THE PERIODIC SYSTEM OF ATOMIC NUCLEI AND THE PRINCIPLE OF REGULARITY AND CONTINUITY OF SERIES

By William D. Harkins
George Herbert Jones Laboratory
The University of Chicago

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Abstract

New relations which concern the existence and stability of atomic nuclei are presented, together with a discussion of evidence for the relations given earlier as exhibited by the newer data on the existence of isotopes. It is shown that the four series, the helium, uranium, lithium and beryllium series, exhibit a considerable amount of regularity and are now almost continuous. The more abundant species of odd atomic number keep in general to a constant isotopic number as the atomic number increases, or else the isotopic number increases by the same amount as the atomic number. There is a general tendency as the atomic number increases for the isotopic number of the most abundant isotope of elements of both even and odd atomic number (a) to remain constant, (b) to increase at the same rate as the atomic number or (c) to decrease along a line of constant electronic number.

The atomic, mass, isotopic, and electronic numbers of all known isotopes are given in figures which exhibit the periodic and other relations of atomic nuclei. Many undiscovered atomic species (isotopes of each element) between atomic numbers 61 and 18, are predicted, and the general relations predict the existence of a considerable number of additional species among elements of lower number.

These relations are presented in the form of fourteen rules, several of which are new, and three are fundamental laws presented earlier. The bearing of the newer data on these rules is discussed.

The paper discusses nuclear stability and abundance as related to the pairing of nuclear electrons and the oddness and evenness of the electronic number, to the evenness and oddness of the nuclear charge (atomic number) as exhibited by the most recent work on the composition of the crust of the earth, the meteorites, and the atmosphere of the sun, and to the ratio of nuclear electrons to protons.

The neutron, or nuclear neutral particle may play a part in atom building. The figures, fundamental laws, rules, and relations presented, especially the principle of continuity and regularity of series, when taken in connection with known facts, seem to indicate that atomic nuclei are built in steps, and, except in the simplest cases, not as single events. That is the general picture revealed by all of these appears to be in discord with the theory of Millikan and Cameron.

1. Introduction

The atomic species, often, but incorrectly, called isotopes, give a pattern which exhibits a considerable number of regularities when they are plotted in any natural way. The most important of these regularities have been expressed by the writer in the form of a set of relations or rules in a series of papers.[1,2]

[1] Harkins and Wilson, J. Am. Chem. Soc. **37**, 1367–9 (1915), Phil. Mag., (1915).

[2] Harkins, J. Am. Chem. Soc. **39**, 859, Table II (1917); Science **50**, 580–1; Phys. Rev. **15**, 85 (1920); Phil. Mag. **42**, (1921); J. Am. Chem. Soc. **42**, 1976 (1920); J. Am. Chem. Soc. **43**, 1050 (1921); J. Franklin Inst. **195**, 554 (1923); J. Am. Chem. Soc. **45**, 1426 (1923).

While the most important of these rules have thus been known for a considerable time, the present paper gives additional interesting relations whose importance is revealed by more recent work. This has been so extensive, due to the efforts of Aston and others, that every one of the first sixty elements, except only columbium, masurium, rhodium, and palladium, has been tested for isotopes. While the number of isotopes which exist for such elements as strontium and barium is much larger than the number thus far found, the attainment of the present stage of completeness makes it essential to examine the relations which exist between the species now known.

2. Periodic System of the Atomic Species (Elements 1 to 60)

The values for two experimentally determined variables which relate to atomic nuclei, are well known. These variables are the mass number (P), supposed to give the number of protons in the nucleus, and the atomic number (Z). A derived variable, $P-Z$, is supposed to give the number of nuclear electrons (N).

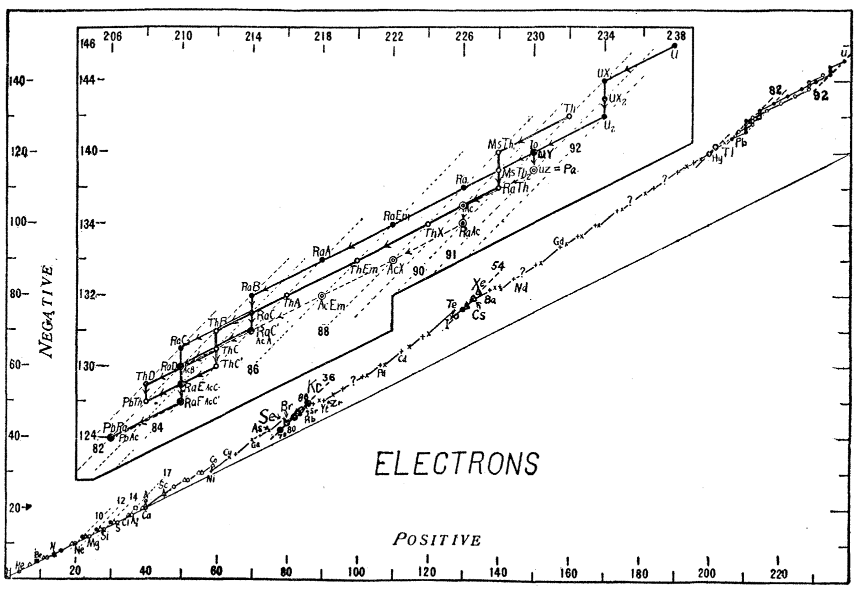

Fig. 1. The negative electron content of atomic nuclei as a function of the number of protons (positive electrons)

Fig. 1 shows the general form of the diagram which is obtained when the number of protons is plotted on the X-axis and the number of electrons on the Y-axis. The most abundant atomic species are found to lie in this plot on a line with a slope of $\frac{1}{2}$ which passes through the origin, and all of the other species are found to lie on 54 other equidistant lines above and parallel to this line. The scale of Fig. 1 is too small to show these lines except in the enlarged section in which the radioactive species are shown. These 55 parallel lines, when numbered, give the isotopic number, (n), a number as natural as, and on a par with, the atomic number.

The isotopic number has been defined by the writer[3] by the equations:

$$n = P - 2Z \quad (1)$$

$$n = 2N - P \quad (2)$$

$$n = N - Z. \quad (3)$$

If the formula of any nucleus is written as $(p_2e)_z(pe)_n$, then n is the isotopic number if p represents a proton and e, an electron.

If Fig. 1 is now rotated clockwise through the angle whose sine is $\frac{1}{2}$, and skewed so that the lines of constant atomic number are vertical, Fig. 2 results. This is the most compact and simple diagram which presents the relations between atomic nuclei. This and other forms of representation have been discussed by Harkins and Madorsky.[4]

In the figure every intersection of a vertical with a horizontal line represents a possible atomic species. The general position of the symbols which represent the atomic species shows that the band of greatest stability has somewhat the form of one limb of an hyperbola.

Species which belong to the thorium series ($P = 4M$) are designated by circles, those of the uranium series ($P = 4M+2$) by diamond shaped symbols, those of the lithium series ($P = 4M+3$) by triangles, and those of the beryllium series ($P = 2M+1$) by squares. M is taken to represent any whole number. The thorium and uranium series are named for the radioactive series which they include and the other two series begin with the principal isotope of lithium and of beryllium, respectively.

The principal general pattern of Fig. 2 is that of a double network of squares, produced by the lines which give the atomic and the isotopic number. The heavier lines of this network represent even and the light lines odd numbers. It is evident that the greatest number of species occur where heavy horizontal lines meet heavy vertical lines.

The considerable regularity in the pattern exhibited is in accord with the rules listed in the next section.

It may be noted that the proton or hydrogen nucleus has an atomic number 1 and an isotopic number -1. The electron has an atomic number -1 and an isotopic number 2.

In Fig. 2, the lines of slope -1 give the number of nuclear electrons, and the dashed lines of slope -2 give the number of protons or the mass number. The double arrow-heads designate the mean atomic weight for the element. If these are not shown the mean value coincides somewhat closely with that for the principal isotope of the element.

The ratio N/P of negative electrons to protons is given by the lines which radiate from the origin.

The most abundant isotope of columbium or of rhenium has not been found by the positive ray method but the existence of both these species is indicated by the atomic weight of the element, so they are included in the figure.

[3] W. D. Harkins, Phil. Mag. **42**, 305 (1921)

[4] W. D. Harkins and S. L. Madorsky, Phys. Rev. **19**, 135 (1922).

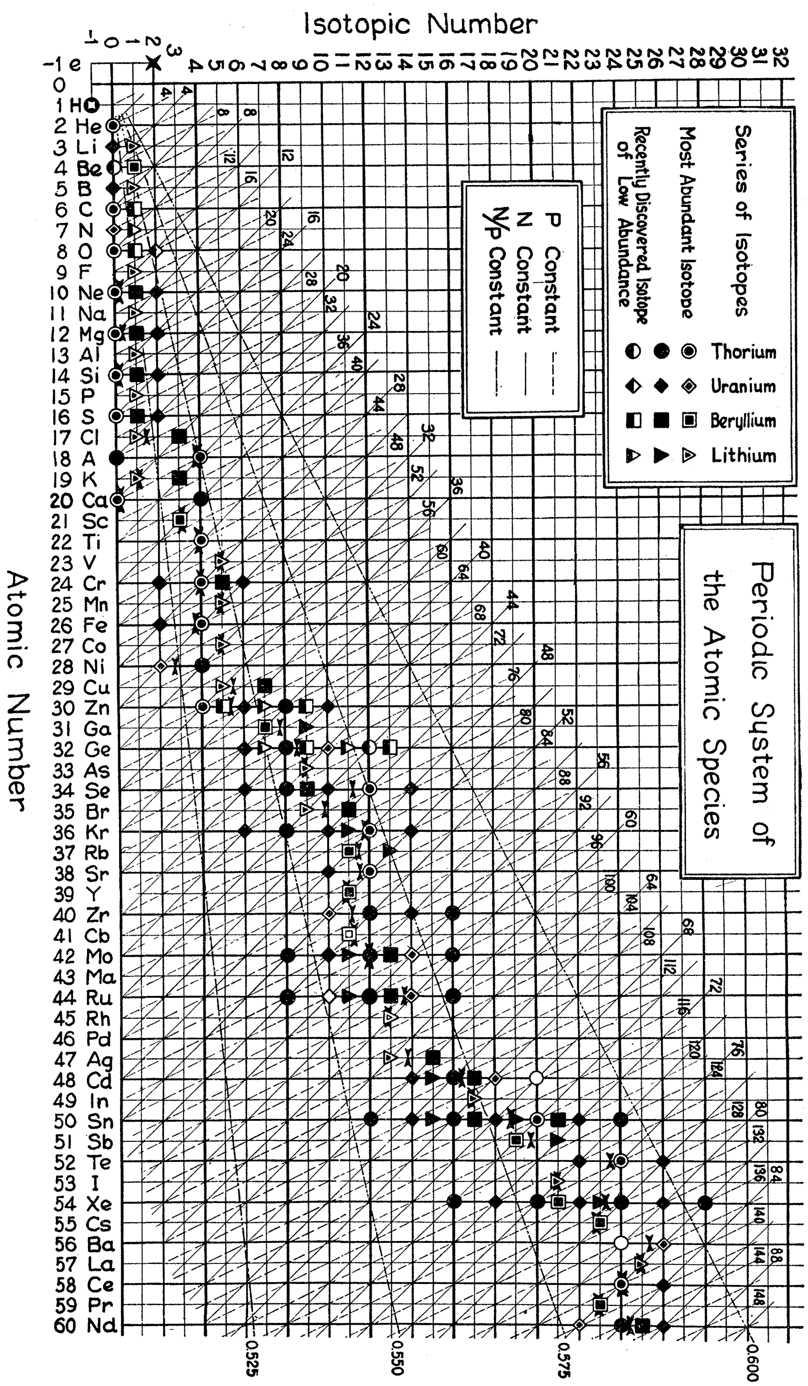

Fig. 2. Periodic system of atomic nuclei of nuclear charges −1 to 60.

3. Rules Concerning the Abundance and Stability of Atomic Nuclei

The most important rules which concern the stability and abundance of atomic nuclei are given below with special reference to Fig. 2, which emphasizes the fact that these rules are of even more general import than the limited earlier knowledge revealed.

In order to exhibit the extent to which the rules themselves apply it is necessary to consider a third dimension, to represent either abundance or stability, in connection with Fig. 2. Certain abundance relations are shown in Fig. 6.

Rule 1. Nearly all atomic nuclei contain an even number of electrons. Thus there seem to be at least 125 atoms of even to one atom of odd electronic number in the earth's crust. The extremely striking evidence for this rule is presented in Section 11, and the more detailed evidence in earlier papers by the writer. Corollary: Most atomic species have an even electronic number. Thus of the 156 known species for elements 1 to 60 inclusive, 125 have an even and 31 an odd electronic number. In Fig. 2 species of even electronic number lie on lines of slope -1, and those of odd number half way between the lines.

Rule 2. The number of electrons in the nucleus of any atom, other than hydrogen, is in no case less than half the number of protons (See Fig. 12).

Rule 3. Nearly all atomic nuclei have an even net nuclear charge, that is the atomic number is almost always even. The remarkable new evidence for this rule is presented in Section 10, and the more detailed earlier evidence in former papers of this series. Corollary: Most atomic species have an even atomic number. For example, of the 156 known species represented in Fig. 2 the atomic number is even for 116, and odd for 40.

Rule 4. Nearly all atomic nuclei contain an even number of protons. Corollary: More atomic species have an even than an odd mass number. Thus Fig. 2 shows 90 species with an even to 66 with an odd protonic number.

Rule 5. The number of protons in atomic nuclei is more often divisible by 4 than is to be expected by chance.

This relation is not so apparent in the number of species as it is in abundance especially of the light atoms. Thus 46 of the 156 species shown in Fig. 2 have mass numbers divisible by 4, and 43 divisible by 2 but not by 4. The number of species with mass numbers divisible by 3 should be 4/3 times the number divisible by 4, or 58, while the number found in Fig. 2 is 50.

However Rule 5 is of considerable significance, since all of the 5 most abundant species known in the meteorites have mass numbers divisible by 4.

Rule 6. If N is even then P is more often even than odd, and if N is odd, P is more often odd than even. Thus there is a certain matching of N and P with respect to evenness or oddness. There are almost no atoms in which the number of nuclear electrons is odd and the number of protons even. The 3 species of this type which exist are lithium 6, boron 10, and nitrogen 14, of isotopic number 0. They are the only species known which belong to Class IV according to Table I.

Rule 7. For light atoms (up to $Z=28$) the isotopic number which represents the chemical atomic weight is in general higher for odd than for even-numbered elements. Above atomic number 28 this value is usually higher for even than for odd-numbered elements; that is, the relation is inverted.

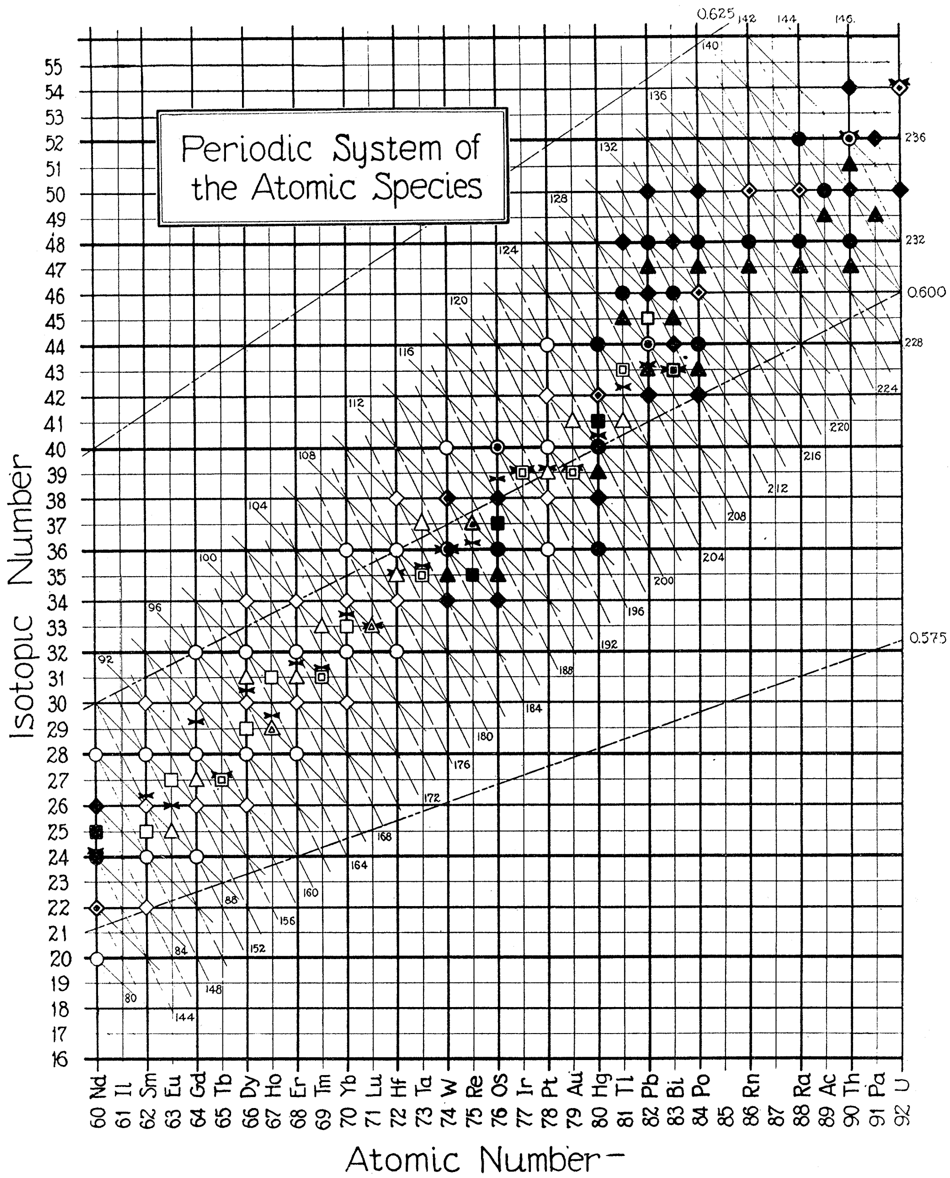

Fig. 3. Elements 60 to 92.

The above seven rules were discovered by the writer. An eighth found by Aston is as follows:

Rule 8. Not more than two isotopes are known for any element of odd atomic number, except among the radioactive elements.

TABLE I. *Classification of atomic nuclei according to even and odd number of electrons, and the corresponding abundance in the meteorites and the crust of the earth.*

Class			Abundance in Atomic Percentage Earth's crust	Meteorites
Class I	N=even	P=even	87.4	95.4
Class II	N=even	P=odd	10.8	2.1
Class III	N=odd	P=odd	1.8	2.5
Class IV	N=odd	P=even	0.0007	0.0

Only 3 species of Class IV are known, and all of these have an isotopic number zero: lithium 6, boron 10, and nitrogen 14.

To the above may be added the following relation:

Rule 9. The difference of isotopic and of mass number between the two isotopes of an element of odd atomic number is always 2, except where species of Class IV of isotopic number 0 occur. (Li^6, B^{10}, N^{14}). The first two of these species have a mass number less by 1 than that of the more abundant isotopes.

4. Periodic System of the Atomic Species (Elements 60 to 92)

The general pattern for elements 60 to 92 is shown in Fig. 3, in which the symbols have the same significance as in Fig. 2.

Undiscovered species which are almost certain to be discovered later are designated by open symbols. A line around the inner part of the symbol indicates the most abundant isotope of the element.

From illinium (61) to tantalum (73) no atomic species have been found since these elements have not been investigated. It may be expected that all of the species listed in this region will be found when these elements are tested by methods with a moderate degree of sensitivity. The general pattern may be expected to be just that given. With more delicate methods the limits may be expected to extend beyond the species listed.

The more abundant isotope for each element of odd number is indicated, and the predictions may be expected to be correct in each case for which the chemical atomic weight is known.

It may be seen that rhenium and thallium are in discord with the otherwise general rule that the lighter of the two isotopes of an element of odd number is the more abundant.

Two other exceptions to this rule are found in lithium and beryllium, but this is due to the abnormal occurrence of isotopes of an entirely different class, those of Class IV according to one of the important schemes of classification introduced by the writer.

5. The Radioactive Series

The radioactive series are shown in Fig. 4. The atomic weight of members of the actinium series are unknown. The values given are those generally thought the most probable. If they are correct, the actinium series is a part of the lithium series. On this basis, the members of this series have odd isotopic numbers and give odd isotopes to the elements of even number. The atomic weights or number of protons, and the number of electrons are given in the figure. Thus for radium the atomic weight is 226 and the number of electrons 138.

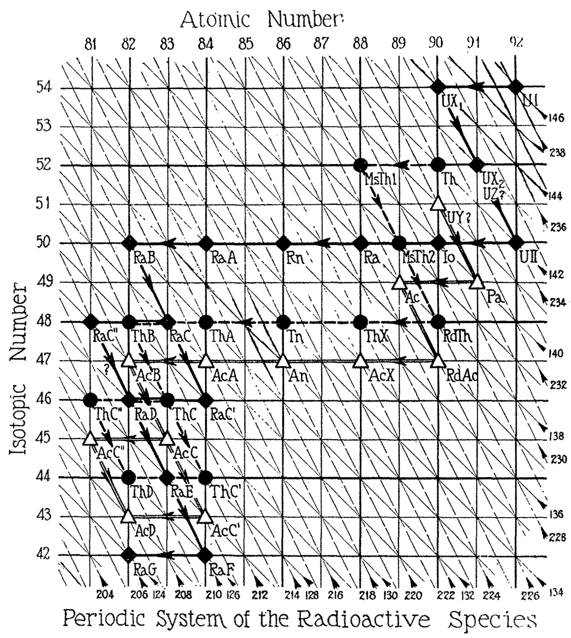

Fig. 4. The radioactive elements.

6. Variation in Abundance of Isotopes

Rule 10. For light elements of even number the most abundant isotopic species in an element of even number has an isotopic number of zero, or one divisible by 4, that is the most abundant isotope belongs to the helium-thorium ($4M$) series.

Up to element 38 there are only three exceptions: beryllium, nickel, and germanium.

Rule 11. For light elements of odd number the most abundant isotope has first an isotopic number 1, which increases (by 4) to 5 for elements 23 to 29.

Thus for either even or odd elements the most abundant isotopes tend to lie on lines of constant isotopic number, which, when varied increase by 4 as the atomic number rises.

Rule 12. (a) For light elements (up to 30) the most abundant isotope of an element of even number has the same electronic number as the next preceding element of odd number. For elements of higher number this relation is commonly reversed.

Rule 12. (b) Thus successive most abundant isotopes often lie on a line of constant electronic number. For example, the electronic number is 82 for the principal isotope of Ba (56), La (57), Ce (58), Pr (59), and Nb (60), and it is 50 for the principal isotope of Sr (38), Yr (39), and Zr (40).

An interesting relation is revealed by Fig. 3. The principal isotope of each element of odd number from Tb (65) to Ir (77) lies on a straight line of slope 1. On this same straight line lie the principal isotopes of the even-numbered elements Nd (60), Hg (80), Ra (88), Th (90), and U (92), and one of the two most abundant isotopes of W (74).

The increment along such a line is p_3e_2 between adjacent elements and p_6e_4 between odd (or even) elements. That this relation is not fortuitous, at least for the elements of odd number, is shown by the fact that the principal isotopes of Rh (45), In (49), Sb (51), I (53), Cs(55), and La (57) also lie on another line of slope 1. The same is true of Cu (29), Ga (31), and As (33), and also of K (19), Sc (21), and V (23).

Rule 13. In general for elements of odd number, with increase of atomic number:

(a) the isotopic number of the principal isotope remains constant, so the mass number increases by 4, and the electronic number by 2—that is the increment has the composition of an alpha-particle, or

(b) the isotopic number increases at the same rate as the atomic number, —that is the increase in mass number is 6, and in number of electrons is 4.

In one case, from lanthanum to praeseodymium, Rule 12 becomes more prominent and the isotopic number decreases along a line of constant electronic number.

The relations expressed by Rule 13 are expressed in Fig. 5.

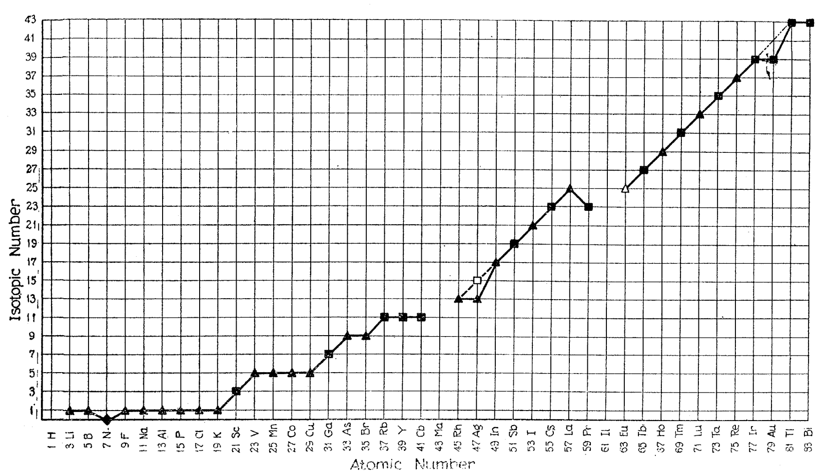

Fig. 5. The variation of the isotopic number for the most abundant isotopes of the elements of odd number. The two isotopes of silver have almost the same abundance.

7. Distribution of Abundance among Isotopes

The distribution of abundance among isotopes is very simple for elements of odd number.

Rule 14. The more abundant of the two isotopes of an element of odd number has in general the lower isotopic and the lower mass number.

This is not true for two elements, lithium and boron, which have isotopes of the exceptional Class IV, but is true for nitrogen. As with certain other rules, some exceptions are found in elements of high atomic number. Thus in rhenium (75) and thallium (81) the higher isotope is the more abundant. In silver the two isotopes have almost the same abundance as judged from the chemical atomic weight and the packing fraction (See Fig. 5).

The variation in abundance of the isotopes of 9 well distributed elements is shown in Fig. 6. The vertical distance between two adjacent horizontal lines represents 50 percent, except for oxygen, at the top where the distance is twice as great, or 100 percent. The values for small percentages are printed in the figure. Thus oxygen consists of 99.9 percent isotopic number 0, 0.01

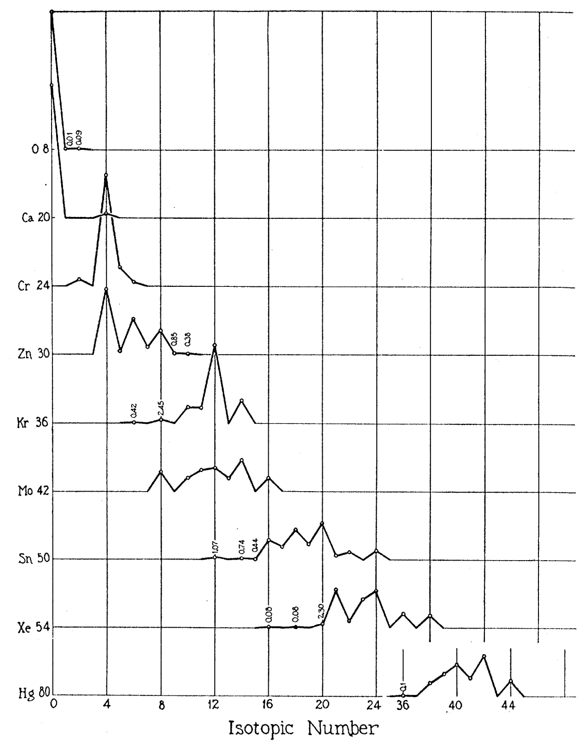

Fig. 6. Abundance of isotopes.

percent number 1, and 0.09 percent number 2. The pattern for neon, magnesium, silicon and sulphur, is in each case the same as for oxygen, except that isotopes 1 and 2 are relatively more abundant, especially for magnesium. The patterns for calcium and argon are the inverse of each other, with isotopes of number 0 and 4, with almost the whole material concentrated in the 0 isotope of calcium, and in isotope 4 of argon. Fig. 2 indicates the probability that both argon and calcium have undiscovered species of number 2, and probably 3, and that argon and possibly calcium probably contain species of isotopic number 1.

As the atomic number increases several peaks of abundance become prominent instead of the single high peak found for oxygen, neon, magnesium, silicon, sulphur, argon, calcium, chromium, and krypton. Also, Rule 15, the abundance is much higher on the whole for even than for odd isotopic numbers. In xenon isotopes 21 and 24 are the most abundant, which represents an exceptional case in so far as 21 is concerned.

The distribution of abundance for two other elements is as follows; as found by Aston:

Isotopic number	Ruthenium, atomic number = 44 Mass number	Percent
8	96	5
10	98	?
11	99	12
12	100	14
13	101	22
14	102	30
16	104	17

Ruthenium, like molybdenum (42) has the maximum of abundance at isotopic number 14, and the two patterns are much alike.

Isotopic number	Osmium, atomic number = 76 Mass number	Percent
34	186	1.0
35	187	0.6
36	188	13.5
37	189	17.3
38	190	25.1
40	192	42.6

Here is an exceptional case, in that the highest isotope (thus far found) is the most abundant.

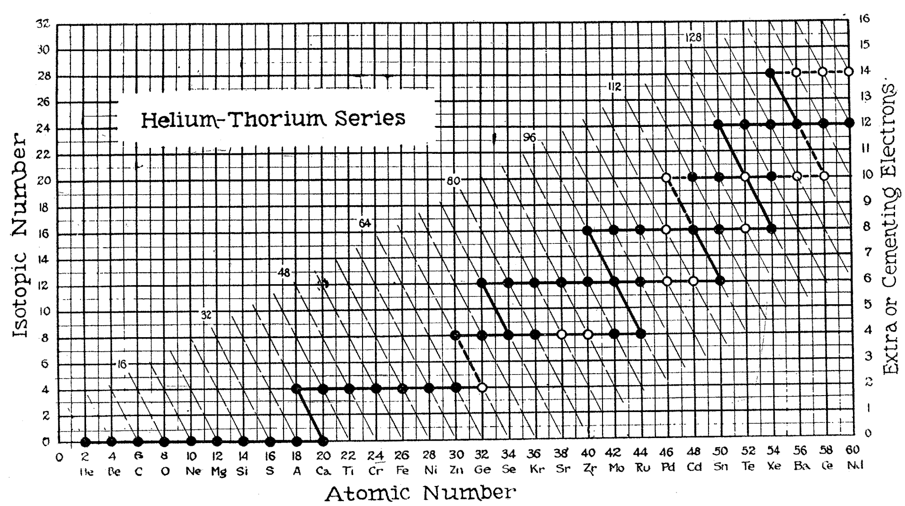

Fig. 7. Continuity in the helium-thorium series.

8. The Principle of Continuity and Regularity of Series of Atomic Nuclei (Atomic Species)

Certain regularities in the system of atomic nuclei are made more apparent by a separation of the atomic species into the four following series:

A. Even Series
   1. Helium-Thorium ($4M$) Series
   2. (Lithium 6) -Uranium ($4M+2$) Series

B. Odd Series
   3. Lithium 7 or lithium ($4M+3$) Series
   4. Beryllium 9 or beryllium ($4M+1$) Series

Thus the helium-thorium series (Fig. 7) exhibits a regular pattern as shown: the isotopic number increases by 4 at each step, and between calcium

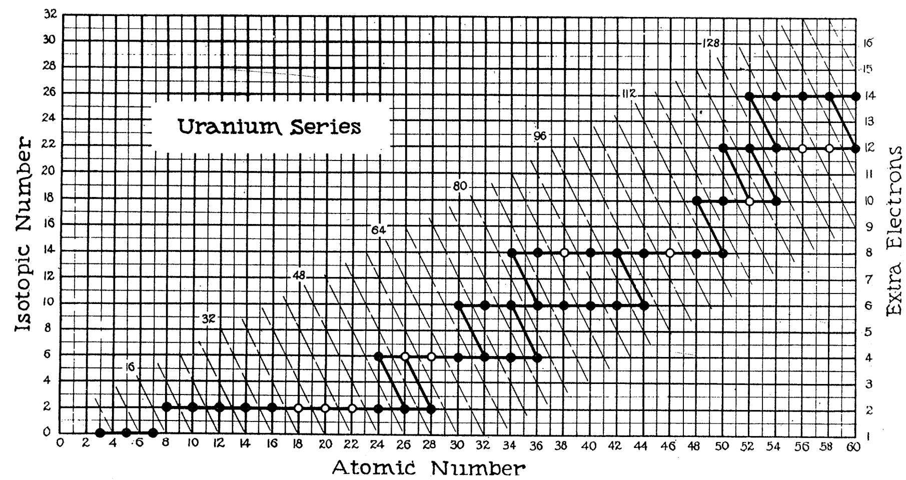

Fig. 8.

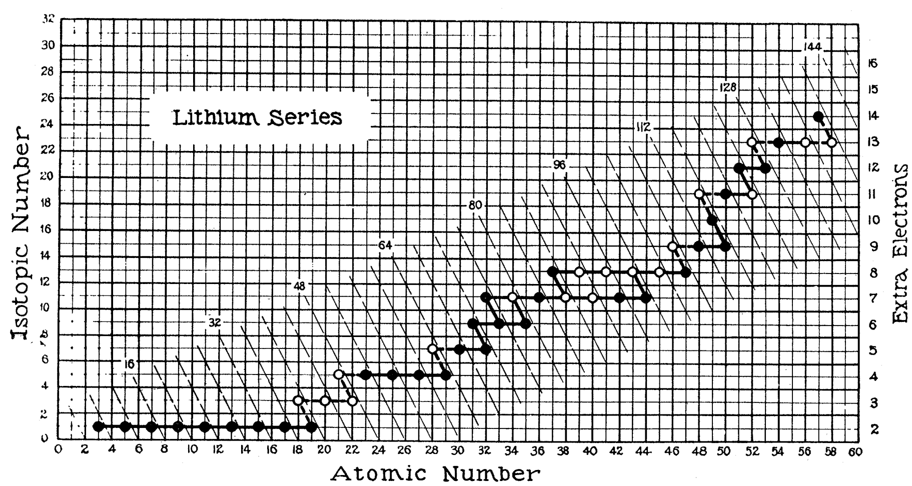

Fig. 9.

($P=40$, $n=0$) and argon ($P=40$, $n=4$) the atomic number decreases by two as the isotopic number makes its first step above zero. According to the principle of continuity all species which belong to the series and which lie on a line of constant isotopic number between the limits of known species are in general supposed to exist.

Thus the principle of continuity definitely predicts the following species: strontium ($n=8$, $P=84$), zirconium ($n=8$, $P=88$), palladium, two unknown species ($n=12$, $P=104$, and $n=16$, $P=108$), cadmium ($n=12$, $P=108$), tellurium, two unknown species ($n=12$, $P=120$ and $n=16$, $P=126$), or seven species in all, while 47 of the 54 species are now known.

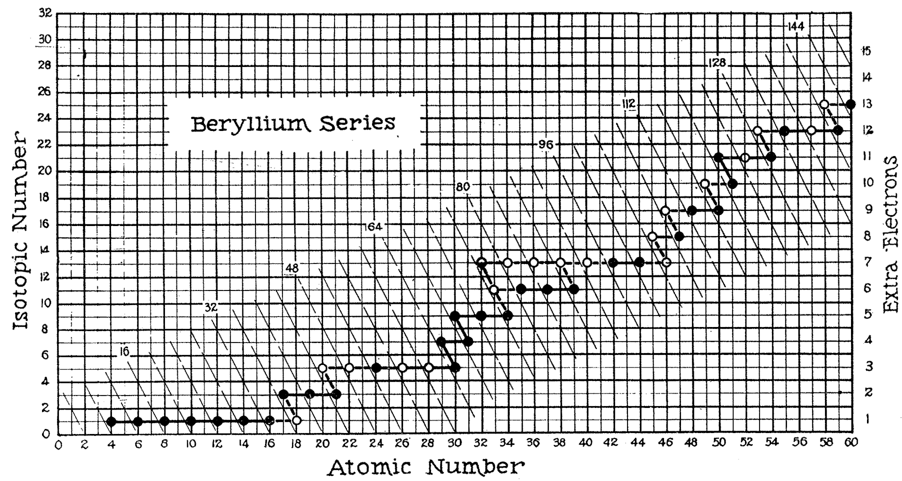

Fig. 10.

Species such as germanium ($n=4$, $P=68$) are not so definitely predicted, for here the existence of nickel ($n=8$, $P=64$) would meet the condition of regularity as well. It is also not so certain that the particular type of regularity which would be preserved by the existence of either of these two species is so persistent as the general form of the pattern otherwise.

There are undoubtedly great differences in the stability of species along any line of constant isotopic number, just as in the radioactive series, It, therefore, need not be surprising if a small number of species predicted by this principle remain undiscovered until much more delicate means of detection are discovered.

What is more apparent, however, is that the isotopic composition now given for such elements as strontium and barium is entirely inadequate, that zirconium contains a lower isotope than is now known, etc. The principle indicates that masurium ($Z=43$) has either an isotope of mass number 97 or of 99, and that probably both are present. The following table gives the length of each level as at present known:

This agrees with Latimer's nuclear model which is based on a part of the above relation expressed by Fig. 7, as given by the writer[5] in 1921.

[5] Harkins, Phil. Mag. **42**, 306, Pl. XII (1921).

Level	Isotopic Number	Number of Species Between Known Limits	In Table
1	0	10	10
2	4	7	8
3	8	8	8
4	12	10	10
5	16	8	8

The helium-thorium series is shown in another form in Fig. 11 in which lines of constant atomic number have a slope of 2, and the atomic number at the X-axis is twice the number of α-particles, and the number of electrons 2 times the number of α-particles plus the number of cementing or extra

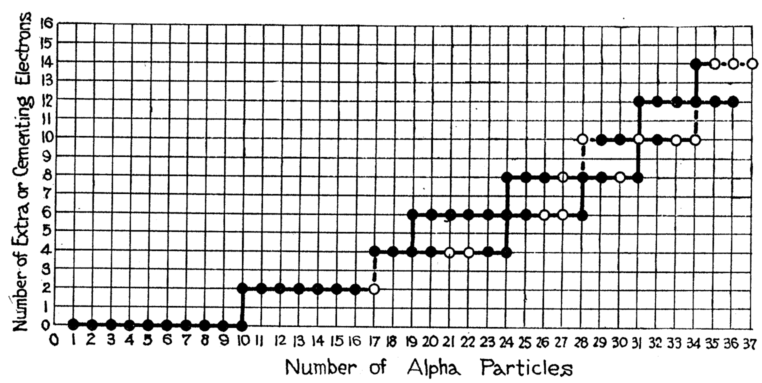

Fig. 11. The helium-thorium series. The atomic number is twice the number of alpha particles minus the number of cementing or extra electrons.

electrons. This form of representation was used early by the writer and has been adopted by Gamow and others.

The uranium series is much like the thorium series, but shifted two isotopic numbers higher.

A marked difference occurs in that the two lowest levels are only two isotopic numbers apart, but this is due to the presence of the three abnormal species of Class IV.

Level	Isotopic Number	Number of Species in Known Series
0	0	(3)
1	2	11
2	6	7
3	10	8
4	14	9

Here as in the thorium series levels 1 and 4 are the longest.

Odd Series. The odd series exhibit extremely interesting relations. Thus the two series would become almost coincident if the atomic number of every species in the beryllium series were increased by one. Unlike the even series, which occupy even isotopic levels but not in common (exception Class IV), each of the two odd series occupies every odd isotopic level. Like the even series the first level is especially long.

The lithium and the beryllium series together constitute what may be considered as a single combined or odd series.

9. The Ratio of Nuclear Electrons to Protons and the Isotopic Number

The isotopic number, defined in Section 1, has not come into general use, because, although it is an entirely natural and necessary number, it does not seem to be related to a sufficiently simple characteristic of atom nuclei to make it easily comprehensible to physicists or chemists in general. If, as in Fig. 12, the ratio of nuclear electrons to protons is plotted on one axis, and the atomic number (or the number of protons) on the other, it is found that every point which represents an atomic species lies on one of 55 lines. These

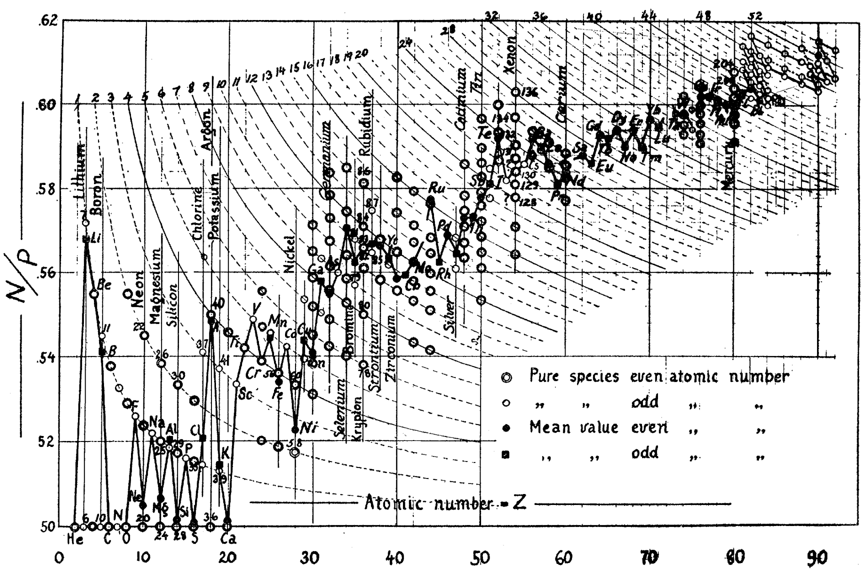

Fig. 12. Variation of the relative negativeness (N/P) of atomic nuclei with their net positive charge (z).

lines give the isotopic number. In Fig. 12 one of these lines is straight, while each of the others has nearly the form of one branch of an equilateral hyperbola. The straight line, which is thus different from all the rest, is given the isotopic number zero, and the curved lines are numbered from 1 to 54.

As has already been shown by the writer the stability of an atomic nucleus is highly dependent upon the values of N/P and Z. Thus as the net positive nuclear charge (Z) grows larger the relative negativeness (N/P) of the nucleus must also increase if the nuclei formed are to be stable. For any value of Z stable nuclei have a certain range of values of N/P.

The present known range for N/P is largest for lithium (0.071), is 0.055 for beryllium and oxygen, 0.045 for selenium, and almost this last value for tin and germanium. The range of N/P decreases in general as the nuclear positive charge (Z) increases. It is appreciably less than 0.02 for mercury or any radioactive element.

The range in the known isotopes of sulphur ($Z=16$) is 0.029, which is abnormally low for a light element. According to the early theory of the writer, adopted in Latimer's recent nuclear model, this is due to the fact that in the sulphur nucleus the first pair of cementing elections, which are present in argon 40 ($Z=18$), have not as yet entered the nucleus. Thus in addition to a matching of N/P and Z in the nucleus, certain specific constituitive influences affect the stability.

No atomic species is known in which the ratio N/P is greater than 0.62.

10. The High Abundance of the Chemical Elements of Even Number (Rule 3)

The theory of nuclear structure and stability developed by the writer[1] in 1915 indicated that the elements of even number should be much more stable and abundant than those which are odd. It is very surprising that such an important and striking fact should have remained so long unrecognized.

The data which supported this rule were considered comprehensively in the 1917 paper.[2] However the great progress made since that time in the investigation of the abundance of the elements in the rare earths by Goldschmidt, in the meteorites and in the earth's crust by Ida and Walter Noddack, in the atmosphere of the sun by Russell, and in the stars by Payne, as carried out by x-ray and ordinary spectroscopic methods,[6] makes it essential to consider the relationship between the rule and the newer data. This is particularly important, since, as was predicted when the rule was discovered, its application in connection with cosmic composition is now found to be of fundamental importance.

Thus the newest data indicate that the atomic nuclei of the elements of even number are 50 times more abundant in the meteorites, 10 times more abundant in the surface of the earth, 10 times more abundant in the atmosphere of the sun, and more abundant, by an unknown factor, in the stars than the elements of odd number.

The meteorites give the best idea of the composition of material in general, since they are more available for analysis than the stars, and come from much more widely distributed regions than the crust of the earth. The six most abundant elements in the meteorites are all even in atomic number, and these six alone contain 97 percent of all of the atoms in the meteorites. Their relative abundance in terms of number of atoms is as follows:

Oxygen	1
Iron	0.59
Silicon	0.30
Magnesium	0.25
Nickel	0.42
Sulphur	0.04

[6] V. Goldschmidt and Thomassen, Videnskaps. Skrift. I. Mat.-naturw. Kl. 1924, No. 5. I. and W. Noddack, Naturwissenschaften **18**, 757 (1930); H. N. Russell, Astrophys. J. **70**, 11 (1929); Miss Payne ,Stellar Atmospheres (Harvard Observatory Monographs, No. 1), Cambridge, Mass., p. 184 (1925).

The recent data of Ida and Walter Noddack are represented in Fig. 13. All of the high peaks are for elements of even number. Of all of the 31 peaks only one, for arsenic, represents an element of odd number. This element

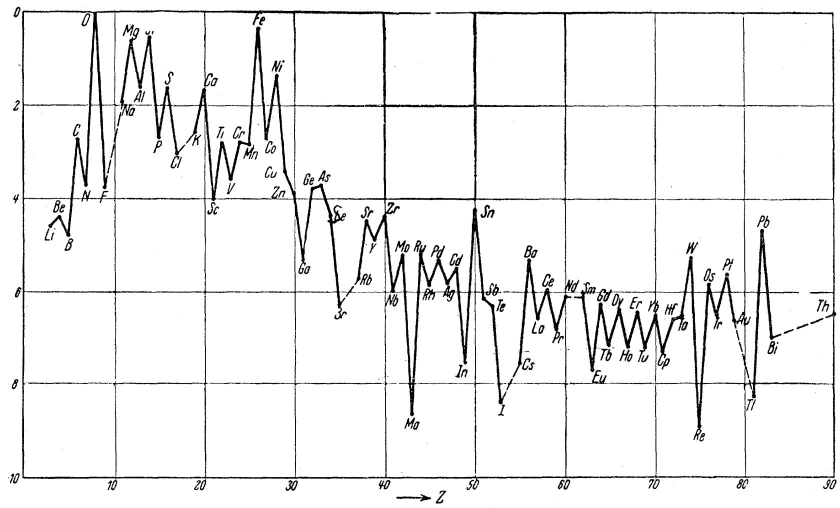

Fig. 13. Logarithm of the atomic abundance of the elements in the meteorites (Noddack). (Abundance of oxygen taken as unity).

seems anomalous in the earth's crust also, with an abnormally high abundance (only 5.5×10^{-6} parts by weight, however) and is found to have an abnormally

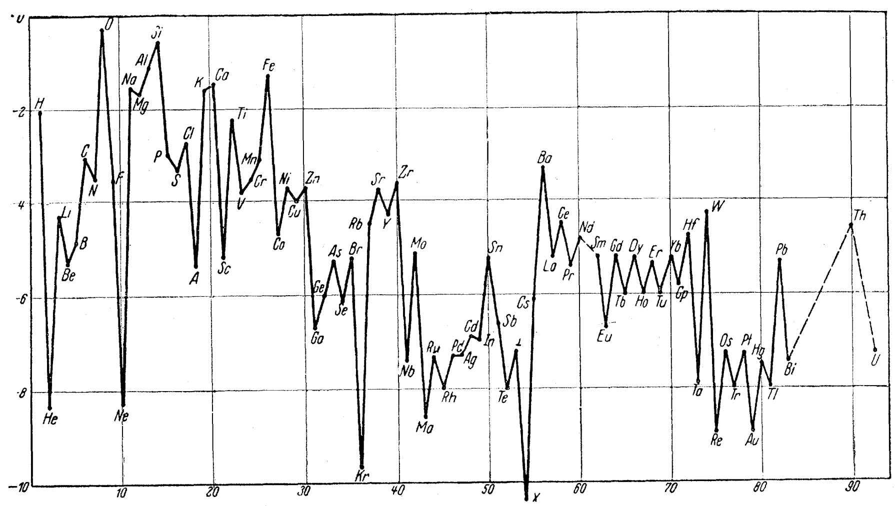

Fig. 14. Logarithm of the atomic abundance of the elements in the earth's crust. (Noddack). (Fraction of the total number of atoms.)

low abundance in the atmosphere of the sun. Fig. 14 represents the crust of the earth, in which 32 of the 34 peaks (hydrogen excluded) represent elements of even number.

The fact that the lowest troughs occur for the rare gases indicates that here the chemical and physical characteristics rule, and not the stability of the nuclei. Otherwise masurium, rhenium, and gold are the rarest in the earth's crust, and masurium and rhenium in the meteorites.

In general in both the meteorites and the earth's crust, each element of even number is much more abundant than either of the two adjacent elements of odd number. In individual cases where this is not true the element of even number is more abundant than the arithmetic mean of the two that of the two adjacent elements of odd number.

Concerning the atmosphere of the sun Russell states "Every element of even number except beryllium, is more abundant than the mean of the adjacent elements, and every odd element less abundant, with the exception of europium, for which the data are uncertain. Among the rare earths only those with even atomic numbers have been conclusively identified in the sun". He adopts the early idea of the writer that the low abundance of lithium and beryllium may be due to the small number of the component parts of which their nuclei are built: too few to give high stability. It should be remembered that there are several types of stability.

11. The Pairing of Nuclear Electrons and the High Abundance of Atomic Nuclei of Even Electronic Number (Rule 1)

The theory that the electrons in the nucleus are almost always associated in pairs was developed on the basis of the "hydrogen-helium" theory[1] according to which the nucleus of the atom is built up of groups of the composition of alpha particles, and other groups, almost all of which contain a pair of electrons. In addition it was noticed that cementing electrons occur in general in pairs. Thus in the 26 light species listed in 1917[7] the formulae give 209 pairs of electrons to 2 unpaired electrons. The pairs seem to be more prominent still in the heavier atoms.[8]

The theory that the electrons are associated in pairs suggested Rule 1, according to which nuclei in which the electronic number is even are extremely more abundant than those in which it is odd.

Only two species of odd electronic number for which the atomic fraction in the earth's crust is greater than 1×10^{-5} are known;—magnesium 24 and silicon 29. Of the 214 atomic species listed in Figs. 2 and 3 as discovered by radioactive means, by positive rays, or by band spectra, 52 or nearly one-fourth have an odd electronic number. However, the species of odd electronic number have an extremely small abundance. Thus there seem to be at least 125 atoms of even to one of odd electronic number in the earth's crust. The most important experiment in this connection would be to determine accurately the quantitative isotopic composition of silicon and magnesium.

Although recent theory attributes nuclear spin entirely to the protons of the nucleus, and although there seems to be some connection between nuclear spin and stability, the above considerations seem to indicate that the

[7] W. D. Harkins, J. Am. Chem. Soc. **39**, Table II, 859 (1917).

[8] W. D. Harkins, Phys. Rev. **15**, Tables II and III, pages 85 and 86 (1920).

pairing of nuclear electrons is a more fundamental phenomenon in relation to stability than spin. Up to the present time the new quantum mechanics has not been successful in bringing this most fundamental pairing into the theory. This type of pairing seems in some way to be associated with the presence of protons. The pairing of electrons in the nucleus, as discovered by the writer, is more general, and represents a much more intimate association, than their pairing in molecules as found by Stark and G. N. Lewis.

12. Atom Building in Steps

The general relations presented in this paper, especially those concerned with the principle of continuity and regularity of series, and with the relations of the most abundant isotopes, suggest strongly that atom nuclei are built in steps, and not in single events. That is they seem to be in entire disagreement with the idea that atomic nuclei are all formed almost instantaneously (say 10^{-12} seconds) as is assumed in the theory of Millikan and Cameron.[9]

That atoms are actually built in steps under some conditions is demonstrated by the well known synthesis of oxygen 17 from nitrogen 14.

13. Atom Building by Neutrons

There is no evidence whatever that neutrons, or electrically neutral nuclear particles, play any part in atom building, or even that they exist. However the difficulty which a positively charged particle would in general have in penetrating the potential barrier around a nucleus of high charge, suggests that some other process may be utilized in the formation of atomic nuclei. Proceeding from this point of view both Rutherford and Harkins suggested independently in 1920 that such neutral nuclear particles (neutrons) may add themselves to atomic nuclei.[10] The same idea has been revived by Langer and Rosen[11] who seem to consider it to be an entirely new suggestion. Neutrons could not be detected by chemical means, and their percentage in the earth's crust would be very minute, provided they exist.

Rule 2, according to which the ratio of electrons to protons in any nucleus which contains both, is in no case less than $\frac{1}{2}$, is not in discord with this idea, but the fact, shown so plainly in Fig. 12, that there is no known nucleus in which this ratio is more than 0.62, shows that the existence of neutrons would give an entirely different order of magnitude for this ratio. This seems to indicate that neutrons may not exist, but the simple neutron (*pe*) represents a limiting case, which might well be an exception to the rule.

If, as is now supposed, nuclear spin is associated entirely with electrons, the simple neutron would be expected to exhibit a spin of $h/2\pi$. The general properties of neutrons and neutronal material as assumed by Langer and Rosen are the same as those given earlier.

[9] R. A. Millikan and Cameron, Phys. Rev. **31,** 921 (1928).

[10] W. D. Harkins, J. Am. Chem. Soc. **42,** 1965 (1920), Chemical Reviews, **5,** 431 (1928). Ernest Rutherford, Proc. Roy. Soc., London, **42,** 1964 (1920).

[11] R. M. Langer and N. Rosen, Phys. Rev. **37,** 1579 (1931).