

6. It remains to discuss the roots of the equation

$$F(\alpha) \equiv \sigma \cos \alpha a \sin \mu \alpha (b-a) + \sin \alpha a \cos \mu \alpha (b-a) = 0.$$

From the graphs of

$$y = \sigma \cot \alpha a$$

and $y = -\cot \mu \alpha (b-a)$

it is clear that there are infinite number of real roots, and the position of the same can be determined.

Also $F(\alpha)$ is an odd function of α and the real roots may be denoted by

$$0, \pm \alpha_1, \pm \alpha_2, \dots$$

By examining $F'(\alpha)$, it will be seen that these roots are not repeated.

Also it is clear that $F(\alpha)$ has no pure imaginary root. We have now to show that it has no roots of the form $\xi \pm i\eta$.

Consider the functions U_1, U_2 defined as follows:—

$$U_1 = \sin \alpha x, \quad 0 < x < a$$

$$U_2 = \frac{\sin \mu \alpha (b-x)}{\sin \mu \alpha (b-a)} \sin \alpha a, \quad a < x < b,$$

where α is a root of $F(\alpha) = 0$,

and $\sigma = K_1/K_2\mu, \quad \mu = \sqrt{(\kappa_1/\kappa_2)}.$

Then we have

$$\frac{d^2 U_1}{dx^2} + \alpha^2 U_1 = 0, \quad 0 < x < a; \dots (1)$$

$$\frac{d^2 U_2}{dx^2} + \mu^2 \alpha^2 U_2 = 0, \quad 0 < x < b. \dots (2)$$

Also $U_1 = 0,$ when $x = 0. \dots (3)$

$$\left. \begin{array}{l} U_1 = U_2 \\ K_1 \frac{dU_1}{dx} = K_2 \frac{dU_2}{dx} \end{array} \right\} \text{when } x = a. \dots (4)$$

And $U_2 = 0,$ when $x = b. \dots (5)$

Let β be another root of $F(\alpha) = 0$, and V_1, V_2 the corresponding functions.

Then we have, from (1) and (2),

$$\frac{\mu}{\sigma} (\alpha^2 - \beta^2) \int_a^b U_2 V_2 dx + \frac{1}{\sigma \mu} \int_a^b (V_2 U_2'' - U_2 V_2'') dx = 0,$$

and

$$(\alpha^2 - \beta^2) \int_0^a U_1 V_1 dx + \int_0^a (V_1 U_1'' - U_1 V_1'') dx = 0.$$

Therefore

$$\begin{aligned} (\alpha^2 - \beta^2) & \left[\int_0^a U_1 V_1 dx + \frac{\mu}{\sigma} \int_a^b U_2 V_2 dx \right] \\ & = \int_0^a (U_1 V_1'' - V_1 U_1'') dx + \frac{1}{\sigma \mu} \int_a^b (U_2 V_2'' - V_2 U_2'') dx \\ & = [U_1 V_1' - V_1 U_1']_0^a + \frac{K_2}{K_1} [U_2 V_2' - V_2 U_2']_a^b. \end{aligned}$$

It follows from (3), (4), and (5), that

$$(\alpha^2 - \beta^2) \left[\int_0^a U_1 V_1 dx + \frac{\mu}{\sigma} \int_a^b U_2 V_2 dx \right] = 0.$$

Thus $F(\alpha) = 0$ cannot have imaginary roots of the form $\xi \pm i\eta$.

LIX. *The Mass-Spectra of Chemical Elements.* By F. W. ASTON, M.A., D.Sc., Clerk Maxwell Student of the University of Cambridge*.

[Plate XV.]

THE following paper is an account of some results obtained by the analyses of gases by means of the Positive Ray Spectrograph or, as it may be more conveniently termed, Mass-Spectrograph. The principle of the method by which a focussed spectrum is obtained depending solely on the ratio of mass to charge has already been described †, but for the sake of others experimenting in this field it is now proposed to give an account of the actual apparatus in some detail.

* Communicated by the Author.

† F. W. A., Phil. Mag. xxxviii. Dec. 1919, p. 707.

By this arrangement it will be seen that not only is loss of rays by collision and neutralization reduced to a minimum, but any serious leak of gas from the bulb to the camera is eliminated altogether.

The Electric Field.

The spreading of the heterogeneous ribbon of rays formed by the slits into an electric spectrum takes place between two parallel flat brass surfaces, J_1 , J_2 , 5 cm. long, held 2.8 mm. apart by glass distance-pieces, the whole system being wedged immovably in the brass containing-tube in the position shown. The lower surface is cut from a solid cylinder fitting the tube and connected to it and earth. The upper surface is a thick brass plate, which can be raised to the desired potential by means of a set of small storage-cells. In order to have the plates as near together as possible, they are sloped at 1 in 20—i. e., half the angle of slope of the mean ray of the part of the spectrum which is to be selected by the diaphragms. Of these there are two: one, K_1 , an oblong aperture in a clean brass plate, is fixed just in front of the second movable one, K_2 , which is mounted in the bore of a carefully ground stopcock L . The function of the first diaphragm is to prevent any possibility of charged rays striking the greasy surface of the plug of the stopcock when the latter is in any working position. The variable diaphragm is in effect two square apertures sliding past each other as the plug of the stopcock is turned, the fact that they are not in the same plane being irrelevant. When the stopcock is fully open as sketched in fig. 2, the angle of rays passing is a maximum, and may be stopped down to any desired extent by rotation of the plug, becoming zero before any greasy surface is exposed to the rays. Incidentally the stopcock serves another and very convenient use, which is to cut off the camera from the discharge-tube, so that the latter need not be filled with air each time the former is opened to change the plate.

The Magnetic Field.

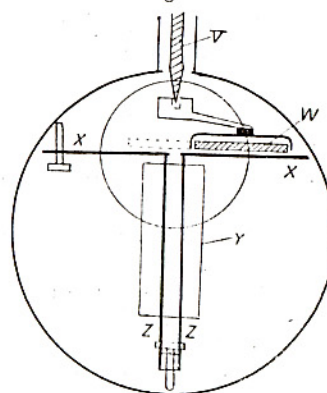
After leaving the diaphragms the rays pass between the pole-pieces M of a large Du Bois magnet of 2500 turns. The faces of these are circular, 8 cm. diameter, and held 3 mm. apart by brass distance-pieces. The cylindrical pole-pieces themselves are soldered into a brass tube O , which forms part of the camera N . When the latter is built into position, the pole-pieces are drawn by screwed

bolts into the arms of the magnet, and so form a structure of great weight and rigidity and provide an admirable foundation for the whole apparatus. Current for the magnet is provided by a special set of large accumulators. The hydrogen lines are brought on to the plate at about 0.2 ampere, and an increase to 5 amperes, which gives practical saturation, only just brings the singly-charged mercury lines into view. The discharge is protected from the strong field of the magnet by the usual soft iron plates, not shown.

The Camera.

The main body of the camera N is made of stout brass tube 6.4 cm. diameter, shaped to fit on to the transverse tube O containing the pole-pieces. The construction of the plate-holder is indicated by the side view in fig. 1 and an end-on view in fig. 3. The rays after being magnetically deflected

Fig. 3.



pass between two vertical brass plates Z, Z about 3 mm. apart, and finally reach the photographic plate through a narrow slot 2 mm. wide, 11.8 cm. long, cut in the horizontal metal plate X, X . The three brass plates forming a T-shaped girder are adjusted and locked in position by a set of three levelling-screws at each end; the right-hand upper one is omitted in fig. 3. The plates Z, Z serve to protect the rays completely from any stray electric field, even that caused by the photographic plate itself becoming charged, until within a few millimetres of their point of impact.

The photographic plate W , which is a 2 cm. strip cut

lengthwise from a 5×4 plate, is supported at its ends on two narrow transverse rails which raise it just clear of the plate XX. Normally it lies to the right of the slot as indicated, and to make an exposure it is moved parallel to itself over the slot by means of a sort of double lazy-tongs carrying wire claws which bracket the ends of the plate as shown. This mechanism, which is not shown in detail, is operated by means of a torque rod V working through a ground glass joint. Y is a small willemite screen.

The adjustment of the plate-holder so that the sensitized surface should be at the best focal plane was done by taking a series of exposures of the bright hydrogen lines with different magnetic fields on a large plate placed in the empty camera at a small inclination to the vertical. On developing this, the actual track of the rays could be seen and the locus of points of maximum concentration determined. The final adjustment was made by trial and error and was exceedingly tedious, as air had to be admitted and a new plate inserted after each tentative small alteration of the levelling-screws.

Experimental procedure.

The plate having been dried in a high vacuum overnight, the whole apparatus is exhausted as completely as possible by the pump with the stopcock L open. I_1 and I_2 are then cut off from the pump by stopcocks and immersed in liquid air for an hour or so. The electric field, which may range from 200 to 500 volts, is then applied and a small current passed through the magnet sufficient to bring the bright hydrogen molecule spot on to the willemite screen Y, where it can be inspected through the plate-glass back of the cap P. In the meantime the leak, pump, and coil have all been started to get the bulb into the desired state.

As soon as this is obtained and has become steady, J_1 is earthed to prevent any rays reaching the camera when the plate is moved over the slot to its first position, which is judged by inspection through P with a non-actinic lamp. The magnet current having been set to the particular value desired and the diaphragm adjusted, the coil is momentarily interrupted while J_1 is raised to the desired potential, after which the exposure starts. During this, preferably both at the beginning and the end, light from a lamp T is admitted for a few seconds down the tube R (fig. 1) the ends of

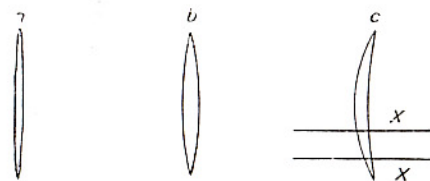
which are pierced with two tiny circular holes. The lower hole is very close to the plate, so that a circular dot or register spot is formed from which the measurements of the lines may be made.

The exposures may range from 20 seconds in the case of hydrogen lines to 30 minutes or more, 15 minutes being usually enough. As soon as it is complete the above procedure is repeated, and the plate moved into the second position. In this way as many as six spectra can be taken on one plate, after which I_1 is shut, I_2 warmed up, and air admitted to the camera. The cap P, which is on a ground joint, can now be removed, and the exposed plate seized and taken out with a special pair of forceps. A fresh plate is now immediately put in, P replaced, and the camera again exhausted, in which state it is left till the next operation.

Form of the Spectrum Lines.

As has been shown (Phil. Mag. Dec. 1919, plate ix.), the shape of the spot formed when undeflected rays from such a slit system strike a photograph surface normally, is somewhat as indicated at *a* (fig. 4). When they strike the plate obliquely the image would be spread out in one direction, as in *b*. This would be the actual form in the apparatus, if the

Fig. 4.



deflexions of the mean and extreme rays (*i. e.*, the rays forming the centre and the tips) were identical. This is true of the magnetic field since each cuts the same number of lines of force; but it is not so in the case of the electric deflexion. Since the form of the plates, and therefore roughly of the boundaries of the field, is rectangular, the extreme rays passing diagonally will be deflected more than the mean rays and the spot bent into the form shown at *c*. The convex side will be in the direction of the magnetic deflexion, as this is opposed to the deflexion causing the

bend. The image on the plate will therefore be the part of this figure falling on the narrow slot in X, X; and as the apparatus is not exactly symmetrical, its shape in the spectra is the figure lying between the lines X, X in fig. 4, c.

Measurement of the Lines.

The plates are measured against a standard Zeiss scale on a comparator designed by the late Dr. Keith Lucas and kindly lent by the Physiological Department. Some of the very faint lines, although easily visible to the unaided eye, were lost even with the lowest power eyepieces obtainable. To measure these, an eyepiece giving a magnification of about $2\frac{1}{2}$ was designed by Dr. Hartridge of King's College.

The general method of deducing mass from position has already been described (Phil. Mag. April 1920, p. 453). Owing to some geometrical cause (probably analogous to a caustic in optics), the more deflected edge of the line is always the brighter and sharper, and it is the distance of this from the register spot which is found to give the most reliable values. For the highest accuracy, owing to halation, one must only compare lines of approximately equal intensity. As this edge is unfortunately not at right angles to the spectrum, measurements can never be regarded as absolute, unless extreme care is taken in the levelling of the spectrum on the comparator. So although theoretically it is sufficient to know the mass of one line to determine (with the correction curve) those of all others, in practice every effort is made to bracket any unknown line by reference lines, and only to trust comparative measurements when the lines are fairly close together. Under these conditions the accuracy claimed for the instrument is about one part in a thousand.

Order of Results and Nomenclature.

The various elements studied will be considered as far as possible in the order in which the experiments were performed. This order is of considerable importance, as in most cases it was impossible to eliminate any element used before the following one was introduced. Evacuation and washing have little effect, as the gases appear to get embedded in the surface of the discharge-bulb and are only released very gradually by subsequent discharge.

The problem of nomenclature became serious when the very complex nature of the heavy elements was apparent,

After several possible systems had been discussed it was decided, for the present, to adopt the rather clumsy but definite and elastic one of using the chemical symbol of the mixed element with an index corresponding to its mass: *e.g.*, Ne^{22} , Kr^{84} . This system is made reasonable by the fact that the masses of constituents of mixed elements have all so far proved whole numbers on the scale used.

In cases of particles carrying more than one charge it will be convenient to borrow the nomenclature of optics and refer to the lines given by singly, doubly, and multiply charged particles respectively as lines of the first, second, and higher orders. Thus the molecule of oxygen gives a first order line at 32, and its atom first and second order lines at 16 and 8.

The empirical rule that molecules only give first order lines (J. J. Thomson, 'Rays of Positive Electricity,' p. 54) is very useful in helping to differentiate between elementary atoms and compound molecules of the same mass. Some very recent results give indications that in certain exceptional cases it may break down, so that inferences made from it must not be taken as being absolutely conclusive.

OXYGEN (At. Wt. 16.00) and CARBON (At. Wt. 12.00).

On a mass-spectrum all measurements are relative, and so any known element could be taken as a standard. Oxygen is naturally selected. Its molecule, singly-charged atom, and doubly-charged atom give reference lines at 32, 16, and 8 respectively. The extremely exact integral relation between the atomic weights of oxygen and carbon is itself strong evidence that both are "pure" elements, and so far no evidence appears to have arisen to throw any doubt on this point. Direct comparison of the C line (12) and the CO line (28) with the above standards shows that the expected whole number relation and additive law hold to the limit of accuracy, *i. e.* one part in a thousand; and this provides standards C^{++} (6), C (12), CO (28), and CO_2 (44). In a similar manner, hydrocarbons give the C_1 and C_2 groups already mentioned (Phil. Mag. April 1920, pp. 452, 453); so that a fairly complete scale of reference is immediately available.

NEON (At. Wt. 20.20).

The results obtained with this gas have already been fully dealt with (Phil. Mag. April 1920, p. 449). It has been shown to consist of two isotopes of masses 20 and 22 respectively, with the faint possibility of a third of mass 21.

Spectrum I. on Pl. XV. shows the singly-charged lines of neon, to the left of the C_2 group. It is reproduced here to show the condition of the discharge-tube immediately before compounds of chlorine were introduced.

CHLORINE (At. Wt. 35.46).

Spectra indicating that this element was a mixture of isotopes were first obtained by the use of hydrochloric acid gas, but as this was objectionable on account of its action on mercury, phosgene ($COCl_2$) was substituted. Spectra II., III., and IV. are reproduced from one of the plates taken with this gas. It will be seen that chlorine is characterized by the appearance of four very definite lines in the previously unoccupied space to the right of O_2 (32): measurement shows these lines to correspond exactly to masses 35, 36, 37, and 38. *There is no indication whatever of a line at a point corresponding with the accepted atomic weight 35.46.* On Spectrum II., taken with a small magnetic field, faint lines will be seen at 17.5 and 18.5. These only appeared when chlorine was introduced, and are certainly second order lines corresponding to 35 and 37. These figures seem to leave no possible escape from the conclusion that chlorine is a mixture of isotopes and that two of these have masses 35 and 37. It might be argued that 36 and 38 are also elementary lines and at present there is no evidence to deny this, but it is much more probable that they are the hydrochloric acids HCl^{35} and HCl^{37} . The line 18 is no indication of an element 36, as it is doubtless due to OH_2 . Corroborative evidence that Cl^{35} and Cl^{37} are the main if not the only constituents is given by the strong lines 63 and 65 (Spectrum IV.) probably due to $COCl^{35}$ and $COCl^{37}$. If chemical atomic weight is regarded as a statistical average, any lines due to Cl^{35} or its compounds should be considerably stronger than the corresponding ones due to Cl^{37} . This is actually found to be the case. In all spectra taken with chlorine present a faint line is distinguishable corresponding to 39. It is just possible that this is a third isotope.

The unquestionable accuracy of its combining weight on the one hand and the striking whole-number masses given on its mass-spectra by its individual particles on the other, leave little doubt that chlorine is a mixed element, but much critical work will be necessary before its constituents and their relative proportions are decided with certainty.

ARGON (At. Wt. 39.88 Ramsay, 39.91 Leduc).

At the close of the experiments with phosgene the discharge-tube broke down and had to be cleaned and partially rebuilt,

so that by the time it had reached suitable working conditions again, all traces of chlorine had disappeared. The tube was run with a mixture of CO_2 and CH_4 , and then about 20 per cent. of argon added. The main constituent of the element was at once evident from a very strong line at 40 (Spectrum VI.) reproduced in the second and third orders at 20 and 13.33 (Spectrum V.). The third order line is exceedingly well placed for measurement, and from it the mass of the singly-charged atom is found to be $40.00 \pm .02$. At first this was thought to be the only constituent, but later a faint companion was seen at 36, which further spectra showed to bear a very definite intensity relation to the 40 line. No evidence drawn from multiple charges is available in this case owing to the probable presence of OH_2 and C; but the above intensity relation and the absence of the line from spectra taken just before argon was introduced, make it extremely likely that it is a true isotope. The presence of about 3 per cent. would account for the fractional atomic weight determined from density.

NITROGEN (At. Wt. 14.01).

This element shows no abnormal characteristics: its atom cannot be distinguished, on the present apparatus, from CH_2 nor its molecule from CO. Its second order line on careful measurement appears to be exactly 7, so it is evidently a pure element, as its chemical combining weight would lead one to expect.

HYDROGEN (At. Wt. 1.008) and HELIUM (At. Wt. 3.99).

The determination of masses so far removed as these from the reference lines offers peculiar difficulties, but, as the lines were expected to approximate to the terms of the geometrical progression 1, 2, 4, 8, etc. the higher terms of which are known, a special method was adopted by which a two to one relation could be tested with some exactness. Two sets of accumulators were selected, each giving very nearly the same potential of about 250 volts. The potentials were then made exactly equal by means of a subsidiary cell and a current-divider, the equality being tested to well within 1 in 1000 by means of a null instrument. If exposures are made with such potentials applied to the electric plates first in parallel and then in series, the magnetic field being kept constant, all masses having an exact two to one relation will be brought into coincidence on the plate (Phil. Mag. April 1920, p. 453). Such

coincidences cannot be detected on the same spectrum photographically; but if we first add and then subtract a small potential from one of the large potentials, two lines will be obtained which closely bracket the third. To take an actual instance—with a constant current in the magnet of 0.2 ampere, three exposures were made with a gas containing hydrogen and helium at potentials of 250, 500+12, and 500-12 volts respectively. The hydrogen molecule line was found symmetrically bracketed by a pair of atomic lines (Spectrum VII. *a* and *c*), showing that the mass of the molecule is exactly double the mass of the atom within experimental error. When after a suitable increase of the magnetic field the same procedure was applied to the helium line and that of the hydrogen molecule, the bracket was no longer symmetrical (Spectrum VII. *b*), nor was it when the hydrogen molecule was bracketed by two helium lines (*d*). Both results show in an unmistakable manner that the mass of He is less than twice that of H₂. In the same way He was compared with O⁺⁺, and H₃, obtained from KOH by Sir J. J. Thomson's bombardment method, with C⁺⁺.

The method has some definite advantages and some disadvantages. It is not proposed to discuss these in detail at present. The values obtained by its use can be checked in the ordinary way by comparing He with C⁺⁺ and H₃ with He, these pairs being close enough together for the purpose. The following table gives the range of values obtained from the most reliable plates:—

Line	Method.	Mass assumed.	Mass deduced.
He	{ bracket	O ⁺⁺ = 8	3.994—3.996
	{ direct	C ⁺⁺ = 6	4.005—4.010
H ₃	{ bracket	C ⁺⁺ = 6	3.025—3.027
	{ direct	He = 4	3.021—3.030
H ₂	bracket	He = 4	2.012—2.018

From these figures it is safe to conclude that hydrogen is a "pure" element and that its atomic weight, determined with such consistency and accuracy by chemical methods (1.008), is the true mass of its atom.

The above results incidentally appear to settle the nature of the molecule H₃ beyond doubt.

KRYPTON (At. Wt. 82.92) and XENON (At. Wt. 130.2).

The results with these elements were particularly interesting. The only source available, for which the author is indebted to Sir J. J. Thomson, was the remains of two small samples of gas from evaporated liquid air kindly supplied by Sir James Dewar some years ago for examination by the "parabola" method. Both samples contained nitrogen, oxygen, argon, and krypton, but xenon was only detected in one and its percentage in that must have been quite minute. Krypton is characterized by a remarkable group of five strong lines at 80, 82, 83, 84, 86, and a faint sixth at 78. This group or cluster of isotopes is beautifully reproduced with the same relative values of intensity in the second, and fainter still in the third order. These multiply-charged clusters give most reliable values of mass, as the second order can be compared with A (40) and the third with CO or N₂ (28) with the highest accuracy. It will be noted that one member of each group is obliterated by the reference line, but not the same one. The singly and doubly charged krypton clusters can be seen to the right and left of Spectrum VIII. It will be noticed that krypton is the first element examined which shows unmistakable isotopes differing by one unit only.

On the krypton plates taken with the greatest magnetic field faint, but unmistakable indications of lines in the region of 130 could just be detected. The richest sample was therefore fractionated over liquid air, and the last fraction, a few cubic millimetres, was just sufficient to produce the xenon lines in an unmistakable manner. These can be seen on Spectrum IX., but are somewhat fuzzy owing to the wide diaphragm used to get maximum intensity. They are apparently five in number and appear to follow the integer rule. Until pure xenon is available no final figures can be given, but the values may be taken provisionally as 128, 130, 131, 133, and 135.

MERCURY (At. Wt. 200.6).

Owing to the presence of mercury vapour (which is generally beneficial to the smooth running of the discharge) the multiply-charged particles of this element appear on nearly all the plates taken. They appear as a series of blurred clusters of decreasing intensity around points corresponding to 200, 100, 66.6, 50 ... etc., some of which are indicated in the spectra reproduced. It may be stated provisionally that they indicate a strong component 202, a weak one 204, and a strong band from 197 to 200 containing three or four more unresolvable at present.

Table of Results.

Element.	Atomic number.	Atomic weight.	Minimum number of isotopes.	Mass of isotopes in order of intensity.
H	1	1.008	1	1.008
He	2	3.09	1	4
O	6	12.00	1	12
N	7	14.01	1	14
O	8	16.00	1	16
Ne	10	20.20	2	20, 22, (21)
Cl	17	35.46	2	35, 37, (39)
A	18	39.9	(2)	40, (36)
Kr	36	82.92	6	84, 86, 82, 83, 80, 78
X	54	130.2	5	(128, 131, 130, 133, 135)
Hg	80	200.6	(5)	(197-200, 202, 204)

[Numbers in brackets provisional only.]

The Whole-number Rule.

The most important generalization yielded by these experiments is the remarkable fact that (with the exception of H_1 , H_2 , and H_3) all masses atomic or molecular, element or compound, so far measured are whole numbers within the accuracy of experiment. It is naturally premature to state that this relation is true for all elements, but the number and variety of those already exhibiting it makes the probability of this extremely high.

On the other hand, it must not be supposed that this would imply that the whole-number rule holds with mathematical exactness, but only that the approximation is of a higher order than that exhibited by the ordinary chemical combining weights and is quite close enough to allow of a theory of atomic structure far simpler than those put forward in the past; for such theories were forced to attempt the explanation of fractions which now appear to be merely fortuitous statistical effects due to the relative quantities of the isotopic constituents.

Thus one may now suppose that an elementary atom of mass m may be changed to one of mass $m + 1$ by the addition of a positive particle and an electron. If both enter the nucleus an isotope results, for the nuclear charge is unaltered. If the positive particle only enters the nucleus, an element of next higher atomic number is formed. In cases where both forms of addition give a stable configuration, the two elements will be isobares.

The electromagnetic theory of mass asserts that mass is not generally additive but only becomes so when the charges

are relatively distant from each other. This is certainly the case when the molecules H_2 and H_3 are formed from H_1 , so that their masses will be two and three times the mass of H_1 with great exactness. (It must be remembered here that the masses given by these experiments are those of positively charged particles, H_1 being presumably a single particle of positive electricity itself, and that the mass of an electron on the scale used is .00054 and too small to affect the results.)

In the case of helium, the standard oxygen, and all other elements, this is no longer the case; for the nuclei of these are composed of particles and electrons packed exceedingly close together. The mass of these structures will not be exactly the sum of the masses of their constituents but probably less, so that the unit of mass on the scale chosen will be less than that of a single hydrogen atom.

The Heavier Elements.

The results hold out the probability of great complexity in elements of high atomic number, which has already been proved by entirely different methods in the case of lead. The present apparatus has a resolution factor too low to deal adequately with these; so attention is being given to elements within its scope and to which the analysis can be applied. Results are steadily accumulating, which will be published in due course.

In conclusion the author wishes to express his indebtedness to the Government Grant Committee of the Royal Society for defraying the cost of some of the apparatus employed.

Summary.

A positive ray spectrograph capable of giving a focussed mass-spectrum is fully described in detail and its technique explained.

The results of a provisional analysis of eleven chemical elements—H, He, C, N, O, Ne, Cl, A, Kr, X, Hg—are given, showing that of these the first five only are "pure," the others being apparently composed of various numbers of isotopic constituents, krypton containing no less than six.

With the exception of those due to H_1 , H_2 , and H_3 , all masses measured, allowing for multiple charges, are exactly whole numbers within the error of experiment ($O=16$).

The lines due to hydrogen indicate that the mass of the atom of this element is greater than unity on this scale and in good agreement with the chemical value 1.008. Reasons for this are suggested.

Cavendish Laboratory,
March 1920.

