closed tightly enough, and that the bomb had been steadily leaking since its removal from the liquid air.

TABLE IV.

Experiment.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Weight to counterpoise **H** bulb (i.)	3·75204	3·46445	4·68724	4·15682	4·86858	4·55449	3·94573	5·06434
,, ,, ,, (ii.)	1·60311	1·42130	2·90747	2·15938	3·21745	2·44905	2·21624	2·97199
Difference	2·14893	2·04315	1·77977	1·99744	1·65113	2·10544	1·72949	2·09235
Vacuum correction for weights	− 0·00031	− 0·00030	− 0·00028	− 0·00030	− 0·00019	− 0·00031	− 0·00019	− 0·00040
Weight of **H** taken	2·14862	2·04285	1·77949	1·99714	1·65094	2·10513	1·72930	2·09195
,, ,, unburnt	0·00343	0·00412	0·00328	0·00366	0·00405	0·00356	0·00388	0·00345
,, ,, burnt	2·14519	2·03873	1·77621	1·99348	1·64689	2·10157	1·72542	2·08850
Weight to counterpoise Cl bulb (i.)	76·2643	74·4982	67·8051	71·5454	67·9675	76·5493	67·6478	81·4772
,, ,, ,, (ii.)	0·6859	2·6033	5·1922	1·2732	9·9306	2·4563	6·8464	7·8584
Difference	75·5784	71·8949	62·6129	70·2722	58·0369	74·0930	60·8014	73·6188
Vacuum correction for weights	− 0·0113	− 0·0107	− 0·0093	− 0·0105	− 0·0086	− 0·0110	− 0·0091	− 0·0110
Weight of **Cl** taken	75·5671	71·8842	62·6036	70·2617	58·0283	74·0820	60·7923	73·6078
,, ,, unburnt	0·0645	0·1338	0·1032	0·0979	0·0612	0·1158	0·0761	0·1087
,, ,, burnt	75·5026	71·7504	62·5004	70·1638	57·9671	73·9662	60·7162	73·4991
Weight of H + Cl burnt	77·6478	73·7891		72·1573			62·4416	75·5876
,, ,, HCl caught	77·6469	73·7880		72·1565			62·4401	75·5859
Ratio $\frac{\mathrm{Cl}}{\mathrm{H}}$	35·196	35·194	35·188	35·197	35·198	35·195	35·189	35·192
Ratio $\frac{\mathrm{HCl}-\mathrm{H}}{\mathrm{H}}$	35·196	35·194		35·196			35·189	35·191

Mean ratio $\frac{\mathrm{Cl}}{\mathrm{H}}$, 35·194 ± 0·0009.

Mean ratio $\frac{\mathrm{HCl}-\mathrm{H}}{\mathrm{H}}$, 35·193 ± 0·0009.