of the relatively large and complex gold atom as 3.4×10^{-12} cm., while Crehore, who proposes another theory of the structure of the atom, considers that none of the electrons have orbits of a greater radius than 10^{-12} cm. The high velocity with which the β-particles are shot out in radioactive transformations has been considered as evidence that these electrons must come from much closer to the center of the atom than the assumed radius of the atom. It therefore seems practically certain that the electrons and positively charged particles which make up the nucleus of a complex atom, are packed exceedingly closely together. As a result of this close packing, the electromagnetic fields of the charged particles must overlap to a considerable extent, which would mean that the mass of the atom ought not to be equal to the sum of the masses of the individual particles from which it is built.

5. The closeness to which a positive and a negative electron would have to approach to give a decrease of mass equal to 0.77%, or the average value of the packing effect, is found by calculation to be to a distance of 400 times the radius of the positive electron. This case does not correspond to any element actually known, for the simplest of the atoms considered, helium, may be supposed to have a nucleus built up from four hydrogen nuclei and two negative electrons. However, the magnitude of the effect seems to be of the order which would be expected.

6. The probability for the first 27 elements, that the sum of the deviations of the atomic weights (on the oxygen basis from whole numbers) should by accident be as small as it is, is found to be one chance in fifteen million. On the other hand, a change of only 0.77% from the oxygen basis to that of hydrogen gives one chance in ten that the atomic weights should be as close to whole numbers as they are.

The second paper on atomic structure, which follows this one, gives still more evidence that the complex atoms are built up from hydrogen atoms as units of structure.

CHICAGO, ILL.

[CONTRIBUTION FROM THE KENT CHEMICAL LABORATORY OF THE UNIVERSITY OF CHICAGO.]

THE STRUCTURE OF COMPLEX ATOMS. THE HYDROGEN-HELIUM SYSTEM.

[SECOND PAPER ON ATOMIC STRUCTURE.]

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In the preceding paper it has been shown that the atomic weight relations of the elements are such as to make it extremely probable that the atoms are complex structures built up from hydrogen atoms. It therefore becomes important to determine in what way the hydrogen atoms unite together to make up the complex. Rutherford proved that the α-particles which are shot out in the disintegration of the radioactive elements, have a mass of four units,[1] and that they give ordinary helium gas when they escape through the walls of a thin glass capillary tube in which the emanation is stored.[2] Fajans,[3] Soddy,[4] Russell,[5] von Hevesy,[6] and Fleck,[7] have found that, when a radioactive substance ejects an α-particle, the new substance has different properties, and a different valence from those of the parent material. The change is such that the new element lies two places to the left in the periodic table, and therefore has an atomic number which is two less than before the alpha disintegration. It has been found that uranium, for example, can lose eight α-particles in eight steps, and change into a form of lead. From this it is seen that the radioactive elements, which have high atomic weights, must, at least in part, be built up of α-particles, and therefore of helium atoms, with this difference, that while the α-particle is probably present as a whole in the complex atom, the nonnuclear electrons of the helium atom, undoubtedly rearrange themselves in the complex atom, so that the helium atoms as a *whole* do not preserve their identity.

Now that it has been proved that the atoms of high atomic weight are built up, in part at least, of helium atoms, the question arises as to whether the same relations hold for the lighter atoms which have not been found to give an appreciable alpha disintegration. If they do, then a change of two places to the right in the periodic table, which is more accurately expressed as an increase of two in the atomic number, should increase the atomic weight by the weight of one helium atom, or by the number four. Since a change of two in the atomic number should increase the atomic weight by four, according to this theory, the average increase in the atomic weight per atomic number should be two. From this it might be expected that the tenth element would have an atomic weight equal to 20, and the twentieth element, an atomic weight of 40. That this is actually the case is seen, for neon, the tenth element has an atomic weight of 20, and calcium, the twentieth element, has a weight of 40. In order to investigate the question more in detail, a start may be made with helium, of an atomic number 2 and a weight of 4. The element of

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[1] *Phil. Mag.*, [6] **28**, 552–72 (1914).

[2] Rutherford and Soddy, *Phil Mag.*, **3**, 582 (1902); 453 and 579 (1903); Ramsay and Soddy, *Nature*, p. 246 (1903); *Proc. Roy. Soc.*, **72**, 204 (1903); **73**, 346 (1904); Curie and Dewar, *Compt. rend.*, **138**, 190 (1904); Debierne, *Ibid.*, 141, 383 (1905); Rutherford, *Phil. Mag.*, 17, 281 (1909).

[3] *Physik. Z.*, 14, 131–6 (1913).

[4] *Chem. News*, **107**, 97 (1913), and *Jahrb. Radioakt.*, **10**, 188 (1913).

[5] *Ibid.*, 107, 49 (1913).

[6] *Physik. Z.*, **14**, 49 (1914).

[7] Fleck, *Trans. Chem. Soc.*, **103**, 381 and 1052 (1913).

an atomic number four, should be heavier by the weight 4, or its atomic weight should be equal to eight. Above this the elements, if built up according to this helium system would have the weights:

Atomic number.	Atomic weight.	Group number.
6	12	4
8	16	6
10	20	0
12	24	2
14	28	4
16	32	6

where each step is made by adding the weight of one helium atom. The equation which represents the idea that the atomic weights of the lighter elements, belonging to even numbered groups, change in the same way as the elements in a radioactive series (namely, by an amount equal to four for a change of two groups in the periodic table), is

$$W = 2n,$$

where W is the atomic weight and n is the atomic number.

If a similar system is supposed to hold for the odd numbered elements, then beginning with lithium of an atomic weight seven, and an atomic number three, the atomic weights according to the simple helium system would be:

Atomic number.	Atomic weight.	Group.
3	7	1
5	11	3
7	15	5
9	19	7
11	23	1
13	27	3
15	31	5
17	35	7
19	39	1

It is thus seen that for the odd groups as well as the even, the increase in the atomic weight is just that predicted for the addition of one helium atom for each step of two atomic numbers. The even and odd numbered elements are thus seen to belong to two different series. A single equation for both of these series may be easily written by introducing a term which disappears when n is even, and is effective when n is odd. If W is the atomic weight,[1]

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[1] Although it was not known to the writers at the time when this paper was written, it was found on looking up the subject that Rydberg, in an extremely important paper published in 1896 (*Z. anorg. Chem.*, **14**, 80) found from a study of atomic weight relations that the elements belong to two series corresponding to the two formulas $4n$ and $4n-1$, where n is a whole number. Thus from an empirical basis he derived the same relationships as are developed in this paper from an entirely different standpoint; that is by the application of the relations found between the elements in a single radioactive series to the elements of small atomic weight.

$$W = 2n + \left\{1/2 + [(-1)^{n-1} \times 1/2]\right\}.$$

In Table I the atomic weights calculated according to this equation are given for the elements up to and including cobalt.

TABLE I.—A COMPARISON OF THE CALCULATED AND THE DETERMINED VALUES OF THE ATOMIC WEIGHTS.[1]

Element.	n.		Calculated.	Detd.	Diff.	Probable error in detn.
He	2		4	4.0	0	0.01
Li	3		7	6.94	+0.06	0.05
Be	4		8	9.1	—1.1 (= 1H)	0.05
B	5		11	11.0	0	0.05
C	6		12	12.00	0	0.005
N	7		15	14.01	+0.99 (= 1H)	0.005
O	18		16	16.00	0	...
F	9		19	19.0	0	0.05
Ne	10		20	20.0	0	...
Na	11		23	23.00	0	0.01
Mg	12		24	24.32	—0.32	0.03
Al	13		27	27.1	—0.1	0.1
Si	14		28	28.3	—0.3	0.1
P	15		31	31.04	—0.04	0.1
S	16		32	32.07	—0.7	0.01
Cl	17		35	35.46	—0.46	0.01
A	18		36	39.88	—3.88 (= 1He)	0.02
K	19		39	39.10	—0.10	0.01
Ca	20	n'	40	40.07	—0.07	0.07
Sc	21	1	44.1	44.1	—0.1	0.1
Ti	22	2	48	48.1	—0.1	0.1
V	23	2	51	51.0	0	0.1
Cr	24	2	52	52.0	0	0.05
Mn	25	2	55	54.93	+0.07	0.05
Fe	26	2	56	55.84	+0.16	0.03
Co	27	2	59	58.97	+0.03	0.02

It is interesting to note that of the 28 elements in this table, 13, or very nearly half, have atomic weights which are divisible by 4, and that of all of the possible multiples of 4, only two are missing, *i. e.*, 2 × 4 and 9 × 4. Seemingly to make up for the omission of the 9 × 4, the 10 × 4 occurs twice. This may be represented as follows:

1 × 4 = He
2 × 4 = missing, but represented by (2 × 4) + 1
3 × 4 = C
4 × 4 = O
5 × 4 = Ne
6 × 4 = Mg
7 × 4 = Si
8 × 4 = S
9 × 4 = missing, but replaced by 10 × 4 = A
10 × 4 = Ca
11 × 4 = Sc
12 × 4 = Ti
13 × 4 = Cr
14 × 4 = Fe

Of the atomic weights given in the table only one is divisible by 2, which is at the same time not divisible by four. Seven, or one-fourth of

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[1] For the final equation including n' see section 3 of the summary.

the atomic weights, are divisible by 3, though the threes are not evenly spaced like the fours; three are divisible by 5, and two of these, argon and calcium, have the same atomic weight. Five are divisible by 7, and two by 9, and every possible multiple of 16 appears. According to this the most important numbers are 4 and 3, which is in accord with the equation given for the atomic weights, 3 being an important secondary unit.

Of the twenty-six elements given in this table, it is found that the equation gives the atomic weights of nine, or more than a third, with no difference between the calculated and determined values, and for six other elements the difference is practically within the limits of error of the determinations. For the three elements, Be (+1.1), N (—0.99), and argon (—3.88), the differences in the first two cases are practically equal to the weight of a hydrogen atom, and for argon the difference, when allowance is made for a possible change of the packing effect, is the weight of a helium atom. The deviations of magnesium (0.32), silicon (0.3), and chlorine (0.46), are somewhat large, the largest deviations being that of chlorine, which is equal to 1.3% of its atomic weight. These deviations are also exceptional in that they are greater on the basis of oxygen as 16 than they are on the basis of hydrogen as 1.00.

If these six cases of deviation, three of which can be explained as due to a deviation in the number of hydrogen or helium units, are neglected, it is found that for the other twenty elements the equation gives the atomic weights with so great an accuracy that the average deviation is only 0.045 unit, which is practically equal to the average probable error in the experimentally determined values as given by Landolt-Börnstein.

It has been seen that for the first twenty elements the average increase in weight is 2.00, or exactly the same increase as is found for the uranium or the thorium radioactive series. For the heavier elements the increase is somewhat more rapid. The increments are tabulated in Table II.

TABLE II.—THE CHANGE IN THE ATOMIC WEIGHT WITH THE ATOMIC NUMBER.

Change of atomic number.	Final element.	Atomic wt.	Average increment.
0–10	Ne	20	2.0
10–20	Ca	40.07	2.007
20–30	Zn	65.37	2.53
30–40	Zr	90.6	2.53
40–50	Sn	119.0	2.84
50–60	Nd	144.3	2.53
60–70	Yb	172.0	2.52
70–79	Au	197.2	2.80
79–92	U	238.5	3.20

The table shows that the increment 2.00 occurs twice, and 2.52 four times in the table. The increment in general increases with the atomic number.

As has been stated, if the first nine elements are considered, the average deviation of the atomic weights (O = 16) from whole numbers is only 0.019 unit, which is an extremely small deviation. If the last ten elements in Table I of the preceding paper are taken, it is found that the deviation, though much larger, is still small, and is equal to 0.075 unit. The last of these ten elements is cobalt, the second element in the eighth group for the first occurrence of the eighth group in the periodic table. Table III shows that at this point the deviation suddenly jumps to a relatively large value, being 0.32 for nickel, 0.43 for copper, and 0.37 for zinc, with an average of 0.247 for the ten elements beginning with nickel and ending with rubidium. The average deviation for the next ten elements, beginning with strontium and ending with cadmium, is also 0.247 unit, for the ten from indium to cerium it is 0.199, and for the

TABLE III.—DEVIATIONS OF THE ATOMIC WEIGHTS FROM WHOLE NUMBERS, SHOWING THAT FOR THE HEAVIER ELEMENTS THERE IS NO TENDENCY FOR THESE WEIGHTS TO APPROXIMATE WHOLE NUMBERS.

Heavier elements.								Lighter elements.[1]		
Element.	At. wt.	Diff. from whole no.	Probable error in at. wt.	Element.	At. wt.	Diff. from whole no.	Probable error in at. wt.	Element.	At. wt.	Diff. from whole no.
Ni....	58.68	0.32	0.02	In....	114.8	0.2	0.5	He....	4.00	0.00
Cu...	63.57	0.43	0.05	Sn....	119.0	0.0	0.5	Li....	6.94	0.06
Zn....	65.37	0.37	0.05	Sb....	120.2	0.2	0.3	Be....	9.1	0.10
Ga...	69.9	0.10	0.5	Te....	127.5	0.5	0.2	B.....	11.0	0.00
Ge...	72.5	0.50	0.5	I......	126.92	0.08	0.03	C.....	12.00	0.00
As....	74.96	0.04	0.05	Xe....	130.2	0.2	0.2	N.....	14.01	0.01
Se....	79.2	0.20	0.1	Cs....	132.81	0.19	0.05	F.....	19.00	0.00
Br....	79.92	0.08	0.1	Ba....	137.37	0.37	0.03			———
Kr...	82.92	0.08	0.1	La....	139.0	0.0	0.3	Av. variation,		0.024
Rb...	85.45	0.45	0.05	Ce....	140.25	0.25	0.1			
		———				———		Na....	23.00	0.00
Av. variation,		0.247		Av. variation,		0.199		Al....	27.10	0.10
								P.....	31.02	0.02
Sr....	87.63	0.37	0.03	Ta....	181.5	0.5	1.0	S.....	32.07	0.07
Y....	89.0	0.0	0.2	W....	184.0	0.0	0.5			———
Zr....	90.6	0.4	0.2	Os....	190.9	0.1	0.4	Av. variation,		0.047
Cb...	93.5	0.5	....	Ir.....	193.1	0.1	0.2			
Mo...	96.0	0.0	0.1	Pt....	195.2	0.2	0.1	Ar....	39.88	0.12
Ru...	101.7	0.3	0.1	Au....	197.2	0.2	0.1	K.....	39.10	0.10
Rh...	102.9	0.1	0.05	Hg....	200.6	0.6	0.4	Ca....	40.07	0.07
Pd...	106.7	0.3	0.1	Tl....	204.0	0.0	0.2	Ti....	48.10	0.10
Ag...	107.88	0.12	0.02	Pb....	207.1	0.1	0.1	V.....	51.00	0.00
Cd...	112.4	0.4	0.03	Ra....	226.4	0.4	0.3	Cr....	52.00	0.00
		———		Th....	232.4	0.4	0.5	Mn...	54.93	0.07
Av. variation,		0.247		U.....	238.5	0.5	0.5	Fe....	55.84	0.16
						———		Co....	58.97	0.03
				Av. variation,		0.260				———
								Av. variation,		0.072

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[1] For a complete table of the lighter elements see Table II of the preceding paper.

twelve elements from tantalum to uranium, it is 0.260 unit. However, the value of Table II, as it stands, is very slight on account of the large probable errors in many of the atomic weights. This can be remedied by the choice of only such elements from the table as have accurately determined atomic weights. If thirteen elements are thus chosen as follows: nickel, copper, zinc, arsenic, bromine, rubidium, strontium, rhodium, silver, cadmium, iodine, caesium, and barium, the average deviation is 0.248 unit, while the theoretical deviation calculated on the basis that the atomic weights show no tendency to be near whole or any other special numbers, is 0.250 unit. Therefore, the tendency for the atomic weights to approximate whole numbers, which is very marked for the elements from helium up to an atomic weight of 59 (cobalt), seems to altogether disappear at the atomic weight 59 (beginning with nickel) and is not found for any of the elements which have an atomic weight higher than this value.

The reason for this abrupt change at the atomic weight 59, is not apparent. It may be in some unknown way connected with the first appearance at this point of new series, possibly formed by disintegration instead of aggregation; to a change in the effect of packing, or, if atoms exist which are lighter than hydrogen, it might possibly be due to their inclusion. If the first suggestion is considered, it is found that when the elements of high atomic weight are reached several series are known to exist. Thus the isotopes of lead, lead from radium and radium B differ in atomic weight by eight units, the isotopes radium F and radium A differ by the same amount, and radio-thorium and uranium X_1 differ by six units. If the members of the actinium series could be included, some of these differences in the weights of one species of atom would be made even larger. Where such differences exist in the weights of the different atoms having a single atomic number, it cannot be expected that any very simple relations can be found to exist for atoms of a high atomic weight, except where it is possible to compare the weights of the members of a single series, such as the uranium-radium, the thorium, or the actinium radioactive series.

It is quite possible that these differences of series go downward in the periodic system to relatively low atomic weights. Thus Aston claims to have separated neon, with an atomic weight 20.2, into neon and meta-neon, the atomic weights for which have been found by Thomson to be 20 and 22, so that the deviation of neon from the law of the approximate whole number by the amount +0.2 is probably only an apparent one. It is of interest that the difference between the atomic weights of neon and meta-neon, as found by Thomson, is two, which is the same as the average increment in the weights of the lighter elements, and is equal to the average difference between the weights of isotopes in the radioactive series. This average difference has been supposed to be also the actual difference between any two adjacent isotopes as listed below under any single atomic number:

Atomic number.	
82.	Lead from Ra, Lead from Th, Ra D, Th B, Ra B.
83.	Bi, Ra E, Th C, Ra C.
84.	Ra F, Th C, Ra C, Th A, Ra A.
86.	Th Em, Ra Em (Nt).
88.	Th X, Ra, Ms Th.
90.	Ra Th, Io, Th, UX_1.

However, these assumed differences of two have depended upon the fact that the atomic weights used for uranium and thorium have been 238.5 and 232.4, or a difference of practically 4 plus 2. The latest determination of the atomic weight of uranium by Hönigschmidt[1] gives a value of 238.18, which would not accord with this relationship for the individual differences. The difference between two isotopes belonging to a single radioactive series is, however, not affected by this result, and may still be assumed as four. However, in radioactive changes where a helium atom is lost, the new atom which is formed is not exactly four units lighter than the parent atom, since the packing effect varies with the change. How this effect varies in these heavy atoms cannot be told from the data now available, since the accuracy of the atomic weight determinations is not sufficient for this purpose, but the variation may be calculated approximately from the heat evolved in all cases where the heat change can be determined. It is of course self-evident that for deductions in regard to such atomic weight relations, the percentage accuracy must be much greater than is necessary for the study of the lighter elements. The difference between Hönigschmidt's values for uranium and for radium[2] (at. wt. = 225.97) is 12.21, or 0.21 more than the weight of three helium atoms.

Now that certain elements have been found to exist in isotopic forms, it becomes apparent that still other elements may do the same in cases which have not been recognized, so that in dealing with any single species of element it is uncertain whether this is an individual with respect to its atomic weight. The great regularity with which the elements follow the relationships given in these papers, up to an atomic weight of 59, suggests that with the exception of the cases of neon, silicon, magnesium, and chlorine, isotopes probably do not exist to any large extent for any of these elements, if they exist at all. There is still another possibility which suggests itself, and that is that the different atoms of a single atomic species differ in weight among themselves, and that the atomic weights as found are simply statistical averages. If this were true, the constancy

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[1] *Z. Electrochem.*, **20**, 449 (1914).

[2] *Sitzungsb. kais. Akad. Wien.*, **121**, *Abt. IIA*, 1973 (1912); *Monatsh.*, **34**, 283 (1913).

of the results obtained in atomic weight determinations which after all is not of an extremely high order, would be due to the fact that in a single determination such an enormous number of atoms is used. For example, if in one determination the weight of silver chloride obtained were 7.16 g., the number of chlorine or silver atoms in the precipitate would be 3×10^{22}, or thirty thousand billion billion. The statement of the above idea is not meant to be understood as an advocacy of such a theory, but only to point out the possibility that such might be the case.

TABLE IV.—A SYMBOLICAL REPRESENTATION OF THE ATOMIC WEIGHTS OF THE ELEMENTS IN THE FIRST THREE SERIES OF THE PERIODIC TABLE.

H = 1.0078.

	0.	1.	2.	3.	4.	5.	6.	7.	8.	
Ser. 2.	He He	Li He+H_3	Be 2He+H	B 2He+H_3	C 3He	N 3He+H_2	O 4He	F 4He+H_3		
Theor.	4.00	7.00	9.0	11.0	12.00	14.00	16.00	19.00		
Det..	4.00	6.94	9.1	11.0	12.00	14.01	16.00	19.00		
Ser. 3.	Ne 5He	Na 5He+H_3	Mg 6He	Al 6He+H_3	Si 7He	P 7He+H_3	S 8He	Cl 8He+H_3		
Theor.	20.0	23.00	24.00	27.0	28.0	31.00	32.00	35.00		
Det..	20.0	23.00	24.32	27.1	28.3	31.02	32.07	35.46		
Ser. 4.	A10He	K 9He+H_3	Ca 10He	Sc 11He	Ti 12He	V 12He +H_3	Cr 13He	Mn 13He +H_3	Fe 14He	Co 14He +H_3
Theor.	40.0	39.00	40.00	44.0	48.0	51.0	52.0	55.00	56.00	59.00
Det..	39.9	39.10	40.07	44.1	48.1	51.0	52.0	54.93	55.84	58.97

Increment from Series 2 to Series 3 = 4He
Increment from Series 3 to Series 4 = 5He (4He for K and Ca)
Increment from Series 4 to Series 5 = 6He

Table IV gives Series 2, 3 and 4 of the periodic system, built up by adding the weight of one helium atom for each change of two places to the right, and by adding enough multiples of the weight of a hydrogen atom to make up the atomic weight. In order to make the relationship apparent a symbolical representation has been used, He being taken to stand for the weight 4, and H for the weight 1.00. Built up in this way, the atomic weights of all of the members of the even numbered groups (with the exception of beryllium) may be represented by a whole number of symbols He, while all of the atomic weights in the odd groups may be represented by 3H plus a whole number of symbols He.

In the fourth, or argon series, the atomic weights begin to increase more rapidly than in the second and third series. This effect is first seen in the case of argon, which with a calculated atomic weight of 36, has instead a weight of practically forty, or too much by the weight of one helium atom. This effect dies out in potassium and calcium, and then appears again in scandium, titanium and the other members of this series. It becomes apparent in another way on studying the increment of weight in passing from a member of one series to the corresponding member of the series below it. Thus the second member in each group is obtained from the first by adding 4He. In going from the second to the third member of the group the increase is the same (4He) to give potassium or calcium, but is 5He to give argon, titanium, vanadium, chromium, and manganese.[1] This in a sense explains how the atomic weight of argon comes to be greater than that of potassium, and practically equal to that of calcium. In going from the third to the fourth member of each group, it is necessary to add 6He, but the increase in this case seems to be due to the interposition of the eighth group elements, iron, cobalt, and nickel.

While both the law of the approximate whole number, and the hydrogen–helium system here presented, become suddenly much less accurate beginning with the element nickel, this does not necessarily mean that the hydrogen–helium system breaks down at this point, since there are several possible causes, already mentioned, which may account for the sudden increase in the deviations. The eighth group fills the position of a transition group between the seventh group and the first, which shows that it fills exactly the place of the zero group in the other series. The first member of the eighth group tried thus has an even number as its atomic number. The second member has an odd, and the third an even number, which gives to the first group an odd atomic number. This is entirely in accord with the system, which would fail at this point if there had been two instead of three members in each position in the eighth group.

According to the rule that the atomic weights of the elements increase alternately by 3 and by 1, then since iron has a weight of 56, that of cobalt should be 59 (detd. = 58.97), nickel should be 60 (detd. = 58.68), and copper 63 (detd. = 63.57). The first large negative deviation among the elements of even atomic numbers, of any of the actual atomic weights from the theoretical value, is thus found for the element nickel. Now it has been found that if it is studied from the standpoint of its behavior toward X-rays, nickel behaves as an element of a considerably higher atomic weight than the determined value. The wave lengths of the strong K radiations as found by Moseley are proportional to the reciprocals of the squares of the atomic weights. If cobalt is taken as a standard of reference (the square of the atomic weight and wave length being taken as 100 for this element), the values, part of which were calculated by Kaye,[2] come out as follows:[3]

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[1] In comparison with the other members of the same series it is potassium and calcium rather than argon, which are exceptional.

[2] "X-Rays," 200.

[3] This table could be extended by including the values of the nuclear charge, when it would be seen that the wave lengths seem to be determined by the nuclear charge as found by Moseley, rather than by the atomic weight.

	Al.	Si.	Cl.	K.	Ca.	Ti.	V.	Cr.	Mn.
(Atomic weight)	21.1	23.0	36.1	44	46	66	75	78	86
1/Wave length..........	21.5	25.2	37.8	47	53	65	72	78	85

	Fe.	Co.	Ni.	Cu.	Zn.	Rh.	Pd.	Ag.
(Atomic weight).............	90	100	99	116	123	304	328	334
1/Wave length.............	92	100	108	116	124	298	314	321

The atomic weight of nickel, if calculated from the value 108 as given in this table, comes out as about 61.2, while the other elements from titanium up to and including rhodium, give a very close agreement. The principle as given above is derived from Whiddington's result that the energy of a characteristic X-ray is roughly proportional to the atomic weight, and from the quantum theory of radiation, according to which the energy of a radiation is inversely proportional to its wave length.

A study of the packing effects, as given in Table II of the preceding paper, shows that where an atom is built up entirely of helium atoms, then, on the average, the decrease in mass is practically due entirely to the primary formation of the helium atoms, and not at all to the aggregation of these into atoms which are heavier. From this point of view an atom composed entirely of helium units would have extreme instability in so far as its disintegration into helium units, in *comparison* with its instability with reference to a hydrogen decomposition. Such an atom in a radioactive transformation should lose α-particles much more readily than hydrogen nuclei, in fact, if it is remembered that the alpha decomposition is itself not complete in any case, it will be seen that it is doubtful if such an atom would ever give a detectable hydrogen disintegration.

If the atoms are built up entirely according to the special system presented in Table IV, according to which the members of even numbered groups are in general aggregates of helium alone, then since all of the radioactive elements which are now known to give a simple alpha decomposition (that is without an accompanying beta change) belong to even numbered groups, they could not be expected to give hydrogen upon disintegration. Thus one of the chief objections to the theory that the atoms are hydrogen complexes, which is based on the fact that up to the present time no hydrogen has been detected as the product of any radioactive change, is seen to be not contrary to, but rather in accord with, the theory as presented in these papers. The exceptional case of beryllium shows, however, that even numbers of even numbered groups sometimes contain a hydrogen nucleus which was not contained in one of the helium nuclei from which the atom was built, so that there still remains the possibility, though the probability seems small, that hydrogen nuclei might be liberated from atoms belonging to these groups. There is no evidence that the particular system presented in Table IV holds exactly for the atoms of high atomic weight, but the general form of the system indicates at least that the atoms contain more helium than independent hydrogen units, and this seems in accord with the fact that uranium loses α-particles in eight steps, and is changed into a form of lead, without any apparent loss of a hydrogen nucleus.

The stability with which the hydrogen nuclei which are not contained in helium groups, but which generally occur in threes (H_3 in Table II), are built into the complex atoms, is not indicated with any degree of accuracy, but in the case of lithium it seems to be great, for lithium shows the extremely large packing effect equal to 1.57%, which might seem doubtful but for the care taken by Richards and Willard[1] in the determination of this atomic weight.

The hydrogen–helium system here presented is entirely in accord with, but independent of, the astronomical theory that the order in which the elements appear in the stars is first nebulium, hydrogen and helium, then such of the lighter elements as calcium, magnesium, oxygen, and nitrogen, and finally iron, and the other heavy metals, although in the present system it has not been found necessary to include nebulium. Some of the nebulae give bright line spectra of nebulium, hydrogen and helium, such Orion stars as those of the Trapezium give lines for hydrogen and helium, while those that are more developed show magnesium, silicon, oxygen and nitrogen, and some of the other low atomic weight elements in addition. Bluish white stars such as Sirius give narrow and faint lines for iron, sodium, and magnesium, and the solar stars give much weaker hydrogen spectrum, and many more and stronger lines for iron and the heavy metals. The astronomical theory that the heavier elements are thus formed from those of smaller atomic weight is of extreme interest, but the evidence for it is somewhat uncertain, since it is possible that it is the difference in the density of the different elements which is the effective factor in causing the spectra to appear in the order in which they are found to occur. The relative brightness of the different lines also varies greatly, such lines as the calcium H and K lines being extremely strong, and this also interferes with the determination of the order of the appearance of the elements in the stars. On the other hand, the evidence presented in these papers, which seems to show that the elements are atomic compounds of hydrogen and helium, appears to give some support to the theory of the evolution of the heavier atoms from those which are lighter. The evidence for the hydrogen–helium system is, however, very much stronger and more complete than that for the evolution of the elements in the stars.

Summary.

1. The fundamental idea of this, the second paper on atomic structure, is to show that the system which has been found to apply to the atomic weight and valence relations of the members of each of the radio-

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[1] Richards and Willard, This Journal, 32, 4 (1910).

active series, also holds true for the lighter atoms. In a radioactive series it is found that a loss of an α-particle with a mass of four decreases the valence by two, and thus shifts the element two groups to the left in the periodic table, and decreases the atomic number by two. If this is true for the lighter elements, beginning with helium, then the addition of the weight of a helium atom for each increase of two in the atomic number ought to give the atomic weights of the elements belonging to the even numbered groups. The atomic weights found by this method are the same on the whole as the determined values, which shows that the theory accords with the facts.

2. The lithium atom, which is the first atom in the odd numbered group, is heavier than the helium atom by the weight of three hydrogen atoms. It would be very remarkable if the atoms of odd atomic number follow the same rule as those of even atomic number, but that they do is indicated by Table IV, which shows that for the odd numbered groups as well, each increase of two in the atomic number results in an increase of four in the atomic weight.

3. The atomic weights of the lighter elements are given with considerable accuracy by the equation

$$W = 2n + (1/2 + 1/2\,(-1)^{n-1}),$$

where W is the atomic weight and n the atomic number. In the case of the heavier elements another term enters, so that the more general equation may be given:

$$W = 2\,(n + n') + [1/2 + 1/2\,(-1)^{n-1}]$$

4. Of the 27 elements from helium to cobalt, 13, or nearly one-half, have atomic weights divisible by four, and these elements in general belong to even numbered groups in the periodic table. Of all the possible multiples of four only two are missing, *i. e.*, 2×4 and 9×4, and seemingly to make up for the omission of the 9×4, the 10×4 occurs twice. An explanation of the omission of the 2×4 and its occurrence as $(2 \times 4) + 1$ will be given in a later paper.

5. If the atomic weights increase by the weight of one helium atom for an increase of two in the atomic number, the average increase in the atomic weight per atomic number should be 2. That this is in accord with the facts is shown, for neon with an atomic number 10 has an atomic weight of 10×2 or 20, and calcium, with an atomic number 20, has an atomic weight equal to 20×2 or 40.

6. According to the first paper, the magnitude of the packing effect for helium is 0.77%, which is the same as the average of the packing effects for the first 27 elements, so that if a more complex atom is built of helium groups alone, then in general nearly all of the packing effect is due to the primary formation of the helium nucleus from four hydrogen

nuclei and two negative electrons, and almost no packing effect results from the aggregation of these helium nuclei into more complex atoms. On this view the helium nuclei must be very greatly more stable than the nuclei of the more complex atoms which they form, so that such an atom, made up entirely from helium units, should give helium and not hydrogen by its primary decomposition. This is in accord with the behavior of the radioactive elements when they disintegrate. It is of interest to note that the members of the radioactive series which are now known to give helium on decomposition, belong to the even numbered groups on the periodic table, and therefore to those groups which are shown in Table IV, as helium aggregates alone. That these heavy atoms must contain a considerable number of helium units is shown by the fact that uranium changes into lead by eight steps in which it loses α-particles.

7. The hydrogen–helium system gives an explanation of the fact that argon has an atomic weight of 40, which is higher than that of potassium, which has an atomic number higher by 1. A study of Table IV makes the reason apparent, and shows that in *comparison* with other members of Series 4 in the periodic table, it is potassium and calcium, and not argon, which are exceptional. In comparison with the members of Series 3, and potassium and calcium, it is of course the argon which is exceptional. As the atoms grow heavier there is a tendency to take on helium (or perhaps hydrogen) groups more rapidly than is the rule in the case of the lighter elements.

Later papers by one of the writers will consider the nuclear and non-nuclear electrons, and the relations of the periodic system to the hydrogen–helium system presented in this paper.

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[CONTRIBUTION FROM THE KENT CHEMICAL LABORATORY OF THE UNIVERSITY OF CHICAGO.]

RECENT WORK ON THE STRUCTURE OF THE ATOM.

[THIRD PAPER ON ATOMIC STRUCTURE.]

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When Dalton[1] advanced his atomic theory of the constitution of matter, he thought of the atom as the ultimate material unit. The discovery of the phenomena of radioactivity, however, made it evident that this view was incorrect, and showed that the atom must be complex. The question of its structure has remained unsolved for a long time, and it is only very recently that there has been any experimental work upon which to base a theory. In this paper practically all of the important

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[1] "On Chemical Synthesis, from a New System of Chemical Philosophy," Manchester, 1808, pp. 211–6, 219–20.