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

THE EVOLUTION OF THE ELEMENTS AND THE STABILITY OF COMPLEX ATOMS.

I. A NEW PERIODIC SYSTEM WHICH SHOWS A RELATION BETWEEN THE ABUNDANCE OF THE ELEMENTS AND THE STRUCTURE OF THE NUCLEI OF ATOMS.

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The Hydrogen-Helium Structure of Complex Atoms.

It has been shown in previous papers[1] that the elements are very probably intra-atomic compounds of hydrogen. The hydrogen first forms helium, and this becomes a secondary unit of fundamental importance in the formation of all of the elements with atomic weights higher than its own.

It is the purpose of this paper to present a periodic system of the elements which relates their abundance to the structure of the nuclei of their atoms. This system is called *new* to distinguish it from the ordinary periodic system of Mendeléeff, to which it bears no relation. *It is important, too, that this is the first periodic relationship of the elements to be discovered which is independent of the ordinary periodic system.*

While the periodic variation of the abundance of the elements as here presented might have been discovered empirically, the fact is that the relations found were first predicted from the standpoint of theory, and were afterward found to be true. It therefore seems important to trace, at least in part, the reasoning by which this new law was discovered, even although its validity in no way depends upon the truth of the hypotheses which were used. However, the bearing of these new facts upon the important problem of the evolution of the elements, can best be understood if the subject is approached from a theoretical standpoint.

In the fifth paper of this series evidence has been presented for the theory that the variation in the chemical, and in such physical properties of the elements as cohesion, atomic volume, compressibility, coefficient of expansion, melting point, etc., depends first of all upon the arrangement in *space* of the negative electrons in the atom external to the nucleus, and also upon the number of such electrons. The number of these electrons presumably depends upon the nuclear charge. The structure of the nucleus determines what is called the stability of the atom, since it is not considered that the atom breaks up unless the nucleus disintegrates. For example, when negative electrons are given off under the influence of

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[1] THIS JOURNAL, 37, 1367–1421 (1915); 38, 186–214 (1916); *Phil. Mag.*, 30, 723–34 (1915); *Proc. Nat. Acad. Sci.*, 1, 276 (1915); 2, 216–24 (1916); *Z. anorg. Chem.*, April and May, 1916.

light, or from other similar causes, the atom is said not to decompose, but only to become electrically charged.

Now, the earlier papers have shown that the 91 elements other than hydrogen, of our ordinary system, fall into two series. At least among the elements of lower atomic weight, the atoms which have *even atomic numbers* are in general built up from helium atoms, and therefore may be said to have the general formula $n\mathrm{He}'$, where the prime is added to indicate that these elements are intra-atomic, not chemical, compounds. The odd-numbered elements, beginning with lithium, seem in general to have the formula $n\mathrm{He}' + \mathrm{H}_3'$. Thus these elements fall into two series which may be distinguished as *even* or *odd*.[1]

The structure for the atoms is given in Table I. It is not meant to imply that in every *minor* detail the formulas given are exact, but so considerable is the evidence which has been found in favor of the general form of this system, that there seems to be little doubt of its validity from a general standpoint.

In this table the relations have been expressed in the form usually used for the Mendeléeff periodic table, though it may be easily seen that the only periodicity here involved is that between even and odd atomic numbers, that is, a variation in periods of two elements each, which is entirely independent of the periodicities found by Mendeléeff, since in his system no period contains less than eight elements.

If the assumption, now quite common in papers on atomic theory, that the nuclear charge is equal to the atomic number, is made, and if the composition of the nucleus only is represented, then Table I becomes converted into Table II. While, on account of this assumption, the latter table is on a more hypothetical basis than the former, it illustrates a probable difference between the nuclei of the atoms of even and of odd atomic numbers, and seems to indicate a much more complicated structure in the case of the odd numbered atoms. If η is taken to represent the positive nucleus of the hydrogen atom; α, the alpha particle or the nucleus of the helium atom; β, the negative electron; and ν, the positive nuclei of three hydrogen atoms ($\nu = 3\eta$), then it will be seen that in general the increment between an atom of even atomic number and the corresponding odd-numbered atom seems to be $\nu + 2\beta$. The external electrons show no similar relationship.

Now, if the variations in the chemical and the ordinary physical properties of the cohesional type (properties of aggregation) are dependent upon the arrangement and number of the electrons external to the nucleus,

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[1] Rydberg, in a remarkable paper on atomic weight relations, published in 1897, showed that the elements of even valence had atomic weights equal to 2 M, and those of odd valence equal to 2 M + 1 where the M which he used was the same as the atomic number of the element as now used. (See *Z. anorg. Chem.*, **14**, 66–102 (1897).)

TABLE I.—THE HYDROGEN-HELIUM STRUCTURE OF THE ATOMS.

H = 1.0078.

	Even. 0.	Odd. 1.	Even. 2.	Odd. 3.	Even. 4.	Odd. 5.	Even. 6.	Odd. 7.	8.	
At. no...	2	3	4	5	6	7	8	9		
	He	Li	Be	B	C	N	O	F		
Ser. 2...	He	He + H_3	2He + H	2He + H	3He	3He + H_2	4He	4He + H_3		
Theor..	4.00	7.00	9.0	11.00	12.00	14.00	16.00	19.00		
Det....	4.00	6.94	9.1	11.00	12.00	14.01	16.00	19.00		
At. no..	10	11	12	13	14	15	16	17		
	Ne	Na	Mg	Al	Si	P	S	Cl		
Ser. 3...	5He	5He + H_3	6He	6He + H_3	7He	7He + H_3	8He	8He + H_3		
Theor..	20.0	23.0	24.00	27.0	28.0	31.00	32.00	35.00		
Det....	20.0	23.0	24.32	27.1	28.3	31.02	32.07	35.46	Even	Odd
At. no...	18	19	20	21	22	23	24	25	26	27
	A	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co
Ser. 4...	10He	9He + H_3	10He	11He	12He	12He + H_3	13He	13He + H_3	14He	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.

which seems probable if the nucleus is extremely minute, as the results obtained by Rutherford and his students seem to indicate, then the differences between the odd- and even-numbered atoms with respect to nuclear structure would not be expected to be apparent in these properties. That this expectation is confirmed is easily seen, since neither with respect to chemical nor physical properties is there any difference apparent which shows a variation in periods of two elements from even to odd, or odd to even.

TABLE II—HYPOTHETICAL COMPOSITION OF THE NUCLEI OF ATOMS.

Even atomic numbers.				Odd atomic numbers.			
At. no.	Atm.	Nucleus.	External electrons.	At. no.	Atm.	Nucleus.	External electrons.
2.	He	α	2β	3.	Li	$\alpha + (\nu + 2\beta)$	3β
4.	Be	$2\alpha + \eta + \beta$	4β	5.	B	$2\alpha + (\nu + 2\beta)$	5β
6.	C	3α	6β	7.	N	$3\alpha + (\nu + 2\beta)$	7β
8.	O	4α	8β	9.	F	$4\alpha + (\nu + 2\beta)$	9β
10.	Ne	5α	10β	11.	Na	$5\alpha + (\nu + 2\beta)$	11β
12.	Mg	6α	12β	13.	Al	$6\alpha + (\nu + 2\beta)$	13β
14.	Si	7α	14β	15.	P	$7\alpha + (\nu + 2\beta)$	15β
16.	S	8α	16β	17.	Cl	$8\alpha + (\nu + 2\beta)$	17β
18.	A	$10\alpha + 2\beta$	18β	19.	K	$9\alpha + (\nu + 2\beta)$	19β
20.	Ca	10α	20β	21.	Sc	$11\alpha + \beta$	21β
22.	Ti	$12\alpha + 2\beta$	22β	23.	V	$12\alpha + 2\beta + (\nu + 2\beta)$	23β
24.	Cr	$13\alpha + 2\beta$	24β	25.	Mn	$13\alpha + 2\beta + (\nu + 2\beta)$	25β
26.	Fe	$14\alpha + 2\beta$	26β	27.	Co	$14\alpha + 2\beta + (\nu + 2\beta)$	27β

η = + nucleus of hydrogen atom.
α = alpha particle = $4\eta + 2\beta$.
$\nu = 3\eta$.
β = negative electron.

The Hydrogen-Helium System and the Abundance of the Elements.

It might be expected, however, that the composition of the nucleus should affect its own stability, which from radioactive evidence means the stability of the atom. From this standpoint it might be reasonable to suppose that the atoms of one of the series, the even or the odd, should be more stable than those of the other. Now, unfortunately, there is no known method of testing the stability of the lighter atoms, but it might seem, at least at first thought, that the more stable atoms should be the more abundantly formed, and to a certain extent this is undoubtedly true. If then, at the stage of evolution represented by the solar system, or by the earth, it is found that the even-numbered elements are more abundant than the odd, as seems to be the case, then it might be assumed that the even-numbered elements are on the whole the more stable. However, there is at least one other factor than stability which must be considered in this connection. The formula of the even-numbered elements has been shown to be $n\mathrm{He}'$. Now, since the formula for the odd-numbered elements is $n\mathrm{He}' + \mathbf{H}'_3$, it is evident that, if the supply of H_3

was relatively small at the time of their formation, not so much material would go into this system. This would be true whether the H_3 represents three atoms of hydrogen or one atom of some other element.[1]

In studying the relative abundance of the elements the ideal method would be to sample one or more solar systems at the desired stage of evolution, and to make a quantitative analysis for all of the 92 elements of the ordinary system. Since this is impossible, even in case of the earth, it might be considered that sufficiently good data could be obtained from the earth's crust, or the lithosphere.

However, there are several important factors which cause our knowledge of the quantitative composition of the earth's crust to be of much less value for the solution of our problem than it might seem to possess on first thought. In the first place the quantitative analyses which have been made represent the composition of only the mere skin of the earth, the depth of which does not exceed the ten to twenty miles caused by geologic displacements. The surface of the earth has been markedly influenced both by igneous processes which have resulted in magmatic differentiation, and by weathering, solution, and redeposition. For example, the common idea that sodium is a very abundant element undoubtedly has its origin in the fact that the solubility of its salts has caused their very considerable concentration in the oceans. Again, the fact that the salts of sodium are much more fusible than similar salts of the alkaline earths and most other metals in the rocks, has probably caused it to be segregated by magmatic solution and redeposition. Thus, while in the average igneous rock found on the surface of the earth there seems to be about 2.23% of sodium, it is not improbable that this is a larger percentage than would be found if the whole material of the earth could be taken as a sample for analysis.

If the sun is next considered it is found that although a large amount of its surface is exposed to us for spectroscopic investigation, the spectroscope gives no accurate measure of the quantitative composition, and that its findings are largely influenced by the height in the gaseous envelope of the sun at which the observation is taken.

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[1] With regard to the latter alternative, it is at least remarkable that the H_3 occurs 11 times in the system for the first 27 elements, while H_2 and H each occur only once, and it may also be mentioned that Fabry and Buisson (*Astrophys. J.*, 40, 256 (1914), see Dempster, *Ann. Physik.*, 47, 792 (1915)) have by interference methods determined the atomic weight of nebulium to be 2.7, and this they think indicates that its real atomic weight is 3. Also, Campbell (*Proc. Nat. Acad. Sci.*, 1, 590–5 (1915)) has found that in the nebula N. G. C., Index 418, situated in the southern part of the constellation of Orion, the nebulium spectrum is found farther from the interior than that of helium, while the hydrogen spectrum extends out to a much greater distance still. This, he thinks, indicates that the atomic weight of nebulium lies between the values for hydrogen (1) and helium (4).

The Composition of Meteorites as Related to the Structure of Complex Atoms.

There is, however, material available of which accurate quantitative analyses can be made, and which falls upon the earth's surface from space. The bodies which fall are called meteorites, and no matter what theory of their origin is adopted, it is evident that this material comes from much more varied sources than the rocks on the surface of the earth.[1]

In any event, it seems probable that the meteorites represent more accurately the average composition of material at the stage of evolution corresponding to the earth than does the very limited part of the earth's material to which we have access. At least it might seem proper to assume that the meteorites would not exhibit any special fondness for the even-numbered elements in comparison with the odd, or *vice versa,* any more than the earth or the sun as a whole, at least not unless there is an important difference between these two systems of elements, which is just what it is desired to prove.

A preliminary study of the *most recent analyses* of meteorites of different classes showed that, either for any one class or for the meteorites as a whole, *the even-numbered or helium system elements are very much more abundant than those of the old-numbered or helium-hydrogen system.* For a more detailed study use was made of the older but much more complete and more valua-

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[1] Perhaps the theory of origin of the meteorites most in accord with their characteristics is that they are fragments of larger solid bodies, such as planets or planetesimals. Meteorites are known to vary in magnitude from the size of dust particles up to $36^1/_2$ tons, though it is probable that much larger individuals than this maximum may have fallen. Their density varies from less than two to more than eight and one-half. In chemical composition they are much more closely related than the rocks on the surface of the earth, which seems to indicate that the parent bodies were much less affected by differentiative processes. If meteorites have been formed by the scattering of a very large body or bodies, it is evident that a relatively small portion of the material is derived from what may be called the crust, so that a very small part of the material would have been affected by weathering even if the parent bodies had atmospheres. However, whether this is true or not, evidence of weathering has not thus far been obtained. Meteorites may be classified in the three main divisions, iron, iron-stone and stone meteorites, but much more elaborate classifications are found useful in showing the gradations by which one of these systems passes into the other. The fact that the substance of the iron and the stone meteorites passes gradually from one class into the other, that the nickel-iron and pyrrhotite of the stone is the same as that of the iron meteorites, and that the silicates of the stone meteorites gradually diminish in percentage amount as they grade over into iron meteorites, seems to suggest strongly that these different classes were originally present in some cosmic mass or masses, in which the materials were assorted according to their specific gravity. In such a body the lighter stony material would very probably be nearer the surface, and would therefore cool more quickly, while the nickel-iron would lie nearer the center, and would on this account cool very slowly. The physical properties of the two classes of meteorites seem to indicate that they have been cooled in just such a way.

ble data collected by Farrington,[1] who suggests that the average composition of meteorites may represent the composition of the earth as a whole.

The results obtained by averaging the analyses of 318 iron and 125 stone meteorites, 443 in all, show that the first seven elements in order of abundance are iron, nickel, silicon, magnesium, sulfur, and calcium; and *not only do all of these elements have even atomic numbers, but in addition they make up 98.6% of the material of the meteorites.* Of the remaining elements present to a great enough extent to have an appreciable effect upon the percentage values, 7 are odd and 5 are even, but in all only 1.22% are odd numbered, while 98.78% are even. Of the iron meteorites, 99.22% of the material is made up of even-numbered elements, and of the stone meteorites, 97.59%.

TABLE III.—AVERAGE COMPOSITION OF METEORITES ARRANGED ACCORDING TO THE PERIODIC SYSTEM.

Series.	Group 1. Odd.	Group 2. Even.	Group 3. Odd.	Group 4. Even.	Group 5. Odd.	Group 6. Even.	Group 7. Odd.	Group 8.		
								Even.	Odd.	Even.
2				6C 0.04%		8O 10.10				
3	11Na 0.17%	12Mg 3.80	13Al 0.39	14Si 5.20	15P 0.14	16S 0.49				
4	19K 0.04%	20Ca 0.46		22Ti 0.01		24Cr 0.09	25Mn 0.03	26Fe 72.06	27Co 0.44	28Ni 6.50
	29Cu 0.01%									

Table III gives the average composition of iron and stone meteorites, arranged according to the periodic system. The numbers before the symbols represent the atomic numbers, and the numbers underneath give the percentage of the element. It will be noted that *the even-numbered elements are in every case more abundant than the adjacent odd-numbered elements.* The helium group elements form no chemical compounds, and are all gases, so they could probably not remain in large quantities in meteorites. For this reason, and also because the data are not available, the helium or zero group is omitted from the table. The only criticism which could be made of the system of averaging, which is that of including all accurate analyses, is that it places undue emphasis upon the

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[1] Farrington, *Publications* 120 and 151, Field Columbian Museum, Chicago, "Meteorites," 205 (1915); I, *Geol.*, 9, 623 (1901); Bvisse, *Mem. Soc. Lits. Sci. Arts l'Aveyron*, 7, 168; Meuner, "Cours. de Geol. Comparee;" Suess, "The Face of the Earth," (English translation), Vol. 4, p. 543.

iron as compared with the stone meteorites. However, since the two relations shown in Table I are true for each class of meteorites separately, it is evident that they will be true whatever system of averaging may be chosen.

Similar results to those given in Table III but in this case for the stone meteorites alone are expressed graphically in Fig. 1, where the atomic numbers are given as abscissae, and the percentage abundance of the elements is plotted on the Y axis. This figure shows that there is a very marked periodicity in the abundance of the elements in periods of two elements each. The peaks which represent the even-numbered elements are shown to be extremely high in comparison with the troughs in which the odd-numbered elements lie.

It is interesting to note that where two high peaks for even-numbered elements lie adjacent, between them the abundance of the odd-numbered element also becomes high in comparison with that of the other odd-numbered elements. Thus, by far the most abundant of the odd-numbered elements, aluminium and cobalt, lie in each case between two extremely abundant even-numbered elements.

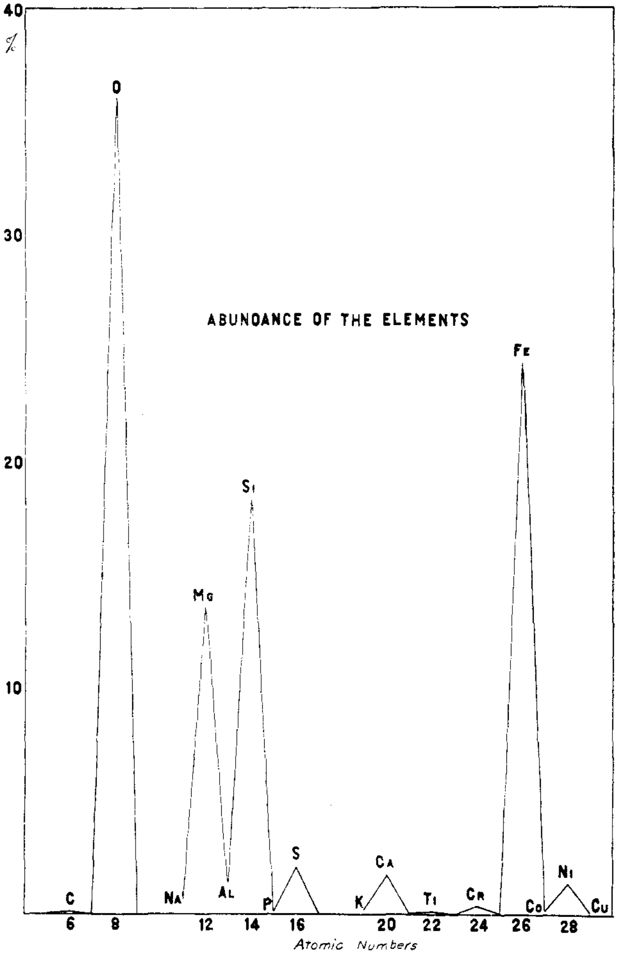

Fig. 1.—The abundance of the elements in the stone meteorites. Every even-numbered element is more abundant than the two adjacent odd-numbered elements.

This would seem to indicate that there is some relationship between the

TABLE IV.—AVERAGE COMPOSITION OF METEORITES, SHOWING THE PREDOMINANCE OF THE EVEN-NUMBERED ELEMENTS, AND OF THE ELEMENTS OF LOW ATOMIC NUMBER.

		Percentage by weight. Stone meteorites.				Weight percentage. 53 stone meteorites.[1]		Atomic percentage. 125 stone meteorites.		Weight percentage.		Atomic percentage.		Atomic percentage. 318 iron meteorites.		Atomic percentage. 350 stone to 10 iron meteorites.[2]	
		125 analyses.		99 analyses.						Average of 318 iron and 125 stone meteorites.							
At. no.	Element.	Even.	Odd.	Even.	Odd.	Even.	Odd.	Even.	Odd.	Even.	Odd.	Even.	Odd.	Even.	Odd.	Even.	Odd.
1.	Hydrogen	...	..	...	..	..	0.084	...	..	...	..	..	...	...	..	...	...
2.		...	..	...	..	..	Trace	...	..	...	..	..	...	...	..	...	...
3.	Lithium	...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	...
4.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	...
5.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	...
6.	Carbon	0.06	..	...	..	0.150	...	0.12	..	0.04	..	0.14	...	0.03	..	0.12	...
7.	Nitrogen	...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	...
8.	Oxygen	36.02	..	35.82	..	36.290	...	54.70	..	10.10	..	25.87	...	...	..	53.16	...
9.	Fluorine	...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	...
10.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	...
11.	Sodium	...	0.59	...	0.70	..	0.645	...	0.62	...	0.17	..	0.30	...	..	...	0.62
12.	Magnesium	13.54	...	13.80	..	13.673	...	13.52	..	3.80	..	6.41	...	...	..	13.15	...
13.	Aluminium	...	1.39	...	1.45	..	1.527	...	1.25	...	0.39	..	0.59	...	..	...	1.21

14.	Silicon	18.41	..	18.18	..	18.154	...	15.79	..	5.20	..	7.53	...	...	..	15.35	...
15.	Phosphorus	...	0.06	...	0.11	..	0.113	...	0.05	...	0.14	..	0.18	...	0.17	..	0.06
16.	Sulfur	1.98	..	1.84	..	1.80	...	1.51	..	0.49	..	0.63	...	0.04	..	1.46	...
17.	Chlorine	...	..	...	..	..	0.080	...	..	...	..	..	...	...	..	..	...
18.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	..	...
19.	Potassium	...	0.17	...	0.27	..	0.174	...	0.11	...	0.04	..	0.04	...	..	..	0.11
20.	Calcium	1.65	..	1.26	..	1.730	...	1.01	..	0.046	..	0.47	...	...	..	0.97	...
21.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	..	...
22.	Titanium	0.01	..	...	..	0.108	...	0.005	..	0.01	..	0.005	...	...	..	0.005	...
23.	Vanadium	...	..	...	..	..	Trace	...	..	...	..	..	...	...	..	..	...
24.	Chromium	0.28	..	0.58*	..	0.321	...	0.13	..	0.09	..	0.07	...	0.01	..	0.13	...
25.	Manganese	...	0.14	...	0.36	..	0.224	...	0.06	...	0.03	..	...	..	..	..	0.06
26.	Iron	24.32	..	24.32	..	23.313	...	10.57	..	72.09	..	52.93	...	90.64	..	12.79	...
27.	Cobalt	...	0.05	...	0.05	..	0.017	...	0.02	...	0.44	..	0.31	...	0.59	..	0.04
28.	Nickel	1.31	..	1.26	..	1.527	...	0.54	..	6.50	..	4.52	...	8.50	..	0.76	...
29.	Copper	...	0.01	...	0.01	..	0.014	...	0.005	...	0.01	..	0.005	...	0.02	0.005	...
	Total	97.59	2.41	97.06	2.94	97.022	2.978	97.89	2.11	98.78	1.22	98.575	1.425	99.22	0.78	97.985	2.105
		100%		100%		100%		100%		100%		100%		100%		100%	

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[1] 40, zirconium, none; 50, tin, none; 56, barium, none; elements 44, ruthenium; 46, palladium; 77, iridium; and 78, platinum, were found in stone meteorites, while 30, zinc; 33, arsenic; 51, antimony; 50, tin; 79, gold; 74, tungsten; and 92, uranium, were not found in the investigations reported by Merrill.

[2] It has been found by Farrington that the known falls of meteorites are in the ratio of 350 stone meteorites to 10 of iron.

even and the odd series, and that the abundance not only follows the periods of two elements but also larger periods or waves, which cannot be said to have regularity in length and do not correspond with any of the divisions found in the ordinary periodic system.

A Comparison of Stone and Iron Meteorites with Respect to Their Composition.

Table IV gives the average composition, in terms of both atomic and weight percentage, of both the iron and the stone meteorites. This table shows in a very marked way that the extreme variation in composition between the iron and the stone meteorites does not affect markedly the predominance of the even-numbered elements. When calculated from the standpoint of the atomic percentages the iron meteorites contain less than 1% of odd-numbered elements, and the stone meteorites less than three per cent.

It is very remarkable that in none of the average analyses presented does the percentage of any odd-numbered element, whether calculated by weight or by atomic proportions, rise higher than 1.53%, which is the highest value given by Merrill for aluminium in any of his averages, while among the even-numbered elements large percentages are common, and range as high as 90.64%.

Composition of the Crust of the Earth.

Since this study of the meteorites has shown that on the average the elements of even atomic number are about seventy times as abundant as those which are odd numbered, it may be well to see just what evidence can be obtained in regard to this point from a study of the composition of the earth's surface. It has already been pointed out that the earth's surface cannot be expected to give such good evidence as the meteorites, on account of its much more local character.

If, in this connection, Clarke's latest average for the composition of the lithosphere is used, it is found that of the five most abundant elements, four have even atomic numbers, while of the first nine, six are even numbered, as follows:

8	Oxygen	47.33	..
14	Silicon	27.74	..
13	Aluminium	....	7.85
26	Iron	4.50	..
20	Calcium	3.47	..
11	Sodium	....	2.46
19	Potassium	....	2.46
12	Magnesium	2.24	..
22	Titanium	0.46	..
		85.74	12.77

The six even-numbered elements will be seen to make up 85.74% of the lithosphere, while the three odd-numbered elements amount to only 12.77%.

If the lithosphere, hydrosphere, and atmosphere are included and all the elements are taken into account, then it is found that the even-num-

TABLE V.—COMPOSITION OF THE CRUST OF THE EARTH, SHOWING THE PREDOMINANCE OF THE ELEMENTS OF EVEN ATOMIC NUMBER AND OF LOW ATOMIC NUMBER (EXCLUDING HYDROGEN).[1]

At. no.	Element.	Lithosphere. Atomic percentage.		Lithosphere, atmosphere and hydrosphere. Weight percentage.		Igneous rocks.			
						Atomic percentage.		Weight percentage.	
		Even.	Odd.	Even.	Odd.	Even.	Odd.	Even.	Odd.
1.	Hydrogen........	..	16.54	..	0.95	..	3.26	..	0.16
2.		..	..	..	..	..	..	..	..
3.	Lithium.........	..	0.01	..	0.004	..	0.01	..	0.004
4.		..	..	..	..	..	..	..	..
5.		..	..	..	..	..	..	..	..
6.	Carbon..........	0.26	..	0.18	..	0.22	..	0.13	..
7.	Nitrogen.........		..	..	0.03	..	..	..	..
8.	Oxygen..........	54.87	..	50.02	..	60.69	..	47.29	..
9.	Fluorine.........	..	0.10	..	0.10	..	0.106	..	0.10
10.		..	..	..	..	..	..	..	..
11.	Sodium..........	..	1.80	..	2.36	..	2.23	..	2.50
12.	Magnesium......	1.50	..	2.08	..	1.93	..	2.29	..
13.	Aluminium.......	..	4.73	..	7.30	..	6.03	..	7.96
14.	Silicon...........	16.00	..	25.80	..	20.32	..	28.02	..
15.	Phosphorus......	..	0.06	..	0.11	..	0.086	..	0.13
16.	Sulfur...........	0.06	..	0.11	..	0.065	..	0.103	..
17.	Chlorine.........	..	0.10	..	0.20	..	0.037	..	0.063
18.		..	..	..	..	..	..	..	..
19.	Potassium.......	..	1.02	..	2.28	..	1.30	..	2.47
20.	Calcium.........	1.41	..	3.22	..	1.78	..	3.47	..
21.		..	..	..	..	..	..	..	..
22.	Titanium........	0.15	..	0.43	..	0.20	..	0.46	..
23.	Vanadium.......	..	0.005	..	0.02	..	0.006	..	0.017
24.	Chromium.......	0.01	..	0.03	..	0.012	..	0.033	..
25.	Manganese.......	..	0.02	..	0.08	..	0.029	..	0.078
26.	Iron.............	1.31	..	4.18	..	1.67	..	4.56	..
27.		..	..	..	..	..	..	..	..
28.	Nickel...........	0.005	..	0.02	..	0.006	..	0.02	..
29.		..	..	..	..	..	..	..	..
38.	Strontium.......	0.004	..	0.02	..	0.006	..	0.033	..
40.	Zirconium.......	0.003	..	0.02	..	0.004	..	0.017	..
56.	Barium..........	0.01	..	0.08	..	0.012	..	0.092	..
Gross total............		75.592	24.405	86.743	13.434	86.906	13.094	86.518	13.482
Total (not including hydrogen)[1].........		75.59	7.86	86.74	12.48	86.91	9.83	86.52	13.32

[1] Hydrogen should not be included in considering the relative abundance of the odd- and even-numbered elements, since it does not belong to the helium system of elements under discussion.

bered elements are present to the extent of 86.74%, while the value for the odd-numbered elements is only 12.49%, or the even-numbered elements are about seven (and if calculated by atomic percentage nearly ten) times the more abundant. In this connection hydrogen is omitted from consideration, since it does not belong to the helium system of elements under discussion. However, even when it is taken into consideration, the percentage of odd-numbered elements amounts only to 13.44. The data are presented in Table V.

Since the surface of the earth has been subjected to far-reaching differentiative processes, it would be valuable if evidence could be obtained in regard to elements which have not been thus affected. While this cannot be done, it might seem that any group of elements, which are very much alike both chemically and in physical properties, would be affected more nearly to the same extent than those which differ widely. The elements most nearly alike are the rare earths, so the writer first made an estimate of the relative abundance of the members of the rare earth group, and then obtained estimates from two celebrated workers in this special field. The three independent estimates agreed exactly for all of the rare earths included in Table VI, which also contains a comparison of the two elements 55 and 56, occurring just before the rare earths in the series of atomic numbers.

In the table the letter *c* indicates common in comparison with the other elements in the table, and *r* indicates rare; *cc* represents very common, etc. The comparison is only a rough one, but it is sufficiently accurate for the purpose, for it indicates that in every case the even-numbered element is more abundant than the adjacent odd-numbered element.

TABLE VI.

Atomic number.	Abundance.	Element.	Atomic number.	Abundance.	Element.
55	*c*	Caesium	63	*rr*	Europium
56	*ccc*	Barium	64	*r*	Gadolinium
57	*c*	Lanthanum	65	*rrr*	Terbium
58	*cc*	Cerium	..	..	....
59	*r*	Praseodymium	..	..	....
60	*c*	Neodymium	..	..	....
61	*rrr*	Unknown	..	..	....
62	*c*	Samarium	..	..	....

If attention is now turned to the whole system of ninety-one elements other than hydrogen it is found that all of the five *unknown* elements, eka-caesium, eka-manganese 1, eka-manganese 2 (dwi-manganese), eka-iodine, and eka-neodymium, have *odd* atomic numbers.[1]

Among the radioactive elements it will be seen too that if the most stable isotope of each element is considered, then the odd-numbered ele-

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[1] In this connection it may be stated that there is some doubt as to whether thulium 2 has been discovered.

ment has in each case a shorter period than the adjacent even-numbered elements, or else is entirely unknown (Table VII).

TABLE VII.

Atomic number.	Element.	One-half period of most stable isotope.	
		Even.	Odd.
92	Uranium	5 billion years	
91	Uranium X_2		1.15 min.
90	Thorium	18 billion years	
89	Actinium		Period unknown, but almost certainly less than radium
88	Radium	1730 years	
87			Element undiscovered
86	Niton	3.85 days	
85			Element undiscovered
84	Polonium	136 days	

The results already presented may be summarized by the statement that *in the evolution of the elements much more material has gone into the even-numbered elements than into those which are odd*, either because the odd-numbered elements are less stable, or because some constituent essential to their formation was not sufficiently abundant, or both.

The Abundant Elements Are Those of Low Atomic Weight with an Atomic Number Less than 29.

It is easy to see that most of the material has been used up in the formation of the elements of low atomic number. Table II shows that in the meteorites the most abundant elements are oxygen in Series 2, the elements of Series 3 except neon, and the members of the first eighth group triad (iron, cobalt, nickel). Clark[1] has found that just these same elements are the most abundant in the lithosphere, although in the lithosphere potassium and calcium in Series 4 are also moderately abundant. If the lithosphere were considered alone it might be, and usually has been considered, that the abundance of these elements is due to changes which have taken place in the lithosphere, or to the rising to the surface of the lighter elements, but this idea is shown to be incorrect when the meteorites are found to show the same relations.[2]

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[1] "The Data of Geochemistry," *Bulletins* 491 (1911) and 616 (1915), Department of the Interior.

[2] The density of the earth's surface rock averages between 2.70 and 2.75, the mean density of the earth is 5.516, and the density of its center has been estimated by Lunn ("Tidal and Other Problems," pp. 201–18, Carnegie Institution (1909)), as 9.6 on the basis of Roche's law of density, and on the supposition that the chemical composition of the earth is uniform. Stone meteorites vary in density from 2.5 to 5, and iron meteorites from about 6 to more than 8, with an average density of 7.8. According to Lunn (*Ibid.*), the pressure at the center of the earth is 2,800,000 atmospheres, and a possible central temperature is 16,610° when both are calculated on the basis of Roche's law, $\rho = \rho_0 (1 - cx^2)$. It seems probable that this law is much more in accord with the behavior of material than the simple Laplacian form usually used. Some writers have

If an artificial line of division is made just after the first eighth group in the periodic model so as to classify the first 29 elements as of low atomic number and atomic weight, and the remaining 63 elements as of high atomic weight, then the following table, based upon data from analyses listed by Farrington and Clarke, may be presented to emphasize the importance of the former class.

TABLE VIII.—PROPORTION IN VARIOUS MATERIALS OF THE ELEMENTS OF LOW ATOMIC NUMBERS.

Material.	Percentage of elements with atomic numbers. 1–29.	30–92.
Meteorites as a whole	99.99	0.01
Stone meteorites	99.98	0.02
Iron meteorites	100.00	0.0
Igneous rocks	99.85	0.15
Shale	99.95	0.05
Sandstone	99.95	0.05
Lithosphere	99.85	0.15

It may be said that, *so far as the abundance of the elements goes, the system seems to play out at the end of the first eighth group in the ordinary periodic system.* It may be of interest to note here, what has been pointed out in former papers, that it is just at this point in the system that the atomic weights cease any longer to be very close to whole numbers, as they are for the lighter-weight elements. Also just at this point the general formulas given for the helium-hydrogen structure of the elements cease to hold well. *These facts do not mean, however, that the system fails beyond the iron group of elements; for it is just among the heaviest elements that it is experimentally verified* by the actual decomposition of the elements into helium.

Although the abundant elements have thus been found to be those of atomic number less than 30, beryllium and lithium are known to be comparatively rare, so that with the exception of the fundamental elements, hydrogen and helium, practically all of those which are abundant are included among the even-numbered elements from 6 to 28.

The Abundance of the Elements Is Related to the Atomic Number and Not to the Ordinary Periodic System.

It has been stated that there seems to be no real connection between

argued from similar data that the center of the earth is mostly iron. However, the extremely long range of extrapolation above the experimental values in both temperature and pressure, makes it seem impossible to get results in this connection which have the least value, however desirable it would be for such a problem as the one presented here if such a deduction could be properly made. Perhaps, then, the most that can be said is that in the three classes of material, the lithosphere, the stone meteorites, and the iron meteorites, in spite of variations in density from 2.5 to 8, the same two rules are found to hold, that (1) the even-numbered elements, and (2) the elements of low atomic number and low atomic weight, are those which occur in abundance.

the abundance of the elements and the periodic system of Mendeléeff, and this is true when the subject is considered from a broad standpoint, that is, without emphasizing unduly the importance of the quantitative composition of the earth's surface as a measure of the relative abundance at the stage of atomic evolution represented by the solar system. It is evident, however, that there will be an *apparent* relation, since, as shown by Fig. 1, the maximum for abundance occurs between elements 8 and 28, therefore in Series 2, 3, or 4 of the ordinary periodic system. Now, since our knowledge of the elements from the systematic standpoint is all tied up with this system, it will be of use to also compare the relative abundance of the elements on the same basis, for even although the fundamental relation is not expressed at all by the form which the system takes, the variable which conditions both the periodic table and the abundance of the elements is the same, that is, the atomic number.

When the attempt is made to show the relative abundance in each group in the periodic system by the use of the data in regard to what we have considered the most representative material whose composition is known to us, that is, the meteorites, it is found that the percentages, the elements of atomic numbers higher than that of copper (29), are so small as not to be represented. Very nearly the same condition would undoubtedly be found with reference to analyses of the crust of the earth, if it were not that by differentiation, and by the formation of veins and other means, the percentage amount of any individual element is often enormously increased, so that elements which are comparatively rare from the general standpoint may become very abundant in certain localized deposits, as, for example, the copper in the Lake Superior district. It is from data in regard to just such deposits as this that we get most of our ideas and estimates of the relative abundance of such elements. Now it is evident, since no one has any accurate knowledge of the fraction of even the earth's surface which is made up of such deposits,. that any estimate of the relative abundance of an element present in a small percentage amount in the earth's crust will not have any claim to accuracy. On the other hand, estimates in regard to elements which are present in large amounts in nearly all rocks, are likely to be very much more nearly of the same magnitude. As an example of this latter case the recent estimate made by Knopf[1] of the average composition of igneous rock may be cited. Knopf made his calculation by the use of proportional factors obtained from data in Daly's "Igneous Rocks and Their Origin," supposed to represent the proportional area covered by each species of rock. The factor was multiplied by the average composition of the species to get the percentage contribution of that species to the composition of the average igneous rock. The values thus obtained are here recalcu-

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[1] *J. Geol.*, 24, 620–2 (1916).

lated to give the percentage amount of each *element*, and in Table IX are compared with Clarke's estimate (Column II, Table IX), which was obtained by averaging a large number of analyses[1] according to the number of determinations made of each constituent, without any reference to the quantitative distribution of the rocks concerned. Though the method which takes account of the distribution of the rocks seems much the better from the theoretical standpoint, the remarkable result expressed by the following table is that it gives almost exactly the same results as were obtained by the older method. However, if by these two same methods, calculations could be made of the average composition of the earth's surface with reference to constituents present in amounts less than 0.01%, it would undoubtedly be found that they would differ widely.

TABLE IX.—THE AVERAGE COMPOSITION OF IGNEOUS ROCKS.[2]

Atomic number.	Element.	I.	II. (Clarke).
8	O	47.25	47.29
14	Si	28.93	28.02
13	Al	8.33	7.96
26	Fe	4.56	4.56
20	Ca	3.62	3.47
23	Na	2.52	2.50
19	K	2.20	2.47
12	Mg	1.79	2.29
22	Ti	0.44	0.46
1	H	0.14	0.16
15	P	0.11	0.13
6	C	..	0.13
16	S	..	0.103
9	F	..	0.10
56	Ba	0.12	0.092
25	Mn	..	0.078
17	Cl	..	0.063
24	Cr	..	0.033
38	Sr	..	0.033
28	Ni	..	0.020
40	Zr	..	0.017
23	V	..	0.017
3	Li	..	0.004
		100.00	100.00

It is evident, *even if in the formation of the elements there is no relationship to the ordinary periodic system, that in all of the differentiative processes which occur after the original formation, the physical and chemical properties would play their part, so that if any special material is taken for con-*

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[1] "The data of Geochemistry," p. 27 (1916).

[2] While Cols. I and II in this table are not strictly comparable, since Col. II gives data for 11 elements not included in Col. I the total percentage of these 11 elements is only about 0.6%, so the data are after all in a form which admits of an easy comparison.

sideration, relationships to that system would appear more and more as the process of differentiation takes place. Thus the fact that very normal results are obtained from the meteorites with respect to the relative abundance of the elements (from the standpoint of the new periodic relationship) does not show that no differentiation has occurred; but only that such processes have not yet proceeded to such an extent as to interfere with the general accord with the odd and even system of abundance. The composition of the earth's surface, as compared with the meteorites, shows a less rigid though still very marked adherence to the odd and even system, but certain groups of elements related in physical and chemical properties are relatively more abundant. Thus the alkali metals, sodium and potassium (Group 1), the halogens (Group 7), and aluminium (Group 3), are very much more abundant in the earth's crust. The percentage abundance of the elements in the lithosphere (hydrosphere and atmosphere included) are presented in Table X. The larger values are those given by Clarke,[1] while the estimates for elements present in percentages less than 0.01 have been taken from various sources, but mostly from Vogt.[2] As has been explained, these smaller numbers have no value as data, but are of considerable use in studies of relative abundance.

Even in a single group, there is in some cases a considerable shift in relative abundance with the change in the material considered. Thus *in the meteorites calcium is very much less abundant than magnesium,* whether calculated by weight or as atomic percentage, while in the lithosphere calcium is more abundant by weight but less plentiful from the standpoint of the number of atoms.

In the table it will be seen that when calculated by weight the third element in the group is the most abundant in Groups 0, 2 and 5, the second element in Groups 2, 3, 4 and 7, and the first element in Group 6. Iron, the first element in Group 8, is the most abundant, but it is in the same series with the third element in the other groups. If calculated as atomic percentage, the second element in Groups 2 and 5 becomes the most abundant. All that this shows is that the maxima in the curve of abundance occur among the elements of low atomic number, but these facts have often been cited as indicating that the abundance of the elements is related to the Mendeléeff system. Not an infrequent question in the literature relating to this special subject is "Does the evolution of the elements take place down the groups in the periodic system or along the series?" The answer which the present study gives is that atomic evolution seems to be in no way related to the groups in this system, but that its only relationship is that with the atomic number.

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[1] *Loc. cit.*

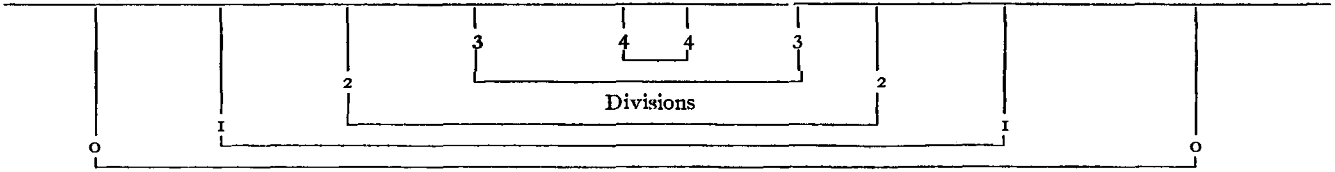
[2] Beyschlag, Vogt, Krusch, "Lagerstätten der Nutzbaren Mineralien und Gesteine," p. 157. English translation by Trescott, "Deposits of Useful Minerals and Rocks" (1915). Vogt, *Z. prakt. Geol.*, 1898, 225, 314, 377, 413; 1899, 10, 274.

TABLE IX.—THE PERCENTAGE ABUNDANCE OF THE ELEMENTS IN THE EARTH'S CRUST, ARRANGED IN THE FORM OF A PLANE PERIODIC SYSTEM, IN THE ORDER OF THE ATOMIC NUMBERS.

1 H = 0.95.

Periods.	Group O.' (Atmosphere.[1])	A Group I. B R_2O.	A Group II. B RO.	A Group III. B R_2O_3.	A Group IV. B RO_2, RH_4.	B Group V. A R_2O_5, RH_3.	B Group VI. A RO_3, RH_2.	B Group VII. A R_2O_7. RH.	Group VIII. RO_4.		
1	2 **He** 5.0	3 **Li** 0.004	4 **Be** $<$0.001	5 **B** $<$0.01	6 C 0.18	7 **N** 0.03	8 **O** 50.02	9 **F** 0.10			
2	10 **Ne** 18.0	11 **Na** 2.36	12 **Mg** 2.08	13 **Al** 7.3	14 Si 25.8	15 **P** 0.11	16 S 0.11	17 Cl 0.20			
3	18 **A** 9410.0	19 **K** 2.28	20 Ca 3.22	21 Sc 44.1	22 Ti 0.43	23 *V* 0.17	24 *Cr* 0.02	25 *Mn* 0.08	26 *Fe* 4.18	27 *Co* 0.001	28 *Ni* 0.02
	[*Fe, Co, Ni*]	29 *Cu* 0.01	30 *Zn* 0.004	31 *Ga* $<0.0_61$	32 *Ge*	33 **As** 0.0003	34 *Se* 0.0_42	35 *Br* 0.0002			
4	36 **Kr** 0.05	37 **Rb** $<$0.001	38 Sr 0.03	39 **Yt** $<$0.001	40 **Zr** 0.015	41 *Cb*	42 *Mo*	43	44 *Ru*	45 *Rh*	46 *Pd*
	[*Ru, Rh, Pd*]	47 *Ag* 0.0_55	48 *Cd* 0.0_52	49 *In* $<0.0_61$	50 *Sn* $<$0.001	51 Sb	52 **Te**	53 **I** 0.00001			

5	54 **Xe** 0.006	55 **Cs** <0.0001	56 **Ba** 0.08	57 **La** 59 **Pr** 60 **Nd** 61 — 62 **Sa** 63 **Eu** 64 **Gd** 65 **Tb** 66 **Dy** 67 **Ho** 68 **Er** 69 **Tm_1** 70 **Yb** 71 **Lu**[2] 72 —	58 **Ce** <0.001	73 *Ta*	74 *W* <0.001	75	76 *Os*	77 *Ir*	78 *Pt*
	[Os, Ir, Pt]	79 *Au* $0.0_{6}1$	80 *Hg*	81 *Tl*	82 *Pb* 0.002	83 **Bi**	84 **Po**	85 —			
6	86 Nt $0.0_{18}4$	87 —	88 **Ra** $0.0_{9}4$	89 **Ac**	90 **Th** <0.0001	91 *Bv*	92 *U*				



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[1] The numbers in Group O give the volumes of gas in 1 million volumes of air, while the values in the other groups give the percentage composition of the lithosphere, hydrosphere and atmosphere, or the known materials of the earth's crust.

[2] The atomic numbers for Dy, Ho, Yb and Lu are those given by the recent work of Firman (*Phil. Mag.*, [6] **32**, 497–9 (1916)).

Table X shows that in each group the abundance usually begins at a low value (with exceptions in the sixth and eighth groups), rises to a maximum, and then falls rapidly and progressively to the element at the bottom, which is in general the rarest of all. There are, however, a few exceptions to the general rule that below the element which is at the maximum, the abundance falls with increase of atomic weight. For example, barium is more abundant than strontium in the lithosphere, but, on the other hand, it has never been found, except in spectroscopic traces, in the meteorites.

While the facts presented in relation to Table X have been known for years, they have had no explanation. In some cases it has been considered that the lighter elements are more abundant because they have come to the surface of the earth. On the other hand, Clarke says, "Here again we are dealing with an evident tendency of which the meaning is yet to be discovered. That the abundance and associations of the elements are connected with their position in the periodic system seems, however, to be clear. The coincidences are many, the exceptions are few." From the standpoint of the results presented in this and previous papers of the series, the facts are most easily explained by considering that the preponderance of the elements of low atomic number comes probably as the result of the evolution of the elements. In this connection the conclusion is easily reached that the more stable the nucleus of the atom, the greater is the chance that the atom will be formed. However, there is another factor than stability to be considered; that is the supply of material available under conditions and in a form suitable for the formation of the nucleus. For example, oxygen seems to be either the most or very nearly the most abundant element known to our experience. However, this does not prove that some other atoms of higher atomic number may not be at the same time more stable and less abundant, since the oxygen atoms, once they are formed, may be sufficiently stable to hold the material. Thus, if the assumption is made that the order of evolution is from lighter to heavier atoms, it is quite evident that at least a part of the preponderance of the atoms of low atomic number may be due to their getting the material first.

Summary.

1. Evidence has been presented in previous papers to show that the elements are very probably intra-atomic compounds of hydrogen, and that one of the first steps in the formation of a complex atom is the change of hydrogen into helium.

2. The elements are found to fall into two series. The series of even atomic number beginning with helium has the general formula $n\text{He}'$, while the odd-numbered series beginning with lithium is represented by

nHe$'$ + H'_3. In these formulas the prime is added to indicate that the compound is intra-atomic and not chemical.

3. If the elements actually belong in two series as the hypothesis indicates, then the distinction between the two should be apparent in at least some fact concerning the respective elements. Now it has already been shown that the atomic weights of the elements interpreted in the light of the method by which radioactive elements disintegrate, give almost conclusive evidence of the validity of the theory.

4. However, extremely striking additional evidence has been discovered, which is entirely in accord with the system outlined. The ordinary periodic system of the elements seems to be a relationship which expresses in a graphic way the variation in the arrangement and the number of the external electrons, especially the valence electrons, in the atom, which finds its expression in the chemical (Abegg's rule of eight valence electrons) and the ordinary physical (cohesional or aggregational) properties of the elements. The hydrogen-helium system is most fundamentally related to the structure of the nuclei of the atoms, and this structure should not affect the arrangement of the external electrons if the nucleus is extremely minute, since this arrangement would depend upon the number of electrons, which in turn depends upon the nuclear charge, but not upon the internal structure of the nucleus except insofar as this structure affects the total charge. The structure of the nucleus should, however, affect its stability, which would have an expression in the abundance of the respective elements. There is another factor, too, which would have an effect upon the abundance, and that is the relative abundance of the special materials used in the formation of the element in question.

5. The abundance of the elements in the earth's crust might seem to give the best information in this respect if it were not known that the surface of the earth has been subjected to very long-continued differentiative processes, and so has a very local character. The meteorites, on the other hand, come from much more varied positions in space, and at the same time show much less indication of differentiation.

6. In the meteorites the elements of even atomic number are on the average about 70 times more abundant than the odd-numbered elements, and, moreover, if the elements are plotted in the order of their atomic numbers it is found that the *even-numbered elements are in every case very much more abundant than the adjacent odd-numbered elements.* Almost more striking than this is the fact that the *first seven elements* in the order of their abundance are *all* even numbered, and, furthermore, make up 98.78% of the material. Both the iron and the stone meteorites separately show just these same relations, whether the percentages are calculated as atomic or by weight. Thus the stone meteorites are 97.6% and the iron meteorites, 99.2% even-numbered elements. It is remarkable too

that the highest percentage found for any odd-numbered element in any class of meteorites is 1.53%, while among the even-numbered elements larger percentages are common, and range even as high as 90.6%.

7. In the lithosphere, while the relationship is not so striking, the even-numbered elements are still 7 to 10 times as abundant as those which are odd, depending upon whether the calculations are made by weight or by atomic percentage. Among the rare earths the even-numbered elements are the more abundant.

8. Among the radioactive elements the odd-numbered element is in each case either of a shorter period than the even-numbered, or else as yet undiscovered.

9. All of the five unknown elements are odd numbered.[1]

10. The elements of the low atomic number are found to be extremely more abundant than those of higher atomic number, both in the meteorites and on earth. Thus the first 29 elements make up about 99.9% of the material, while the remaining 63 are either extremely rare or comparatively rare. Of the first twenty-nine elements those which have been atomic numbers between 6 and 28 include nearly all of the material.

11. The above results seem to show that the elements fall into two series as predicted from the hydrogen-helium structure of the atoms as formerly presented by the writer. The variation in the abundance of elements as found would seem to be the result of an atomic evolution, which is entirely independent of the Mendeléeff periodic system. The formation of the elements seems to be, however, related to the atomic number. Some discussion is given of the effect of the stability of the atoms and other factors upon their formation. The influence of segregation upon the composition of the lithosphere is discussed.

12. The hydrogen-helium structure of the atoms, as presented in this article, is seen to be on as firm a basis as a large part of the ideas of physics and chemistry which are accepted without question, since the predictions originally made have been verified in so striking a way. The first prediction, at the beginning of this work, was that the elements of low atomic number would be found to show evidences in their atomic weights that their atoms are built up according to the general plan, according to which the radioactive elements (of high atomic weight) disintegrate. The second prediction was that the elements of even atomic number would show a marked difference in abundance from those of odd atomic number. The agreement with both of these predictions is very much more striking than was at first expected, and this agreement involves such a large number of data that it is on this account even the more remarkable.

13. The other periodic relations of the elements which have been dis-

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[1] With the possible exception of element 72 which may be lutecium, or may be an unknown element.

covered during the last sixty years are merely details included in the general system developed between 1860 and 1870 by de Chancourtois, Newlands, Mendeléeff, and Mayer. The periodic relationship between the abundance of the elements (or their evolution) and the atomic numbers, as presented in this paper, is entirely independent of the other system.

14. Since the theory here presented establishes to some extent a "normal" average composition for material it should have an important bearing on the history of the differentiative processes which have taken place on the earth. Its applications to geology will be considered in a later paper.

Chicago, Ill.

[Contribution from the Chemical Laboratory of the University of Illinois.]

A KINETIC HYPOTHESIS TO EXPLAIN THE FUNCTION OF ELECTRONS IN THE CHEMICAL COMBINATION OF ATOMS.[1]

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Beginning with Davy[2] and Berzelius, during the first part of the nineteenth century chemists generally accepted the theory that chemical combination is due to electrical forces but when Dumas discovered the chloroacetic acids in which chlorine atoms, supposedly negative, replace positive hydrogen atoms it was believed that the theory had been shown to be false and it was practically abandoned. Following this, for fifty years or more, a theory of valence which took no account of electrical forces was developed and while occasional reference was made to positive and negative atoms and groups, no definite meaning in an electrical sense was attached to these expressions. Helmholtz in his Faraday lecture in 1881[3] drew the attention of chemists once more to the very close connection between chemical forces and electrical phenomena and spoke for the first time of "atoms of electricity." He also pointed out that the "sulfur of sulfuric acid must be charged with positive equivalents of electricity." In 1887, Arrhenius proposed his theory of electrolytic dissociation and with the help of Ostwald and van't Hoff the belief in a separation of molecules into electrically charged parts in solutions was rapidly accepted. J. J. Thompson[4] gave precision to the atomic character of electricity in 1897 when he demonstrated the material character of cathode rays and the very minute mass of the corpuscles carrying negative charges. Van't Hoff[5] seems to have suggested for the first time that electrically charged atoms may play a part in reactions not usually considered as

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[1] Presented before a meeting of the National Academy of Sciences in Washington, April 16, 1917.

[2] *Phil. Trans.*, 1807, 1.

[3] *J. Chem. Soc.*, 24, 291 (1881).

[4] *Phil. Mag.*, 44, 296 (1897).

[5] *Z. physik. Chem.*, 16, 411 (1895).