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THE NUCLEI OF ATOMS AND THE NEW PERIODIC SYSTEM.

BY W. D. HARKINS.

SYNOPSIS.

Structure of atomic nuclei; helium-hydrogen hypothesis. The present paper is a summary and extension of previous articles by the author on this subject. Besides the direct evidence afforded by radioactive transformation and by the disruption of atomic nuclei by alpha rays, the data upon which any theory of nuclear structure must be based are atomic masses, atomic numbers which are supposed equal to nuclear charges, and atomic stabilities which are supposed to be related to the relative abundance of the elements in nature. Now the fact that the atomic weights of the 27 lightest elements and of the radioactive elements are approximately integers and that the difference in atomic weight between elements whose atomic numbers differ by a multiple of 2 is usually a multiple of 4, suggests that the nuclei of these elements are built up of hydrogen and helium nuclei. *Assuming* (1) that the nuclei consist only of helium nuclei (α), hydrogen nuclei (η) and electrons (β); (2) that the mass of a nucleus is very nearly equal to the sum of the masses of its constituents; and (3) that the number of hydrogen nuclei, except as combined to form helium nuclei, is never more than 3 (except when the the mu (μ) group ($\eta_2\beta_2$) characteristic of isotopes is also present), the *formulae for the composition of each of the nuclei of the first 27 elements and of the radioactive elements* may be determined from the atomic weights and the atomic numbers. These formulae are given in Tables II. and III. Remarkable regularities are found. With the exception of beryllium ($\alpha_2\eta\beta$), all the atomic nuclei of the *even-numbered light elements* seem to consist merely of helium nuclei, with a pair of cementing electrons added in the case of the higher numbers; while the *odd numbered light elements*, except nitrogen ($\alpha_3\eta_2\beta$) and scandium ($\alpha_{11}\beta$ or more probably $\alpha_{11}\eta\beta_2$) differ from even elements only by each containing an additional group ($\eta_3\beta_2$). The fact that the odd elements are much less abundant in nature than corresponding even elements suggests that odd light elements are less stable, due presumably to the added group $\eta_3\beta_2$. If this group exists as a separate atom, it is an isotope of hydrogen with an atomic weight 3 and may be the hypothetical *nebulium*. It is suggested that this group $\eta_3\beta_2$ and the helium nucleus, assumed to have the composition $\eta_4\beta_2$, each consist of two ring- or disk-shaped electrons with respectively three and four hydrogen nuclei arranged symmetrically between them. The *stability* of various atomic structures is discussed on the basis of the formulae. It is pointed out that *binding and cementing electrons* usually occur in pairs; there are, however, several exceptions. As for the *radioactive elements*, the corresponding elements of the thorium and uranium series differ in weight by 2 units and their formulae are alike except for the presence of the additional group $\eta_2\beta_2$ or μ group in each element of the uranium series. The latest determinations of the atomic weights of these elements indicate that they are all approximately integers and that the loss of mass due to packing in the nuclei is very small. Why the *elements with numbers from 28 to 80* do not fall in with this scheme can be explained only by assuming that in most cases they consist of mixtures of isotopes. Chlorine, silicon, magnesium, and neon, among the light elements are also mixtures of isotopes. The conclusion from all of the above is that the hydrogen nucleus is the positive electron. In a note appended at the time of correcting the proof for this paper, the writer states that his latest atomic weight results seem to indicate that he has obtained *an experimental separation of chlorine into isotopes. This is the first separation of an element into atomic species which has ever been obtained experimentally.*

ALL of the available evidence indicates that the structure of the nucleus of an atom is not only independent of, but is also much more complicated than that of the outer planetary system of electrons. This is in accord with the theory of Rutherford, which indicates that the nucleus is very minute in comparison with the atom as a whole, and has a diameter of the order of 10^{-13} cm. The number of atoms already discovered, whose nuclei have different structures, amounts to approximately 119, while the number of elements whose non-nuclear planetary systems differ in arrangement is at present only 86, which suggests that the nuclear structure is the less simple. It is also very much more difficult to secure evidence in regard to nuclear structure than with respect to the arrangement of the outer electrons, since the latter manifests itself in almost all of the chemical and physical properties of materials, while with the exception of mass properties, none of the characteristics of the nucleus give indications which are at present observable, except at the time of its disintegration during what is called a radioactive change.

The only ordinary physical property which is now known to be dependent on the nature of the nucleus, aside from those due to its net positive charge, and the minute differences in the wave-lengths in the spectra of isotopes, is that of mass. The ordinary or Mendeléef periodic system of the elements, is an expression of the arrangement in space of the planetary electrons,[1] and is not directly related in its periodicity to any of the following properties which are often discussed as depending upon it: mass, atomic stability, disintegration, and evolution, and the relative abundance of the different atomic species. That there is a second periodic system related to these properties was discovered by me in 1915. The new system is distinguished from that of Mendeléef in a number of ways. First, it is not based on the element numbers, or the so-called atomic numbers, but upon the number of the atomic species.

[1] See references at the end of the paper.

It is somewhat unfortunate that the element numbers of Rydberg, van den Broek, and Moseley, have commonly been styled atomic numbers, since this term should have been reserved for the number of the atomic species. Second, while in the ordinary periodic system the periods are 2, 8, 18, and 32 elements in length, in the new system 2 atomic species are sufficient to constitute a complete period. Third, the new system, as has already been stated, relates to an entirely distinct set of properties.

The Structure and Composition of the Nuclei of Atoms.

In 1915 the writer published formulæ for the composition of atoms, and these give the following system of composition for the nuclei of the atoms carbon, nitrogen, and oxygen:

$$\text{Carbon nucleus} = \alpha_3^{++}$$
$$\text{Nitrogen nucleus} = \alpha_3^{++}h_2\beta^{-}$$
$$\text{Oxygen nucleus} = \alpha_4^{++}$$

where α^{++} is used as the symbol for the nucleus of the helium atom or the alpha particle, h^{+} indicates the nucleus of the hydrogen atom, and β^{-} stands for the negative electron. A considerable amount of evidence in favor of this hydrogen-helium structure of the atoms was presented in this series of papers, which has now received still further confirmation in the driving out of h^{+} or $h_2\beta^{+}$ particles from the nuclei of nitrogen atoms in the experiments of Sir Ernest Rutherford.[1]

The object of the present paper is to give further details of this hydrogen-helium theory of atomic structure, and these details will be summarized in a series of postulates. While these postulates have not been presented before in their present form, the evidence bearing upon them has been presented in part in the earlier papers of this series, and will not be repeated here, even though its omission will cause the assumptions to seem much more arbitrary than is actually the case. For such evidence the earlier papers should be consulted.[1] The postulates will be divided as closely as seems justified into three general classes: first, those of a general nature concerning charge and mass; second, those which relate to the presence of helium nuclei in the nuclei of other atoms, and third, those which consider the inclusion of hydrogen nuclei.

[1] Phil. Mag., *37*, 537–87, (1919). It is of interest to note that if in these experiments the α_3 group remains intact and $h_2^{+}\beta^{-}$ is driven off, then the atom which would be formed is carbon, if $h^{+}\beta^{-}$ is driven out, the remaining nucleus is that of an isotope of nitrogen of atomic weight 13, while if h^{+} alone is expelled, the remaining nucleus would be that of an isotope of carbon of atomic weight 13.

General Assumptions Concerning Charge and Mass.

Postulate 1.—The positive charge on the nucleus of an atom is equal in magnitude to the sum of the negative charges on all of the non-nuclear or planetary electrons. The positive charge on the hydrogen nucleus is equal in this sense to that of one negative electron. This postulate is present in almost all theories of atomic structure.

Postulate 2.—The mass of a complex atom is nearly equal to the sum of the masses of the atoms from which it is built. The evidence for this postulate has been given in the first two papers of this series, and shows that there is very little change of mass when alpha particles unite to form a complex atom with an atomic weight of 56 or less. Calculations made on the basis of the theory of relativity indicate that the loss of mass during the change of uranium into lead (radium G) is equal to only 0.052 of a unit of atomic weight, even although 8 alpha and 6 beta particles are emitted in the change. There is thus very little "packing effect" during alpha disintegrations or aggregations. If the helium nucleus is built up from four hydrogen nuclei, or the helium atom from four hydrogen atoms, then the loss of mass in this process is 0.77 per cent. This is a much more mild assumption than that of Nicholson, according to whom the helium nucleus is built up from two hydrogen nuclei, which unite, occupying the same space, and thus undergo an increase of mass amounting to nearly 100 per cent.

The Helium System of Nuclear Structure.

Postulate 3.—The nuclei of the atoms of even atomic number between numbers 2 and 26 are in general intra-nuclear compounds of alpha particles alone, or of alpha particles and negative electrons.

Postulate 4.—The nuclei of the atoms of even element number between numbers 82 and 92 inclusive, are compounds of the formula $\alpha_m e_n$ for all atoms which are disintegration products derived from thorium, while the members of the uranium disintegration series are intra-nuclear compounds of alpha particles, negative electrons, and hydrogen nuclei, with the general formula $\alpha_m e_n h_2$. Thus the members of the thorium series have the same general formula as the lighter atoms, and may therefore be considered as a continuation of the ordinary system of atoms. The meta-neon supposed to have been found by Thomson and Aston would be a member of the uranium system with a nuclear formula $\eta_4\mu$.

Postulate 5.—As few as three and as many as ten alpha particles may unite to form a stable nucleus without the inclusion of any additional negative electrons or hydrogen nuclei. In atoms thus made up the positive charge on the nucleus is equal to the sum of the positive charges on the alpha particles, or is $2m$, where m is the number of helium nuclei present. Whenever more than ten alpha particles are present in a compound nucleus, at least two negative cementing electrons are also included, provided the atom is of even atomic number. It is these cementing electrons which are ejected in the beta disintegrations of the radioactive atoms. That the negative cementing electrons are associated in pairs is indicated by the fact that whenever beta disintegrations occur they follow the rule that *there are always two successive disintegrations of this type, or else there is one beta disintegration just preceding and one just after an alpha disintegration*, while in three cases as many as four or five alpha disintegrations occur in direct succession.

The atomic weights and nuclear charges of the atoms taken together indicate that just as the nucleus of a radioactive atom may lose as many as five alpha particles in direct succession, so as many as 8 alpha particles, each carrying two positive charges and with a mass of four, may unite to form a sulphur atom nucleus with a positive charge of 16 and a mass of 32, and without a single cementing electron; but the nucleus of a positive charge equal to 18 and a mass of 36, built from 9 alpha particles alone seems not to be stable, so the argon nucleus is stabilized by 2 negative electrons, which make it necessary to include one additional alpha particle in order to give the nucleus its proper charge. This gives to the argon atom a mass of 40 instead of the normal 36. On the other hand, a nucleus consisting of ten alpha particles alone, as in the calcium atom, seems to be stable, giving a nucleus of mass 40 and charge 20. However, when the nuclear charge rises to 22 or more, cementing electrons are always included. Thus the titanium nucleus has the formula $(\alpha_{12}e_2)^{22+}$, where the $22+$ indicates the net charge on the nucleus. The number of cementing electrons remains constant at 2 until the nuclear charge rises to 32 in the element germanium, when the number increases to 4.

Whenever an atom has a higher atomic weight than the atom of next higher atomic number, this is due to the fact that the first atom of the pair contains more cementing electrons in its nucleus than the number corresponding to its position with reference to the adjacent elements, or else the second of the pair contains less of such electrons than corresponds with its position.

If the nucleus of the thorium atom is built of alpha particles and cementing electrons alone, as suggested in the preceding section, then it would consist of 58 alpha particles and 26 binding electrons, which would allow 13 pairs of beta disintegrations and 58 alpha ejections in the process of total disruption, while there are 2 pairs of beta changes and 6 alpha changes in the system from thorium to thorium E, the complete disintegration series as now known. The ratio of 2 to 6 is about one and a half times that of 13 to 58, but the former includes both ends of a disintegration series, with beta changes at both of the ends. Also according to the system proposed, cementing electrons add very slowly with increase of atomic number among the light atoms. In the uranium series there are 8 alpha and 3 pairs of beta disintegrations, as compared with 59 of the former and 13 pairs of the latter for total disruption, or the numerical relations are similar to those found in the thorium series. The uranium nucleus, though it is even in number, evidently contains two hydrogen nuclei, and these are present in all of the forms of lead produced by radioactive disintegration from uranium, and in all of the other members of the radium and actinium series. This gives an explanation of the fact that while the difference in atomic weight of isotopes which come from one ancestor, is four, the difference between adjacent isotopes, which descend from different ancestors, is half of four, or two.

In the Harkins-Wilson equation for atomic weights[1]

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

where N is the atomic number, and W the atomic weight, n may be considered as the number of cementing electrons used in attaching helium nuclei. It does not take account of any electrons used in cementing on hydrogen nuclei. For elements of even atomic number this becomes much simpler, or

$$W = 2(N + n). \qquad (2)$$

Durrant made a study of this equation[2] and found that n is zero from elements 1 to 17, two for element 18, zero for element 20, and 2 for elements 2 to 28. Beginning with element 29 the value of n begins to increase at an almost constant rate in such a way that the tangent of the angle made by the n line and the atomic number (N) axis, is 1/3.

Equation 2 may be put in the form

$$W = 4\left(\frac{N + n}{2}\right), \qquad (3)$$

where the symbols have the same meaning as before, and $(N + n)/2$ is the number of alpha particles in the nucleus of the atom. A simple equation based on these relations is:

$$W = 2\left(N + \frac{N - 26}{2.7}\right) \qquad (4)$$

[1] J. Am. Chem. Soc., 37, 1380 (1915).

[2] J. Am. Chem. Soc., 37, 621–7 (1917).

or

$$W = 4\left(\frac{N}{2} + \frac{N - 26}{5.4}\right), \tag{5}$$

where $(N - 26)/5.4$ represents approximately the number of pairs of cementing electrons, or $(N - 26)/2.7$ the number of such electrons. This term is obviously not to be used when it is negative.

One of the characteristics of the radioactive elements is that the increase in the number of cementing electrons with the atomic number is considerably greater than in the case of any other set of elements in the system. Thus the average for elements of high atomic number is the addition of one cementing electron for each increment of 2.7 in the atomic number, while in the radium series between radium-G and uranium, one such electron is added on the average for each increase of 1.66 in the atomic number.

Postulate 6.—While for atoms of even atomic number between 4 and 26 the atomic weights are divisible by 4, and between numbers 82 and 92, each alpha disintegrative change is such as to involve a loss of mass equal to 4; between atomic numbers 30 and 90 this is not true. This is illustrated by Table I., which shows that the rule postulating divisibility by 4 ceases to hold with extreme abruptness at element 28, which is nickel. The simplest assumption is that already made by the writer, and by Durrant, on the basis of the equation proposed by the writer *that the deviation is caused by the existence of isotopes in elements of atomic number higher than 27*. The evidence in favor of this postulate is less than for any of the others. Experimental work on the

TABLE I.

Illustrates the Helium Structure of the Nuclei of Atoms.

Atomic Number.	Atomic Weight Divided by 4.	Deviation from a Whole Number.
2	1.00	0.00
6	3.00	0.00
8	4.00	0.00
10	5.00	0.00
12	6.08	+0.08
14	7.07	+0.07
16	8.01_5	$+0.01_5$
18	9.97	−0.03
20	10.02	+0.02
22	12.02_5	$+0.02_5$
24	13.00	+0.00
26	13.96	−0.04

Average deviation from a whole number up to this point is the extremely small amount of 0.023.

TABLE I.—*Continued.*

28	14.50	+0.50
30	16.34	+0.34
32	18.12_5	$+0.12_5$
34	19.80	−0.20
36	20.73	−0.27
38	21.91	−0.09
40	22.65	−0.35
42	24.00	0.00
44	25.42_5	$+0.42_5$
46	26.67_5	-0.32_5

Average deviation from a whole number for 10 elements beginning with element 28 is equal to 0.262, or almost what it should be by chance (0.250). *Notice that the break occurs exactly at element 28 (Ni), which is exactly the same element at which the atomic weights themselves cease to be close to whole numbers.*

diffusion of ordinary elements has been carried on in this laboratory for four years, and a conclusion would probably have been reached in at least one instance if the work had not been interrupted by the war.

THE HELIUM-HYDROGEN SYSTEM OF NUCLEAR STRUCTURE.

Postulate 7.—While among the lighter atoms the atoms with an even nuclear charge are in general intra-atomic compounds of helium alone, and the nuclei are intra-nuclear compounds of alpha particles alone, or of alpha particles plus cementing negative electrons, the nuclei which carry an odd numbered positive charge have the same composition as the nucleus of next lower even charge with the addition of r hydrogen nuclei and $r - 1$ negative electrons. The value of r is almost always 3, but in the exceptional case of nitrogen it is 2.

Postulate 8.—The helium nucleus consists of 4 hydrogen nuclei and 2 negative electrons, which serve to bind the hydrogen nuclei together. This postulate has also been assumed by Rutherford.

Postulate 9.—In the helium nucleus the hydrogen nuclei or positive electrons are bound to the negative electrons, but not to each other. That this is the case is indicated by the sign of the mutual electromagnetic mass or the "packing effect" which amounts to a loss of mass of 0.77 per cent. The loss of mass shows that the particles which have come together attract each other, and that the distance of approach is such that the centers of positive and negative electrons are distant about 400 times the diameter of the positive electron. If the positive electron is as small as is assumed by Rutherford, this would mean that the positive electron would lie very near the outer part of the negative electron; and that the alpha particle is probably not much larger than two negative electrons.

TABLE Ib.

Deviations of the Ttomic Weights from Whole Numbers, Showing that for the Heavier Elements there is no Tendency for these Weights to Approximate Whole Numbers, while the Atomic Weights of the Elements below No. 28 are Extremely close to Whole Numbers.

Lighter Elements Without Isotopes.[1]

At. No.	Element.	At. Wt.	Diff. from Whole No.
2	He...	4.00	0.00
3	Li ...	6.94	0.06
4	Be...	9.1	0.10
5	B....	10.9	0.10
6	C....	12.0025	0.0025
7	N....	14.008	0.008
9	F....	19.005	0.005
	Av. variation...		0.039
11	Na...	23.00	0.00
13	Al ...	27.10	0.10
15	P....	31.02	0.02
16	S....	32.07	0.07
	Av. variation...		0.047
18	Ar...	39.9	0.10
19	K....	39.10	0.10
20	Ca...	40.07	0.07
22	Ti ...	48.10	0.10
23	V....	51.00	0.00
24	Cr...	52.00	0.00
25	Mn ..	54.93	0.07
26	Fe ...	55.84	0.16
27	Co...	58.97	0.03
	Av. variation...		0.070

Heavier Elements Which Contain Isotopes.

At. No.	Element.	At. Wt.	Diff. from Whole No.	Probable Error in At. Wt.
28	Ni ...	58.68	0.32	0.02
29	Cu...	63.57	0.43	0.05
30	Zn ...	65.37	0.37	0.05
31	Ga...	70.1	0.10	0.5
32	Ge ...	72.5	0.50	0.5
33	As ...	74.96	0.04	0.05
34	Se ...	79.2	0.20	0.1
35	Br ...	79.923	0.08	0.1
36	Kr...	82.92	0.08	0.1
37	Rb...	85.45	0.45	0.05
	Av. variation..		0.247	
38	Sr ...	87.63	0.37	0.03
39	Y....	89.0	0.0	0.2
40	Zr ...	90.6	0.4	0.2
41	Cb...	93.5	0.5	...
42	Mo ..	96.0	0.0	0.1
44	Ru...	101.7	0.3	0.1
45	Rh...	102.9	0.1	0.05
46	Pd...	106.7	0.3	0.1
47	Ag ...	107.88	0.12	0.02
48	Cd...	112.4	0.4	0.03
	Av. variation..		0.247	

At. No.	Element.	At. Wt.	Diff. from Whole No.	Probable Error in At. Wt.
49	In...	114.8	0.2	0.5
50	Sn...	118.70	0.30	0.2
51	Sb...	120.2	0.2	0.3
52	Te...	127.5	0.5	0.2
53	I....	126.92	0.08	0.03
54	Xe ..	130.2	0.2	0.2
55	Cs...	132.81	0.19	0.05
56	Ba ..	137.37	0.37	0.03
57	La...	139.0	0.0	0.3
58	Ce ..	140.25	0.25	0.1
	Av. variation..		0.229	
73	Ta ..	181.5	0.5	1.0
74	W...	184.0	0.0	0.5
76	Os...	190.9	0.1	0.4
77	Ir ...	193.1	0.1	0.2
78	Pt...	195.2	0.2	0.1
79	Au ..	197.2	0.2	0.1
80	Hg ..	200.6	0.4	0.4
	Av. variation..		0.214	
81	Tl...	204.0	0.0	0.2
82	Pb ..	207.20	0.20	0.1
88	Ra ..	226.0	0.0	0.1
90	Th ..	232.15	0.15	0.1
92	U ...	238.16	0.16	0.1
	Av. variation..		0.102	

Note. One of the remarkable features of this table is that the average deviation from a whole number is very low for both the light and the heaviest atoms, but is large between atomic numbers 28 and 80.

[1] A complete table of the lighter elements will be found in the Journal of the American Chemical Society, *37*, 1370 (1915). The above table gives the elements just before and just after element 28 (Ni) to show the break at that point. The elements Ne, Mg, Si, and Cl, have been omitted from the list of the lighter atoms because each of them is a mixture of two isotopes. It will be seen that where isotopes do not exist the atomic weights are very close to whole numbers.

Postulate 10.—This postulate is more definite than our present evidence, but seems to be better in accord with available knowledge than any other assumption which has occurred to the writer. The helium nucleus is assumed to consist of two negative electrons which have the form of rings, or discs, or spheres flattened into ellipsoids. The rings or discs lie with their greatest dimension perpendicular to the axis of the nucleus, and far from each other relative to their dimensions, between the two discs near their edges are the positive electrons in a symmetrical arrangement, that is at the corners of a square (Fig. 1).

Postulate 11.—Since a nucleus built according to the model assumed in

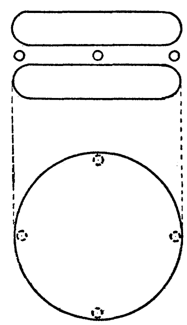

Fig. 1.

Model representing the relative position but not the shape, of the positive and negative electrons in the helium nucleus. The two large discs represent negative electrons and the four small circles represent hydrogen nuclei.

postulate 10 would be electrically negative on the outside, it may be assumed to be incapable of closely binding any negative electrons alone. Also, since its net positive charge is equal to two, it may also be assumed that it will not bind with itself any positive electrons unless it at the same time adds on at least one negative electron. However, such nuclei may unit with each other, since each is at the same time positive and negative.

Postulate 12.—However, two helium nuclei alone do not make a stable structure except when one positive and one negative electron are included (nucleus of beryllium or glucinium), but from three to nine helium nuclei may unite together without any other binding particles. This seems to indicate a tube, ring, or a shell structure for the nuclei of complex atoms, although the ring or shell is probably very closely packed.

Postulate 13.—The group consisting of three hydrogen nuclei and two negative electrons is contained in the nucleus of every atom of odd atomic number between 3 and 27 inclusive, except only nitrogen and scandium. This group is very similar in composition to the helium nucleus, since it contains the same number of negative electrons and only one less positive electron.

Postulate 14.—The extremely frequent occurrence of the group h_3e_2 suggests that it probably occurs alone as a unit.[1] In this case it would be the nucleus of an atom of a nuclear charge equal to one, and in this sense would be an isotope of hydrogen. However, since the frontier of such an atom is much less extensive and much nearer the nucleus than in the radioactive atoms, the atom might not be isotopic with hydrogen in the sense of its spectrum or chemical behavior, although it would probably be very similar. If the hypothetical nebulium exists at all, it is probably this form of hydrogen. One of the arguments in favor of the existence of nebulium is that Fabry and Buisson[2] found by a study of the Döppler effect that its atomic weight is close to 2.7, which, since the method is not exact, was interpreted as an indication that its atomic weight is 3. It is easily seen that the isotope of hydrogen would give just this atomic weight. It is possible that some of this isotope is present in ordinary hydrogen, but since it would probably be an extremely small fraction of the hydrogen, it is likely that its separation would be difficult or impossible. A model for this eka-hydrogen nucleus might well take just the form of that for the helium nucleus, with the substitution of three positive hydrogen nuclei at the corners triangle for the four hydrogen nuclei of the alpha particle.

Postulate 15.—Since the elements whose atomic nuclei carry an odd numbered charge are very much less abundant than those for which the charge is even, and since the former alone contain the eka-hydrogen nucleus, it is evident either that nuclei built of helium nuclei alone are very much the more stable, or else the supply of eka-hydrogen was not very great when such atoms were built.

Postulate 16.—There is a little evidence which seems to suggest that the nuclei of odd-numbered charge are formed from those which have an even charge. This would indicate that in the primary formation of atomic nuclei the aggregation of alpha particles is the primary reaction, and that the eka-hydrogen nuclei $(h_3e_2)^+$ or the h_2e group adds on later. The evidence which points in this direction is that obtained in the new periodic system discovered by the writer as given in Fig. 2, which gives the percentage abundance of the elements in the meteorites as ordinates and the atomic numbers as abscissæ. It may be noted that every even-numbered element is very much more abundant than the adjacent element of odd atomic number, but what is specially in point here is that every one of the more abundant elements of odd number, sodium, aluminium, cobalt, phosphorus, and potassium, lies adjacent to a high

[1] This group will be called a nu (ν) particle.

[2] Astrophys. J., *40*, 256 (1914).

peak for an even number. This is, of course, not at all conclusive, especialy since fluorine, which lies next to oxygen, is not very abundant, but it seems to be in accord with the relations found by Rutherford in the breaking down of the nitrogen nucleus. At least he comes to the conclusion that the hydrogen nuclei are about twice the diameter of the electron away from the center of the complex nucleus,[1] or 7×10^{-13} cm. distant, which is probably near the outer part of the nucleus, and that

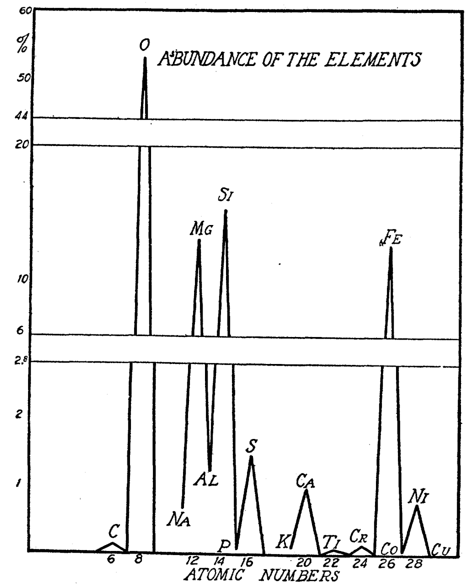

Fig. 2.

Atomic percentage abundance of the atoms in 350 stone to 10 iron meleorites, which is in the ratio of known falls. This is supposed to represent the average composition of materials as perfectly as can now be determined.

at least one of these hydrogen nuclei is driven off in a collision with a fast alpha particle.

Postulate 15 is taken from the earlier papers of the writer,[2] which indicate that of all complex nuclei that of helium and probably also that of the hypothetical meta-hydrogen, that is the nu particle, are by far the most stable, indeed the stability of the α particle is of an entirely higher order than that of other nuclei. Next in order of stability come the nuclei of the light atoms of even atomic number or nuclear charge, that is the nuclei consisting of alpha particles alone, or of alpha particles a pair of and negative electrons. The least stability is that concerned

[1] Phil. Mag., *37*, 586 (1919).

[2] J. Am. Chem. Soc., *37*, 1393 (1915); *39*, 856–79 (1919).

with cementing on two or even three hydrogen nuclei in the groups $h_2\beta$ or $h_3\beta_2$. These groups do not seem to be present in the radioactive nuclei of the heavy atoms. It is to be noted that these theoretical findings have been confirmed by Rutherford's discovery.

Postulate 17.—The presence of an odd number of negative electrons in a nucleus leads to instability, and a low abundance of the atoms, whenever the nucleus consists of alpha particles and negative electrons alone. This relation is found to hold among the radioactive atoms, whether mu (μ) particles are present or absent ($\mu = h_2\beta_2$).

Composition of the Nuclei of Atoms.

The composition of the nuclei of the atoms of low atomic number is given in Table II., while that for the atoms of high atomic number is presented in Table III.

Table II.

Composition of Light Atoms and Their Nuclei.

Atoms of Even Nuclear Charge.					Atoms of Odd Nuclear Charge.				
Symbol.	Formula of		Non-nuclear Electrons.		Symbol.	Formula of		Non-nuclear Electrons.	
	Atom.	Nucleus.	Inner.	Valence.		Atom.	Nucleus.	Inner.	Valence.
He.....	He	α	e_2	..	[Li.....	HeH_3	$\alpha\nu$	e_2	e
Be.....	He_2H	$\alpha_2(\eta\beta)$	e_2	e_2	B.....	He_2H_3	$\alpha_2\nu$	e_2	e_3
C......	He_3	α_3	e_2	e_4	N.....	He_3H_2	$\alpha_3(\eta_2\beta)$	e_2	e_5
O......	He_4	α_4	e_2	e_6	F.....	He_4H_3	$\alpha_4\nu$	e_2	e_7
Ne.....	He_5	α_5	e_{10}	..	Na....	He_5H_3	$\alpha_5\nu$	e_{10}	e_1
Mg....	He_6	α_6	e_{10}	e_2	Al.....	He_6H_3	$\alpha_6\nu$	e_{10}	e_3
Si.....	He_7	α_7	e_{10}	e_4	P.....	He_7H_3	$\alpha_7\nu$	e_{10}	e_5
S......	He_8	α_8	e_{10}	e_6	*Cl*.....	He_8H_3	$\alpha_8\nu$	e_{10}	e_7
A......	{ He_{10}	$\alpha_{10}\beta_2$	e_{18}	..	K.....	He_9H_3	$\alpha_9\nu$	e_{10}	e_1
Ca.....	{ He_{10}	α_{10}	e_{18}	e_2	Sc.....	$He_{11}H$	$\alpha_{11}\beta\eta_2$	e_{18}	e_3
Ti.....	He_{12}	$\alpha_{12}\beta_2$	e_{18}	e_4	V.....	$He_{12}H_3$	$\alpha_{12}\nu\beta_2$	e_{18}	e_5
Cr.....	He_{13}	$\alpha_{13}\beta_2$	e_{18}	e_6	Mn ...	$He_{13}H_3$	$\alpha_{13}\nu\beta_2$	e_{18}	e_7
Fe.....	He_{14}	$\alpha_{14}\beta_2$	e_{18}	e_8	Co....	$He_{14}H_3$	$\alpha_{14}\nu\beta_2$	e_{18}	e_9

NOTATION.

$\eta = h^+ =$ positive nucleus of hydrogen atom, or the positive electron.

$\alpha = he^{++} = \eta_4\beta_4$.

$\nu = \eta_3\beta_2 = h_3{}^+\beta_2$.

$\beta =$ negative electron in the nucleus, and $e =$ electron in non-nuclear system.

Note.—The symbols in italics represent elements for which it is probable that more than one isotope exists, in which case only the formula for one isotope is given. The bracket incloses ISOMERIC atoms. *Note should be taken of the fact that of the thirteen nuclei of odd charge in only one case is the odd charge due to an odd number of negative electrons, and in twelve cases it is due to an odd number of hydrogen nuclei in the nu (ν) group.* The probable formufae ol the isotopic atoms are chlorine $\alpha_8\nu\mu\epsilon'_{10}\epsilon_7$, silicon $\alpha_7\mu\epsilon_{10}\epsilon_4$, magnesium $\alpha_6\mu\epsilon_{10}\epsilon_2$, and neon $\alpha_6\mu\epsilon_{10}$.

TABLE III.

Composition of Heavy Atoms.

A. Uranium Series in order of Disintegration.

Symbol of Element.	Nuclear Charge and No. of External Electrons.	Symbol of Atom.	Formula of Atom.	Formula of Nucleus.	Non-nuclear Electrons. Inner.	Non-nuclear Electrons. Valence.	Type of Change.	Atomic Wt.
U....	92	U	$He_{59}H_2$	$\alpha_{59}\eta_2\beta_{28}$	e_{86}	e_6	α	238
Th...	90	UX_1	$He_{58}H_2$	$\alpha_{58}\eta_2\beta_{28}$	e_{86}	e_4	β	234
Bv...	91	UX_2	$He_{58}H_2$	$\alpha_{58}\eta_2\beta_{27}$	e_{86}	e_5	β	234
U....	92	U_2	$He_{58}H_2$	$\alpha_{58}\eta_2\beta_{26}$	e_{86}	e_6	α	234
Th...	90	Io	$He_{57}H_2$	$\alpha_{57}\eta_2\beta_{26}$	e_{86}	e_4	α	230
Ra...	88	Ra	$He_{56}H_2$	$\alpha_{56}\eta_2\beta_{26}$	e_{86}	e_2	α	226
Nt...	86	Ra Em	$He_{55}H_2$	$\alpha_{55}\eta_2\beta_{26}$	e_{86}	..	α	222
Po...	84	Ra A	$He_{54}H_2$	$\alpha_{54}\eta_2\beta_{26}$	e_{78}	e_6	α	218
Pb...	82	Ra B	$He_{53}H_2$	$\alpha_{53}\eta_2\beta_{26}$	e_{78}	e_4	β	214
Bi....	83	Ra C	$He_{53}H_2$	$\alpha_{53}\eta_2\beta_{25}$	e_{78}	e_5	β	214
Po...	84	Ra C	$He_{53}H_2$	$\alpha_{53}\eta_2\beta_{24}$	e_{78}	e_6	α	214
Pb...	82	Ra D	$He_{52}H_2$	$\alpha_{52}\eta_2\beta_{24}$	e_{78}	e_4	β	210
Bi....	83	Ra E	$He_{52}H_2$	$\alpha_{52}\eta_2\beta_{23}$	e_{78}	e_5	β	210
Po...	84	Ra F	$He_{52}H_2$	$\alpha_{52}\eta_2\beta_{22}$	e_{78}	e_6	α	210
Pb...	82 (end)	Ra G	$He_{51}H_2$	$\alpha_{51}\eta_2\beta_{22}$	e_{78}	e_4	..	206

Secondary Branch of Uranium Series.

Pb...	82	Ra B	$He_{53}H_2$	$\alpha_{53}\eta_2\beta_{26}$	e_{78}	e_4	β	214
Bi	83	Ra C	$He_{53}H_2$	$\alpha_{53}\eta_2\beta_{25}$	e_{78}	e_5	α	214
Tl....	81	Ra C_2	$He_{52}H_2$	$\alpha_{52}\eta_2\beta_{25}$	e_{78}	e_3	β	210
Pb...	82	End?	$He_{52}H_2$	$\alpha_{52}\eta_2\beta_{24}$	e_{78}	e_4	..	210

The brackets inclose isomeric atoms.

The formulæ for the nuclei of the atoms of the uranium series may be simplified by putting μ in place of $\eta_2\beta_2$, when the formula of the nucleus of uranium becomes $\alpha_{59}\mu\beta_{26}$ while that of thorium is $\alpha_{58}\beta_{26}$.

B. Thorium Series in Order of Disintegration.

Symbol of Element.	Nuclear Charge and No. External Electrons.	Symbol of Atom.	Formula of Atom.	Formula of Nucleus.	Non-nuclear Electrons. Inner.	Non-nuclear Electrons. Valence.	Type of Change.	Atomic Wt.
Th...	90	Th	He_{58}	$\alpha_{58}\beta_{26}$	e_{86}'	e_4	α	232
Ra...	88	Ms Th_1	He_{57}	$\alpha_{57}\beta_{26}$	e_{86}'	e_2	β	228
Ac...	89	Ms Th_2	He_{57}	$\alpha_{57}\beta_{25}$	e_{86}'	e_3	β	228
Th...	90	Ra Th	He_{57}	$\alpha_{57}\beta_{24}$	e_{86}'	e_4	α	228
Ra...	88	Th X	He_{56}	$\alpha_{56}\beta_{24}$	e_{86}'	e_2	α	224
Nt...	86	Th Em	He_{55}	$\alpha_{55}\beta_{24}$	e_{86}'	..	α	220
Po...	84	Th A	He_{54}	$\alpha_{54}\beta_{24}$	e_{78}'	e_6	α	216
Pb...	82	Th B	He_{53}	$\alpha_{53}\beta_{24}$	e_{78}'	e_4	β	212
Bi....	83	Th C	He_{53}	$\alpha_{53}\beta_{23}$	e_{78}'	e_5	β	212
Po...	84	Th C'	He_{53}	$\alpha_{53}\beta_{22}$	e_{78}'	e_6	α	212
Pb...	82	Pb Th	He_{52}	$\alpha_{52}\beta_{22}$	e_{78}'	e_4	..	208

Secondary Branch of Thorium Series.

Pb...	82	Th B	{He_{53}	$\alpha_{53}\beta_{24}$	e_{78}'	e_4	β	212
Bi....	83	Th C	He_{53}}	$\alpha_{53}\beta_{23}$	e_{78}'	e_5	α	212
Tl....	81	Th D	{He_{52}	$\alpha_{52}\beta_{23}$	e_{78}'	e_3	β	208
Pb...	82	End?	He_{52}}	$\alpha_{52}\beta_{22}$	e_{78}'	e_4	..	208

The brackets inclose isomeric atoms.

The above changes may easily be written in the form of equations, such as:

$$\underset{\text{Th}}{\alpha_{58}\beta_{26}e_{86}'e_4} \rightarrow \alpha^{++} + 2e^- + \underset{\text{Ms Th}_1}{\alpha_{57}\beta_{26}e_{86}'e_2},$$

$$\underset{\text{Ms Th}_1}{\alpha_{57}\beta_{26}e_{86}'e_2} \rightarrow \underset{\text{Ms Th}_2}{\alpha_{57}\beta_{25}e_{86}'e_3},$$

$$\underset{\text{Ms Th}_2}{\alpha_{57}\beta_{25}e_{86}'e_3} \rightarrow \underset{\text{Ra Th}}{\alpha_{57}\beta_{24}e_{86}'e_4}.$$

The above beta changes are given in abbreviated form. The complete reaction is written:

$$\underset{\text{Ms Th}_2}{\alpha_{57}\beta_{25}e_{86}'e_3} + e^- \rightarrow \alpha_{57}\beta_{24}e_{86}'e_4 + \beta^-.$$

Thus in an alpha change the whole atom loses an alpha particle from the nucleus, and two electrons from the valence layer. In a beta change, while the nucleus loses a beta particle, the valence shell picks up an extra electron, so the *final effect*, so far as the formula is concerned, is the same as if a beta particle had moved from the nucleus into the valence layer. The whole change is similar to a molecular rearrangement, and might be classed as an atomic rearrangement, but with the difference that the electron *gained is not the same individual as that which is lost*. A few equations for members of the uranium series are written below as models from which all of the reactions may be written out.

$$\underset{\text{Ra}}{\alpha_{56}\eta_2\beta_{26}e_{86}'e_2} \rightarrow \alpha^{++} + 2e^- + \underset{\text{Ra Em}}{\alpha_{55}\eta_2\beta_{26}e_{86}'},$$

$$\underset{\text{Ra Em}}{\alpha_{55}\eta_2\beta_{26}e_{86}'} \rightarrow \alpha^{++} + 2e^- + \underset{\text{Ra A}}{\alpha_{55}\eta_2\beta_{26}e_{78}'e_6},$$

$$\underset{\text{Ra A}}{\alpha_{54}\eta_2\beta_{26}e_{78}'e_6} \rightarrow \alpha^{++} + 2e^- + \underset{\text{Ra B}}{\alpha_{53}\eta_2\beta_{26}e_{78}'e_4},$$

$$\underset{\text{Ra B}}{\alpha_{53}\eta_2\beta_{26}e_{78}'e_4} \rightarrow \underset{\text{Ra C}}{\alpha_{53}\eta_2\beta_{25}e_{78}'e_5},$$

$$\underset{\text{Ra C}}{\alpha_{53}\eta_2\beta_{25}e_{78}'e_5} \rightarrow \underset{\text{Ra}}{\alpha_{53}\eta_2\beta_{24}e_{78}'e_6}.$$

The complete beta change may be written:

$$\alpha_{53}\eta_2\beta_{25}e_{78}'e_5 + e^- \rightarrow \alpha_{53}\eta_2\beta_{24}e_{78}'e_6 + \beta^-.$$

Figure 3 gives a diagram representing all of the radioactive disintegrations, with the formula of the nuclei of the uranium-radium and the thorium series. It may be noticed that *corresponding members of the two disintegration series have formulæ which are very similar*, indeed they are identical with the exception that each member of the uranium-radium series contains one μ particle which is absent from the thorium member.[1]

TABLE IV.

Formulæ of Corresponding Atoms in the Disintegration Series.

Thorium Series.		Radium Series.	
(Ra Th)	$\alpha_{57}\beta_{24}e_{86}\ e_4$	$\alpha_{57}\mu\beta_{24}e_{86}\ e_4$	(Io)
(ThX)	$\alpha_{56}\beta_{24}e_{86}\ e_2$	$\alpha_{56}\mu\beta_{24}e_{86}\ e_2$	(Ra)
(Th Em)	$\alpha_{55}\beta_{24}e_{86}$	$\alpha_{55}\mu\beta_{24}e_{86}$	(Ra Em)
(Th A)	$\alpha_{54}\beta_{24}e_{78}'e_6$	$\alpha_{54}\mu\beta_{24}e_{78}'e_6$	(Ra A)
(Th B)	$\alpha_{53}\beta_{24}e_{78}'e_4$	$\alpha_{53}\mu\beta_{24}e_{78}'e_4$	(Ra B)
(Th C)	$\alpha_{53}\beta_{23}e_{78}'e_5$	$\alpha_{53}\mu\beta_{23}e_{78}'e_5$	(Ra C)
(Th C′)	$\alpha_{53}\beta_{22}e_{78}'e_6$	$\alpha_{53}\mu\beta_{22}e_{78}'e_6$	(Ra C′)
(PbTh)	$\alpha_{52}\beta_{22}e_{78}'e_4$	$\alpha_{53}\mu\beta_{22}e_{78}'e_4$	(Ra D)
(Th D)	$\alpha_{52}\beta_{23}e_{78}'e_3$	$\alpha_{52}\mu\beta_{23}e_{78}'e_3$	(Ra C_2)
End_1	$\alpha_{52}\beta_{22}e_{78}'e_4$	$\alpha_{52}\mu\beta_{22}e_{78}'e_4$	End_1

If the actinium disintegration series is what it is now supposed to be its corresponding members have the same formulæ as those of the radium series minus one alpha particle and two beta particles, though it is still possible that the corresponding atoms in the two series have identical formulæ.

It is also well known that when four or five alpha particles are lost in succession in any of the three series, each successive disintegration becomes more violent, and the same is true of successive beta disintegrations. This suggests that the alpha particles are grouped in aggregates of four or five or more alpha particles together with binding electrons and that the smaller the aggregate becomes the more unstable it gets for changes of the above type.

The great similarity in the three disintegration series suggests that while there are many possible compositions for the nuclei of isotopes there are usually only a few compositions and probably only a few structures which are of the requisite stability. The likeness in the three disintegration series is extremely remarkable.

[1] If this μ particle exists alone it forms the atoms of an element of *zero* atomic number.

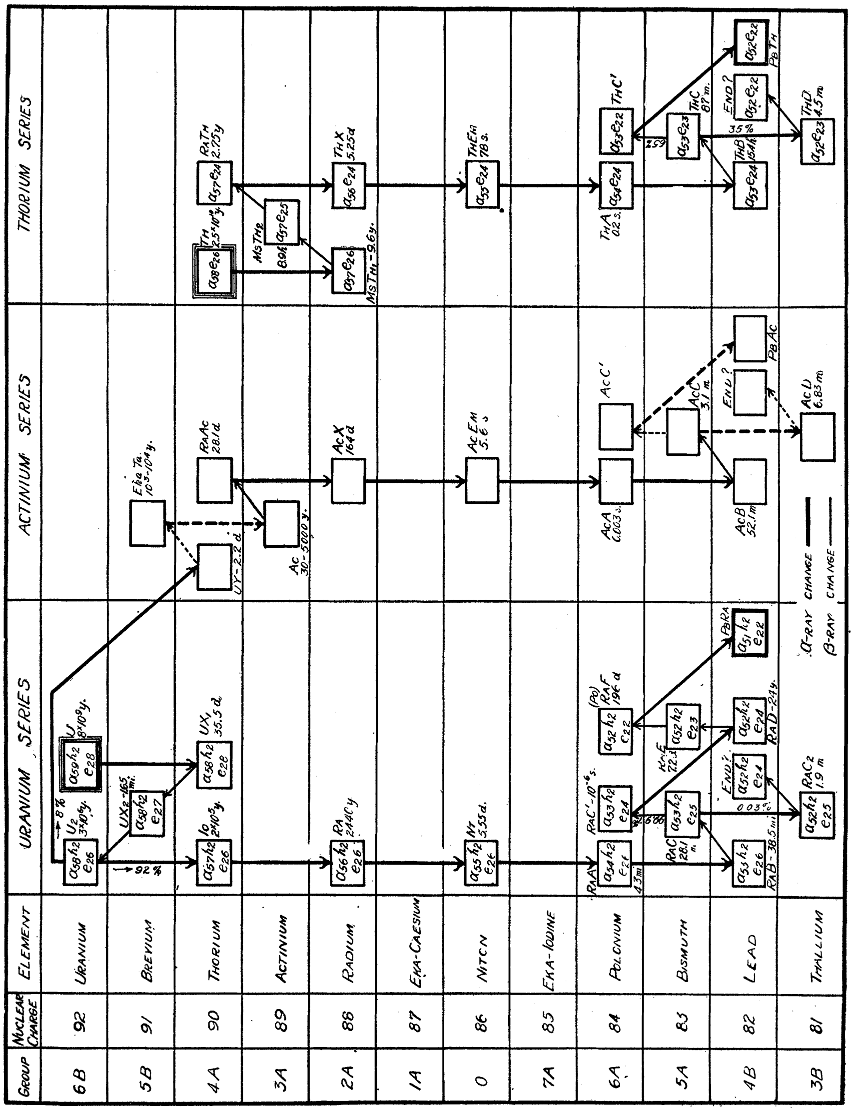

Fig. 3.

Composition of the nuclei of the radio-atoms, with periods of average life. The helium nucleus is represented by α, the hydrogen nucleus by h, and the negative electron by e.

Diagram of the three disintegration series representing the formulæ of the nuclei of atoms. In this diagram the hydrogen nucleus or nu particle, is represented by h, and the negative electron by e. The actinium series may originate in either U_1 as shown in the figure or in U.

Association of the Nuclear Negative Electrons in Pairs.

Tables II. and III. give an excellent illustration of Postulate 5, that the nuclear negative electrons occur in general in pairs, while there is no such pairing of the alpha particles. Thus among the 26 light atoms there are only 2 (or possibly only one) whose nuclei contain an odd number of electrons, while 24 or 25 contain an even number. Also, among the 30 atomic species of the uranium and thorium series there are only seven that give formulæ which indicate an odd number of negative electrons in the nucleus. When it is considered that the frequently occurring alpha ($\alpha = h_4e_2$) and nu ($\nu = h_3e_2$) particles, and the μ group of the uranium series which has the formula h_2e_2, all contain two electrons each, the indication of this pairing is very strong. The actinium series in all probability is similar to the ordinary uranium series in this respect.

It will be noticed that the alpha, nu, and mu particles are all held together by two negative electrons each. These may be called *binding* electrons to distinguish them from the *cementing* electrons which hold on the excess alpha particles of the nuclei of the heavier atoms.

Isomeric Atoms, or Atoms of the Same Intra-atomic Formula and Atomic Weight.

Table 3*A* indicates that there are 3 isomeric species of atoms of the formula $He_{58}H_2$, also 3 of the formula $He_{53}H_2$, and 5 with the formula $He_{52}H_2$. In the thorium series there are 3 isomers for each of the formulas He_{57}, He_{53}, and He_{52}. Similar isomers exist in the actinium series. Isomers may be isotopes, as Ra D and the probable end of the secondary uranium series, but usually they are not isotopic. When three isomers occur in succession in a radioactive series, the two latter isomers are formed by two successive beta disintegrations of the nuclei of the respective atoms. In a beta change an electron is lost from the nucleus, and another electron is picked up by the valence shell of electrons by the time the atom has become neutral, so the formula of the complete atom does not change. The nuclei of isomeric atoms are not themselves isomeric unless the atoms themselves are isotopic, but all nuclei of isotopic atoms are not isomeric; so isotopic atoms may be classified as those with isomeric, and those with non-isomeric nuclei. *Of the ordinary atoms calcium and argon are isomeric, the difference in structure being due to the inclusion of two cementing electrons in the argon nucleus, which in calcium are present in the planetary system of non-nuclear electrons.*

Evidence in Favor of Formulæ Proposed for the Heavy Atoms.

While it has been known for some years that the thorium atom loses 6 alpha particles or nuclei of helium atoms during its disintegration, and finally changes into one form of lead, definite formulæ for the atoms of this series have not been assumed previous to this time, for the evidence in regard to the composition of the rest of the nucleus, that contained in this special form of the lead atom, did not seem to be sufficiently complete. Such evidence is to be found in the atomic weights together with the new periodic system discovered by the writer. The detailed study of the atomic weight relations presented in the former papers of this series cannot be summarized here, and should be consulted in the original, but some additional relations will be discussed.

The best determination of the atomic weight of thorium as made by Honigschmid, gave 232.16. This is only 0.16 of a unit more than exactly 58 times the atomic weight given in the atomic weight tables for helium, or 58 times 4.00. The atomic weight of helium is not known to a sufficient degree of accuracy to cause this 0.16 of a unit to receive any consideration, but the atomic weight of oxygen is 4 times 4.000, that of carbon is 3 times 4.001, and that of sulphur is 8 times 4.008. What is more in point is that if we average the atomic weights of the nine elements from 19, potassium, to 27, cobalt, the average deviation of the atomic weight from a whole number is only − 0.012 units. The average has been taken, since it is probable, when the difficulty of obtaining pure samples is taken into account, that this average is more significant than any single determination of the atomic weight. If iron had exactly this average deviation, its atomic weight would be 55.988, or 14 times 3.999, which is exceedingly close to 4.000, while the determined atomic weight of iron is 14 times 3.988. This indicates that when from ten to fourteen helium nuclei form an aggregate, together with one μ particle in 4 of the 9 cases, the atomic weight of the complex atom is almost exactly a whole number times 4.000, or possibly *very* slightly less than this, when alpha particles are present alone, or 3 plus a whole number times 4.00 when nu particles are also present.

Let us consider that the atomic weight given for thorium, 232.12 is exact; this is 58 times 4.002, which is only 0.05 per cent. higher than 4.0000. When the thorium nucleus disintegrates to form its end product in lead it gives off 6 alpha particles, and 4 electrons, so the loss of atomic weight may be assumed to be 6 times 4.00, or 24.00. However, during this disintegration heat to the amount of about 12.9×10^{11} calories are liberated, and when calculated into terms of mass using the relativity method of Einstein, this gives 0.06 grams or 0.06 units of atomic weight, so that 0.06 of the excess 0.12 units of atomic weight have already been accounted for by this short disintegration period. The atomic weight of this isotope of lead is therefore 208.06, which is 52 times 4.0012. When it is considered that these calculations do not involve the atomic weight of helium itself, but its weight in the complex atoms which it forms, it is seen that the agreement is closer than could be expected from numbers determined by experimental work on atomic weights. It might be better to calculate on the basis of the atomic weights of only those atoms which seem to be aggregates of helium alone. If this is done, using the heavier atoms just preceding those which appear to occur in isotopic forms, that is using calcium, scandium, titanium, chromium and iron, the average atomic weight for combined helium is found to be 4.0032, which when multiplied by 52 gives 208.16 as the atomic weight of thorium-lead, in place of the value 208.06 which comes from the experimentally determined value of the atomic weight of thorium, together with the value of the packing effect as calculated from the energy change, as discussed above. On comparing experimental values alone it is found that 58 times 4.0018 is 232.105, while the experimental value for thorium is 232.12, or a difference of only six thousandths of one per cent. It therefore seems almost certain that the atoms of the thorium series are intra-atomic compounds of helium alone, that is their nuclei consist of alpha particles and negative electrons only. It is of interest to note that the highest experimental atomic weight for this thorio-lead as determined by Hönigschmid, is 207.90 ± 0.013, or 52×3.998, but it is almost certain that this atomic weight is somewhat too low, on account of the inclusion of another isotope.

Fully as good evidence can be presented in favor of the formulæ given for the atoms of the uranium disintegration series, for almost all of the atomic weights in the latter series can be obtained from those of the former by adding almost exactly 2.00, or 2.00 plus the atomic weight of helium (4.00). Thus the difference between the atomic weight of uranium and that of thorium is $4.00 + 2.055$, and while a part of the difference of 0.055 units may be accounted for by differences in the packing effects in the two nuclei, the whole of the deviation is small enough to be easily explained by the necessary errors in the atomic weight determinations. In the uranium-radium series two other atomic weights have been determined by accurate methods. Hönigschmid found the atomic weight of radium to be 225.97, which is extremely close to 226.00, while for uranium he found 238.175. After making allowance for the packing effect of 0.013 units, there is still a discrepancy of 0.19 units to be explained either by experimental error or by the inclusion of an unknown isotope in one or both. For radio-lead (radium G) his lowest determinations gave 206.06, while the similar determinations of Richards and Wadsworth gave 206.08. Since in even these last determinations ordinary lead was probably an impurity present in small amounts, the atomic weights as determined would undoubtedly have been very slightly smaller if the substance had been entirely pure.

[1] J. Am. Chem. Soc., *38*, 2613 (1916).

The accurately determined atomic weights in the radioactive series are summarized in Table IV.

TABLE IV.

Atomic Weights of Radioactive Atoms.

Atom.	Atomic Weight.	Deviation from a Whole Number.	Atomic Weight.
Uramium	238.175	+0.175	59×4.0030+2.00
Thorium	232.12	+0.12	58×4.0023
Radium	225.97	−0.03	56×3.9983+2.00
Radio-lead (Ra G)	206.07	+0.07	51×4.0014+2.00

Thus the heavy atoms as well as the light atoms have atomic weights which lie very close to whole numbers. The value obtained by Heuse for the atomic weight of helium is 4.002, and that of Taylor as recalculated by Guye is 3.998, while column 4 of the above table shows that the values of the atomic weight of intra-atomically combined helium as calculated on the basis of the hydrogen-helium hypothesis are: 4.003, 4.002, 4.001, and 3.998. The atomic weights of carbon and oxygen are 12.002 (according to Guye) and 16.00, which give 4.0007 and 4.0000 for helium, so the average packing effect when helium nuclei unite to form a complex nucleus is extremely small, while the same effect in the formation of helium from hydrogen is very large, amounting to 0.77 per cent., so as has already been stated the helium nucleus is extremely more stable than the more complex nuclei. Compared with the great difficulty of breaking up the helium nucleus it should be easy to disintegrate the more complex nuclei into helium, or into helium and hydrogen or an isotope of hydrogen in the case of the atoms of odd number. In the breaking up of such complex nuclei the only apparent difficulty is to get the energy into the small space occupied by the nucleus.

That the alpha and beta particles emitted in a radioactive change are shot out from the nucleus, has been indicated by Rutherford and Bohr. Recently Hackh in this REVIEW has given an interpretation of the accompanying changes which does not agree with that of the writer. Alpha particles are always shot out at a high speed, so the nucleus suffers a high speed recoil. Thus if the speed of the alpha particle is 20,000 miles per second, that of the nucleus would be nearly 400 miles per second. The nucleus travels at such a high rate of speed, though usually only for a short distance, that it undoubtedly shoots away from a part of its planetary electrons though the most recent work on the subjects seems to indicate that it retains just enough electrons to preserve its electrical neutrality. The loss of two positive charges from the nucleus reduces the nuclear charge by 2, so that the atom which is formed contains 2 less planetary electrons, which means 2 less valence electrons, so the valence is reduced by 2. On the other hand, when a beta particle is shot out by the nucleus, the loss of one negative charge increases the positive charge of the nucleus by one, so that the atom to become electrically neutral picks up a negative planetary electron which goes into its valence shell, thereby increasing the positive valence by one. For a discussion of possible arrangements of the planetary electron papers, by Thomson,[1] Bohr,[2] Kossel,[3] Parson,[4] Lewis,[5] and Langmuir,[6] should be consulted. The writer has long been of the opinion that the facts of organic chemistry indicate a three-dimensional, rather than a plane arrangement of the planetary electrons.

1. Phil. Mag., 27, 757 (1914); 476, 857.
2. Ibid., *26*, 1, (1913); *29*, 332 (1915).
3. Ann. Physik, 49, 229 (1916).
4. Smithsonian Publications, 2371, Washington, (1915).
5. J. Am. Chem. Soc., *38*, 762 (1916).
6. Ibid., *41*, 868–934, 1543–9 (1919).
7. Ibid., *38*, pages 179 and 204 (1916); *39*, 856 (1916).

For a more complete set of references see papers by Harkins and Wilson, ibid., 37, 1367–1421, especially 1420–21.

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