A NEW REGULARITY IN THE LIST OF EXISTING NUCLEI

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Abstract

In the absence of a theory of nuclear constitution, a search for regularities in the list of existing nuclear types is of value. Aston's data form a fairly complete list up to atomic number 61. Previous investigations disclosed evidence of several types of regularity. A new type has been observed in which most of the known nuclei in the range studied fall into three clusters, each characterized by a two dimensional symmetry. More specifically, when the nuclei are plotted as points whose ordinates and abscissas indicate the number of protons and electrons respectively in their constitution, there exists for each cluster a center (P, E) such that if there is a nuclear type $(P-X, E-Y)$ there is, in general, also a symmetrical type $(P+X, E+Y)$. A consideration of the relatively few departures from this rule within the clusters leads to a list of *predicted isotopes* as yet undiscovered. A possible physical interpretation of the new type of regularity is tentatively suggested. The considerations advanced apparently do not apply to a number of points scattered through the regions between the clusters.

Introduction

There is no comprehensive theory of the structure of atomic nuclei. The present position is one in which it is very desirable to examine the available data in search of empirical laws with which to simplify the statement of what is known. The list of nuclei embracing all known isotopes of all elements which actually exist, in contra-distinction to those conceivable nuclei which do not, presents a fruitful field for such a scrutiny. Any rule or regularity of occurrence which can be found will facilitate the development of a satisfactory theory. Beck[1] has pointed out that Aston's work has now furnished a body of excellent data[2] covering nearly all elements up to atomic number 61. A knowledge of the isotopes of many elements heavier than this is as yet lacking so that the data do not have the completeness which is necessary, or at least most desirable, when it is a question of the existence or non-existence of each possible nucleus. Only that part of the list of elements which lies below atomic number 61 is considered in the present paper. For such a list presented in significant tabular form the reader is referred to Beck's papers.

The considerations which Beck advances lead to valuable rules in addition to those already noted by others.[3] The work of Harkins,[4] based on evidence

[1] G. Beck, Zeits. f. Physik **47**, 407 (1928); **50**, 548 (1928).

[2] F. W. Aston, Phil. Mag. **49**, 1191 (1925); Proc. Roy. Soc. **A115**, 487 (1927), p. 509.

[3] A summary of speculations about nuclear constitution and structure is given by E. N. da C. Andrade, "The Structure of the Atom," Chap. VII.

[4] W. D. Harkins, Science **70**, 433 and 463 (1929). Zeits. f. Physik **50**, 97 (1928). Also many earlier papers references to which are made in the two cited.

concerning the relative abundance[5] of the elements in the earths crust and in meteorites, has been particularly fruitful in establishing rules governing the existence and stability of nucleur types. The kinds of regularity pointed out by these and other authors deal with the numbers of α-particles, protons, and electrons in the nuclei. For example, the fact that mass increments of four units together with charge increments of two units occur frequently in almost any sort of classification gives strong evidence of the existence of

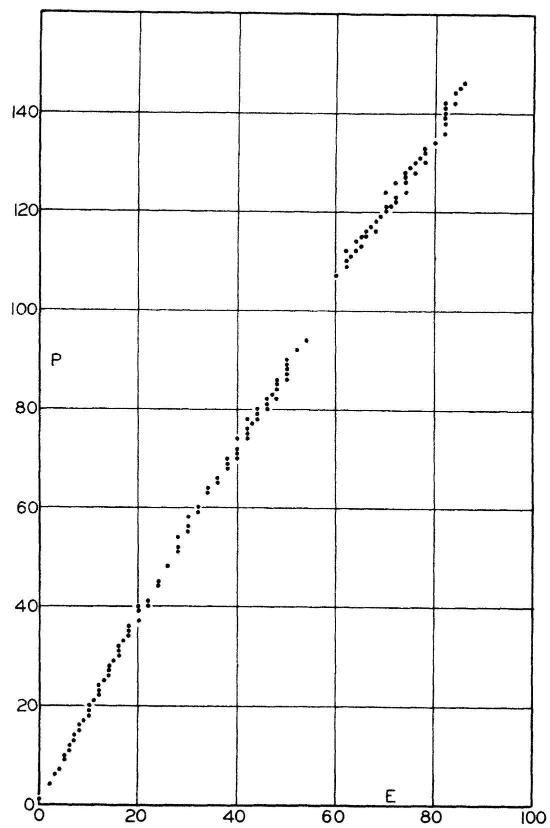

Fig. 1. Constitution of all known nuclear types in the range of elements below atomic number 61.

nuclei which differ from one another merely in the number of integral α-particles they contain. Other rules are, for example, the tendency for the number of nuclear electrons to be even, the limitation to two isotopes in the cases of elements of odd number, etc.

A New Type of Regularity

The writer has recently observed an altogether different type of regularity which does not seem to be described in the literature. It appears when a

[5] F. W. Clark, "The Data of Geochemistry," Bulletins **491** (1911) and **616** (1915), U. S. Dept. of the Interior. "Evolution and Disintegration of Matter," U. S. Geol. Surv., Prof Paper **132-D** (1924). W. D. Harkins, J. Am. Chem. Soc. **39,** 856 (1917).

suitable chart is made of the constitution of the existing nuclei. Fig. 1 is such a chart in which a point is plotted for each nucleus opposite the ordinate P representing the number of protons it contains and the abscissa E representing the number of electrons it contains. P, the number of protons, is approximately equal to the atomic mass. E stands for *all* of the nuclear electrons whether constituting α-particles or not, so the atomic number, or nuclear charge, Z, is equal to $P-E$. The chart was compiled from Aston's data.

It is evident even on this small scale chart that there are three clusters of points separated by regions of relatively low density, i.e., where the ratio of the number of actual to conceivable nuclei is relatively small. The clusters themselves are individually of interest. A superficial examination of a small

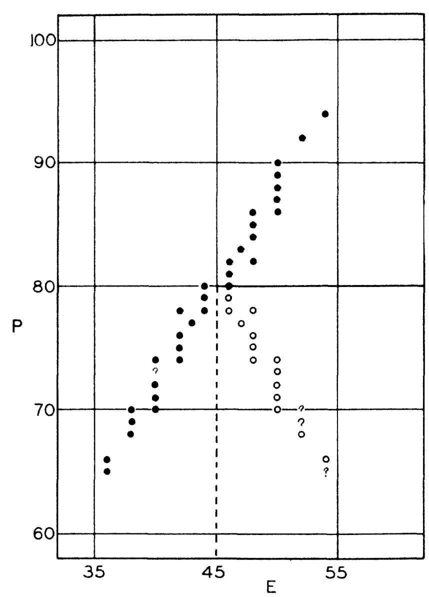

Fig. 2. Enlargement of the middle portion of the chart in Fig. 1 to show the two-dimensional symmetry of the cluster. (Cluster II.)

chart such as Fig. 1 gives little basis for specifying the limits or centers of the clusters. On a larger scale, however, it is apparent that in each group there exists a regularity in the form of a two dimensional symmetry about a definite point near the center of gravity of the clusters. For example, Fig. 2 shows the region of Fig. 1 occupied by the middle cluster. The solid dots are the same as those of Fig. 1. The circles show the positions occupied by the dots in the upper right quadrant if that quadrant is rotated 180° around the axis of symmetry $P=80$. The extent of the symmetry can now be estimated at a glance. In this cluster, evidently centered at $(P, E)=(80, 45)$, the symmetry is perfect except that in the cases of four out of the thirty-two points plotted, the symmetrically located positions are vacant. Such vacant positions are indicated by question marks.

Similar charts of the clusters in the regions of heavier and lighter elements respectively are shown in Figs. 3 and 4. In the cluster made up of heavier elements, it is noteworthy that the symmetry, centering at (124,72) consists largely of two long diagonal lines of points. One of these, starting at (124, 74), runs one way to (112,62), and the other starting at (124, 70), runs the other way to (136,82). The one represents the isotopes of tin and the other the isotopes of xenon. Although two positions are vacant in the case of xenon, the end positions of the two lines are symmetrical, and in each case, the outer end is followed by several points in a vertical row.

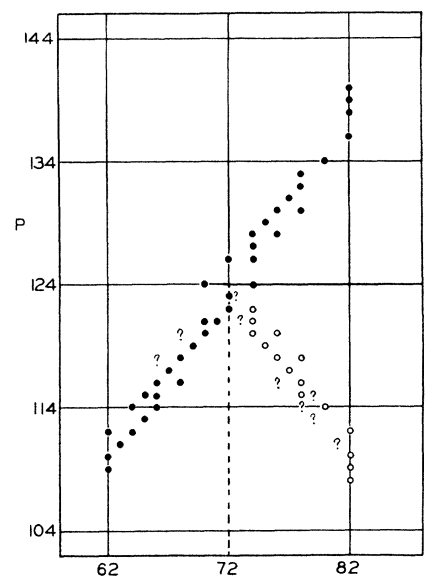

Fig. 3. Cluster III; heavier elements.

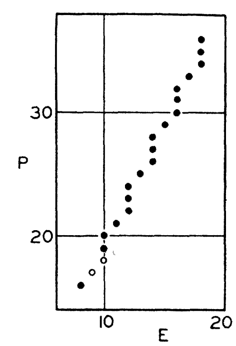

Fig. 4. Cluster I; lighter elements.

The cluster in the region of lighter elements presents so simple a type of symmetry that the center cannot be located without ambiguity. The point (25,13) would serve as well as (27,14). The discovery of the new oxygen isotopes[6] (shown by circles) would tend to shift one's estimate of the "center of gravity" of the cluster downward.[7]

Aston has recently published the result of some further experiments with the mass spectrograph.[8,9] These must be considered now in so far as they

[6] W. F. Giauque and H. L. Johnson, Nature **123,** 318 and 831 (1929). J. Am. Chem. Soc. **51,** 1436 (1929).

[7] It is interesting to note that the new oxygen isotopes are nuclei which would have been predicted by extrapolation of the obvious step-like regularity of the cluster.

[8] F. W. Aston, Nature **120,** 224 (1927); **122,** 167 and 345 (1928).

[9] The writer was not aware of these when he published a preliminary notice. (Phys. Rev. **34,** 1228 (1929)). He wishes to take this opportunity of also acknowledging his error in including in that notice a nuclear type (80+11, 45+7) which has not been shown to exist. Beck has postulated its existence on fairly firm grounds. However, the writer wishes to confine himself to Aston's experimental data with the addition of the isotopes 17 and 18 of oxygen, 15

affect the symmetry of the clusters. New isotopes of lead, mercury, germanium and zinc are announced. It is not of interest for the present purpose to add the corresponding points to Fig. 1. In fact, lead and mercury are above the range of elements investigated. The isotopes of germanium and zinc alter only Cluster II. To bring Fig. 2 up to date it would be necessary to add points corresponding to the additional isotopes of germanium and zinc, namely (73, 75, 76, 71 and 77) and (67 and 65) respectively. The previously known isotopes were of course already plotted in Fig. 2. None of the new points falls into a position symmetrical with one already existing. The symmetry of this cluster is thereby considerably impaired although strong evidence of the tendency remains.

Aston states[8] that it is impossible to exclude the possibility that the mass spectrum lines representing some of these isotopes really represent hydrides of the previously known isotopes. Germanium is known to be like carbon in its tendency to form unstable hydrogen compounds, so it would be expected that such hydrides would appear in the discharge tube in the same way as CH, CH_2, etc. appeared when compounds of carbon were present. The symmetry considerations would be helped if this were found to be the case. On the other hand, it may be that here is an example of the danger of working with only partially gathered data. The relative abundance of the new isotopes is obviously very small since they escaped discovery in Aston's previous study of germanium. It is possible that symmetrical nuclear types of the same order of abundance (very faint isotopes of strontium) may yet be found to restore a high degree of symmetry to the cluster. It is because of these reservations that the cluster has been plotted without, rather than with, the new data.

Discussion

The boundaries of the three clusters as represented in Figs. 2, 3, and 4 are of course, arbitrarily chosen. However, it can be said that there is good evidence of symmetry just inside these boundaries and little of such evidence just outside. There remain, then, the regions below and between the clusters in which fall the points of a number of very common nuclei, among them hydrogen, helium, carbon, calcium, and iron. In these regions no evidence of symmetry has been discovered, so that no claim for applicability over the whole list of natural elements can be made for the type of regularity described in this paper.

Alternative points of view may be taken with regard to the departures from perfect symmetry within the clusters. The vacant positions may be vacant only through lack of data. On the other hand, the existing points symmetrical to these vacant positions may represent nuclei not properly belonging to the cluster in some sense which we do not now know how to define. The first alternative may at least be adopted tentatively. On this

of nitrogen, and 13 of carbon discovered through the band spectra of compounds of these elements. See Ref. 6; also A. S. King and R. T. Birge, Nature **124,** 127 (1929); Phys. Rev. **34,** 376, 379 (1929); S. M. Naudé, Phys. Rev. **34,** 1498 (1929).

basis it is predicted that the question marks in Figs. 2 and 3 represent isotopes which should still be found, perhaps in very small quantity. A list of the isotopes so predicted is given in Table 1.

TABLE I

P, E	Z	Element	Remarks
		(*Cluster II*)	
73,40	33	As	Note 1
90,52	38	Sr	
91,52	39	Y	Note 1
95,54	41	Nb	Note 2
		(*Cluster III*)	
108,62	46	Pd	
118,66	52	Te	
120,68	52	Te	
125,72	53	I	Note 1
127,73	54	Xe	
133,79	54	Xe	
132,76	56	Ba	
134,78	56	Ba	
135,79	56	Ba	Note 3
137,81	56	Ba	

Note 1. Gives this odd element two isotopes at usual mass interval of two units.

Note 2. Isotopic constitution entirely unknown. Atomic weight of 93.1 would suggest strongly the two isotopes 93 and 95 following the rule for odd elements referred to in Note 1.

Note 3. Atomic weight of 137.37 indicates existence of some isotopes lower than the known 138.

At the foot of the table are some notes as to independent reasons for expecting these isotopes to exist or not to exist in the several cases.

The additional isotopes of germanium and zinc, to which reference has already been made, would demand, on the basis of symmetry, the isotopes 83, 84, 85, 87 and 89 of strontium and 93 and 95 of zirconium.

Even if complete data do not make the symmetry perfect, it is nevertheless a strongly marked tendency and calls for explanation. There is probably not sufficient basis as yet for the serious advancement of a theory. As a point for discussion, however, the suggestion which follows is not out of order.

Consider, for example, the middle cluster whose center is at the point (P_2, E_2) representing a conceivable nucleus consisting of 80 protons and 45 electrons. That this nucleus apparently does not exist is a matter of no concern. Suppose that at an early stage in the evolution of the matter from which terrestrial matter was drawn, there were formed fairly abundantly nuclei of constitution ($2P_2$, $2E_2$), i.e., (160, 90) containing just twice as many protons and electrons as the center of the symmetrical cluster. Such a nucleus has not been found to exist in the earth's crust and may hypothetically be regarded as unstable. Suppose there to be a tendency on the part of this nuclear type to break into just two nearly (but not precisely) equal parts. The products of any one such event would be ($80+X$, $45+Y$) and, since the second part is postulated to contain the rest of the nuclear matter, ($80-X$, $45-Y$). Obviously there would thus come into existence always two nuclei symmetrically located X, Y and $-X$, $-Y$ units respectively from the symmetry center (80, 45). The possible values X, Y would presumably be governed by nuclear forces of cohesion. That is, like a crystal, the nucleus might have particular surfaces of division more probable than others.

To explain the three observed clusters, three transitory parent nuclear types must be postulated. They would have the constitutions: a) (248, 144) representing an element a little beyond uranium and, therefore, almost certainly unstable; b) (160, 90) falling near the upper region of the rare earths; and c) possibly (54, 28) the lesser isotope of iron, or (50, 26) an unknown isotope of chromium.

Nothing has thus far been said about the relative abundance of the nuclear types. On the basis of the suggestion that symmetrical nuclei are natal twins, the observed symmetry of existence would be expected to extend itself to a like symmetry of abundance. Roughly speaking this is not found to be the case. A test of such a consideration is difficult when the elements involved are different chemically. It is possible, however, to observe whether the course of abundance of the isotopes of tin corresponds symmetrically to that of the isotopes of the symmetrically located element xenon. Aston places the tin isotopes in the order 120, 118, 116, 124, 119, 117, 122, 121, 112, 114, 115. A comparison of the symmetrical order for xenon with the observed order of that element is given below:

Expected from symm.	128, 130, 132, 124, 129, 131, 126, 127, 136, 134, 133
Found by Aston	129, 132, 131, 134, 136, 128, 130, 126, 124

It may well be the case that an initial symmetry of abundance has ceased to exist on account of differences in the stability of the several nuclear types, and only the symmetry of existence remains as a relic of the originating process.

Before concluding, it should be acknowledged that the suggestion outlined may be entirely supplanted by an assumption of inherent symmetry in the rules giverning the stability of the nuclei. Probably no more explicit statement in this vein may be made for the present.