The Characteristics of "Specific" Zones

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Twenty characteristics distinguishing the "specific" zones from the rest of the nuclide system are listed. Almost all characteristics are substantially different for odd and even Z. The author's opinion is that the specific zones cannot be considered as regions influenced by the "magic" numbers; on the contrary, the "magic" numbers are considered a consequence of the specific zones.

IN 1947 I pointed out[1] specific regions (zones) in which the atomic numbers Z have many properties that distinguish them from all other Z numbers. The first such property is that the odd Z of these regions each have two isotopes. This first distinction vanishes if the atomic nuclei are characterized by the A number rather than the Z number. In this case, however, there are several nuclides having the same A number (two and sometimes even three), but they do not fall in any specific zones. Apparently, it is sensible to assume that Z (the proton number) is the principal characteristic of the nucleus, for there can be no atomic nucleus without any protons. Although the neutron, in accordance with modern representations, is an equally valid component of the atomic nucleus, we nevertheless do not know of any real nuclide consisting of neutrons alone. An atom of matter exists only if it contains a proton. Following Cherdyntsev's initiative, Goeppert-Mayer and Teller advanced a hypothesis concerning polyneutron bodies, but such were never observed. The number Z establishes not only the chemical, but also the physical, nature of matter.

The regions referred to are the Z-number intervals from 16 to 20 (first specific zone); from 28 to 38 (second specific zone, which is, however, more complicated in character) from 46 to 52 (or 54) (third specific zone), from 58 to 62 (or 64) (fourth, not clearly defined) and from 72 to 82 (fifth specific zone, also complex). I tried to prove in several articles certain specific properties of these zones. However, my attempts to highlight them apparently were not recognized by other physicists. Recently, I found still another set of features that distinguish these Z regions and I am listing below all the features, both old and new, in order to exhibit more clearly the role of these regions in the formation of the nuclei.

1. The first feature, as was already indicated, is the existence of two isotopes for odd Z. However, the specific zones extend somewhat beyond this region and include also the neighboring even Z. In Fig. 1, a dotted line passing through all the curves marks the specific zones. The fourth zone, for which no complete data are available, is not marked.

2. The second distinct feature is the discontinuity in the number of free neutrons of the most abundant isotope (see reference 1). It is very clearly pronounced up to $Z = 43$, and then becomes less and less distinct.

3. The third remarkable feature is the symmetric distribution of the odd nuclei with two isotopes about the above-mentioned discontinuity in the number of free neutrons.

4. The fourth feature is the accumulation of the maximum number of odd-Z isotopes in this region. This is shown by curve *I* of Fig. 1.

5. Curve *II*, showing $(N_{max} - Z)/Z$ for the odd nuclei corroborates the fourth feature. Curve *II* has maxima at the same points as the first curve.

Curve *II′* shows $(N_{min} - Z)/Z$ versus Z. It also points to a certain connection with the specific zones, although not as clearly as curve *II*. On the other hand, curve *III*, which gives $(N - Z)/Z$ for the most abundant isotopes, does emphasize feature No. 2 and accentuates the specific zones very sharply.

A characteristic feature of the nuclide system is the clearly pronounced pairing of the nuclear particles. Nuclei with even numbers of protons play a predominant role among the nuclei. The neutrons occur mostly in even numbers. Even Z have predominantly even N, odd Z always have

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[1] M. A. Levitskaia, Dokl. Akad. Nauk SSSR 55, 399 (1947)

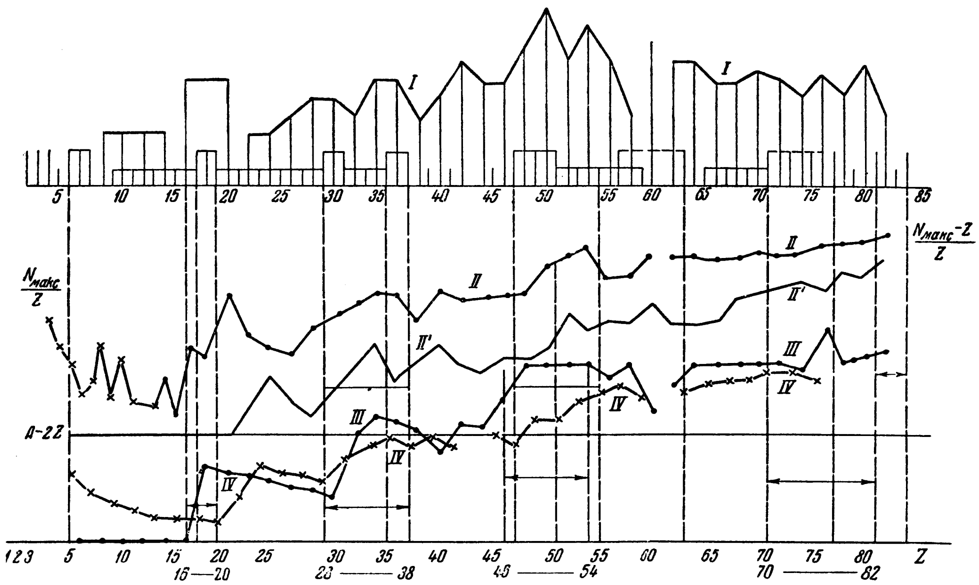

FIG. 1. Curve I -- number of stable isotopes versus Z; II -- $(N_{max} - Z)/Z$; II' -- $(N_{min} - Z)/Z$; III -- $(N - Z)/Z$ for maximum abundance isotopes; IV -- number of neutron pairs divided by number of proton pairs.

even N, except for the La^{138}_{57} nucleus which turns out to be naturally radioactive. We shall discuss only values of Z for the stable nuclides, that is, we shall consider Z up to 84. The very close relationship between the proton and the neutron is universally known. This connection is also clearly exhibited in a system in which the nuclei become more complicated. We shall therefore pay attention to the pairing feature. This points to a sixth characteristic:

6. The ratio between the number of neutron pairs and the number of proton pairs also reaches a maximum in the specific zones (curve IV). This feature is naturally not independent but is a corollary of the fifth one.

Of interest in connection with the pairing of particles is the existence of odd N. This is observed only in conjunction with even Z. If we follow the sequence of nuclei having even Z, we see that a nucleus having odd N occurs once for all Z up to 48, except $Z = 18$, in which there is no such nucleus, and $Z = 42$, which has two such nuclei, evidently because of the neighboring unstable $Z = 42$. Every even-Z nucleus above $Z = 48$ has two odd-N isotopes, except for $Z = 50$ and $Z = 60$, in which there are three such nuclei, $Z = 58$ which has none, and $Z = 66$, 74, 73 and 82, which have one each. No specific zones are indicated with respect to the number of nuclei with odd N. However, if we list the values of odd-N in sequence, they behave in a regular fashion up to $Z = 16$, starting with unity (at $Z = 2$); at $Z = 16$ there is a discontinuity of 6, and further on we observe a discontinuity by 4 in the specific zones.

7. The seventh feature are the discontinuities in the consecutive even N (even nuclei) in the specific zones.

The discontinuities result in dropping out of several odd N, which generally are not found in the stable nuclei at all: 19 and 21 in the first specific zone, 35, 39 and 45 in the second, 57 and 61 in the third, 89, 115 and 123 in the fifth. This points to the following feature:

8. The specifc zones contain values of odd N that do not correspond to a single stable nucleus.

The fact that the greatest number of isotopes and the highest values of N/Z, and with this also of A/Z, are located in the specific zones, indicates that the nuclei have a maximum lifetime (maximum stability) in these zones. American investigators have introduced the concept of magic numbers of proton and neutrons. These numbers (20, 28, 50, 82 and 126) are the upper bound of the specific zones, with the exception of 28, which is a lower bound. As far as the number of neutrons goes, 20 and 28 are in the first zone, 50 is in the second, 82 is in the fourth and 126 is at the upper end of the fifth. The American investigators point at a minimum effective capture neutron cross section σ_t as being the principal feature of nuclear stability. Evidently this applies only to the slowest, thermal neutrons. The effective cross section depends strongly on the neutron energy and at higher energies we encounter cases of resonance or near-resonance. If the specific zones are regions of more stable nuclei, the minimum of σ_t should not be sharp, but sufficiently diffuse in the specific zones. It is quite difficult to plot the effective cross section as a function of Z, since different isotopes having the same Z may have different values of σ_t. Nevertheless, if one of the isotopes have a very small σ_t the total σ_t may be considerably reduced. Table 2 on page 13 of reference 2 lists σ_t for individual isotopes of various elements obtained by thermal activation.

Reference 3 contains a table of σ_t for thermal neutrons and for rapid (1 mev) neutrons. At thermal energies there are such large discontinuities in σ_t from one value of Z to the next, that it becomes necessary to plot separate curves for even and odd Z (and most ordinates have several points each at that). Curve V of Fig. 2 shows that for even Z, up to $Z = 22$, the values of σ_t are generally small, and that the minimum of σ_t is observed in Ti^{50}_{22} (isotope of low abundance), and not in Ca^{40}_{20}. This is followed by a sharp rise; a decrease starts at $Z = 28$ and we have a minimum value at $Z = 32$ to 38. A rise occurs again at $Z = 40$. A decrease starts at $Z = 45$ and small values are observed up to $Z = 58$. The minimum values are found for $Z = 50$ and 54. In regions of larger Z (there are no values up to $Z = 70$) we have extremely large values for Z from 70 to 80, which are followed by a reduction at $Z = 78$. At $Z = 82$ and 83, we have a minimum.

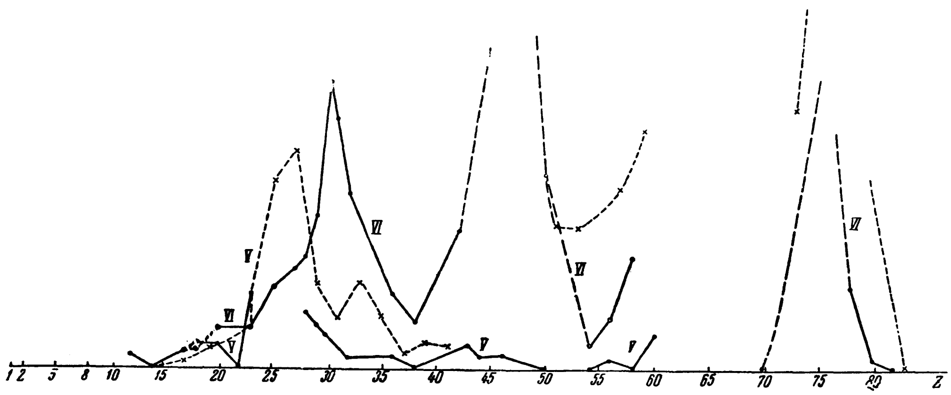

FIG. 2. Curve V -- σ_t for even (points) and odd (crosses) values of Z at thermal energies; VI -- ditto for 1 mev energy.

According to the data of the same reference the values of σ_t are generally small at 1 mev up to $Z = 20$, with a minimum at $Z = 14$ (curve VI). At $Z = 20$, a rise begins; at $Z = 28$, it is already considerable, and at $Z = 30$, we have a maximum. A decrease starts at $Z = 32$ with a minimum at $Z = 38$, followed by a subsequent decrease starting at $Z = 50$; a minimum is reached at $Z = 54$. The value is again very large in the region beyond $Z = 70$, but a decrease starts again at $Z = 80$.

I plotted σ_t from Goodman's Tables for 10 mev neutrons (curve VII, Fig. 3). He apparently gives total values of σ_t. A minimum occurs at $Z = 16$. From $Z = 16$ to $Z = 24$, there are no values for even Z. A rise starts at $Z = 24$ and a maximum occurs at $Z = 28$ (but there is no resonance here). From $Z = 30$ to $Z = 36$, we observe relatively small values of σ_t. A minimum occurs also at $Z = 50$, and an even lower one at $Z = 54$. A rise starts at $Z = 54$, and a maximum occurs at $Z = 76$. A decrease begins at $Z = 78$, but a minimum is reached at $Z = 80$; $Z = 82$ yields a large value of σ_t.

Reference 4 gives a rather large long table of

[2] C. Goodman, *Effective Neutron Cross Sections of Elements*, 1948

[3] D. J. Hughes, R. C. Garth and J. S. Levin, Phys. Rev. 91, 1423 (1953)

[4] R. H. Hildebrand and C. E. Leith, Phys. Rev. **80**, 842 (1950)

σ_t for various Z at 42 mev. The curve plotted from this table (curve *VIII*, Fig. 3) no longer exhibits the considerable discontinuities between even and odd nuclei. This curve shows clearly a smooth reduction in σ_t from $Z = 28$ to $Z = 38$ and from $Z = 46$ to $Z = 54$. The behavior of σ_t for the odd Z is approximately the same. There are undoubtedly valid grounds for stating the existence of the following features:

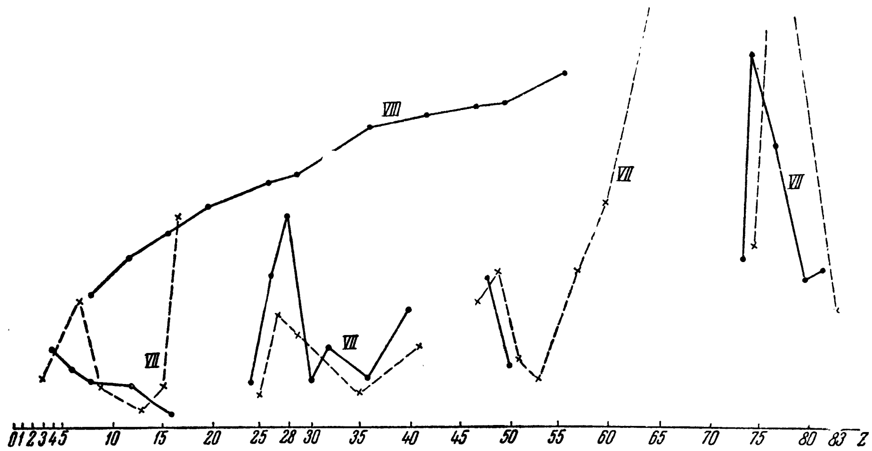

FIG. 3. Curve *VII* -- σ_t versus Z for neutrons with 10 mev; *VIII* -- ditto for 42 mev.

9. The effective capture cross sections become smaller in the region of the specific zone.

10. The magic Z numbers lie on the boundaries of the specific zones, while the magic N numbers lie at the upper bounds of the specific zones.

Let us now proceed to the radioactive properties. Four of these have already been indicated in my earlier works:

11. Naturally radioactive nuclei occur at the boundaries of the specific zones.

12. The Shchukarev-Mattauch pairs (isobars of neighboring Z) are found in the specific zones.

13. The longest half-lives of the isotopes next heavier than the isotopes of the stable nuclei are located at the boundaries of the specific zones[5]. This is directly related to properties 11 and 12.

For even nuclei the longest half-lives of the plus-active nuclei lie also in the specific zone (curve *IX*, Fig. 4), mostly at the boundaries of the larger Z. The odd nuclei exhibit no definite regularity with respect to the half-lives of the plus-active nuclei.

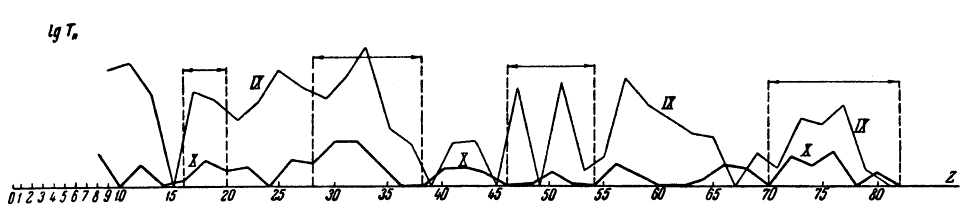

FIG. 4. Curve *IX* -- logarithms of the half-lives of the first plus-active nuclei; X -- gamma-ray energy of first unstable $\overline{\beta}$ isotope.

15. K electron capture is concentrated principally in the specific zones with the half-life being highest for even nuclei[6].

In addition, let us consider the gamma-radiation curve of the isotope that is one unit mass number smaller than the stable nucleus. This isotope

[6] M. A. Levitskaia and L. P. Rapoport, Dokl. Akad. Naku SSSR **70**, 817 (1950)

[5] M. A. Levitskaia, Dokl. Akad. Nauk SSSR **61**, 55 (1948)

emits a $\overline{\beta}$-particle. The greater the change produced by this emission in the stable nucleus, the higher the energy level reaches by this nucleus (the stronger the excitation of the nucleus) and the greater the energy of the quantum emitted as a result of the β-radiation. The gamma-ray energies of such isotopes for even Z are plotted in curve X of Fig. 4; this curve has minima between $Z = 30$ and $Z = 38$, between $Z = 45$ and $Z = 54$, and between $Z = 78$ and $Z = 82$. If we disregard the very low abundance isotopes, the first zone also contains minima. As far as the odd nuclei are concerned, they have maximum gamma-ray energies in the same regions. The small gamma-ray energy associated with the emission of a β-particle is apparently proof that the nucleus is very close to stable equilibrium. Thus, we obtain the sixteenth feature:

16. The energy of the gamma-rays accompanying the decay of the first $\overline{\beta}$-active isotope has a minimum in the region of the specific zones.

The seventeenth feature is the following fact reported earlier by myself and by Rapoport[7];

17. The isomer states are concentrated almost exclusively in the specific zones.

In nuclear transmutations, the specific zones manifest themselves in the $(n, 2n)$ reaction. The emission of two neutrons by capture of a single neutron can naturally be proof of a stronger or weaker neutron bond in the nucleus. The $(n, 2n)$ reaction is observed principally in the first-lightest isotope. In even nuclei having large Z it occurs also in the intermediate nuclei. However, we shall only consider the occurrence of the reaction in the first-lightest isotope. In the case of even nuclei this reaction is not observed in the specific zones. In the case of Ca its occurrence is doubtful, and it does not occur for $Z = 16$ and $Z = 18$. In the second zone it is entirely absent for $Z = 34, 36, 38$, and it is absent for the first stable isotope of $Z = 32$. It is absent in the third zone for $Z = 46$, and is observed for $Z = 50$ only in the last heaviest isotope which is of very low content. It is absent for the first isotope of $Z = 52$, and is entirely absent for $Z = 54$. Above $Z = 56$ the data are generally doubtful; the $(n, 2n)$ reaction has not been observed for the first isotopes of even nuclei, but is always observed for odd nuclei. This again proves the greater stability of the even nuclei, particularly in the specific zones. Thus, we have another feature:

18. The $(n, 2n)$ reaction does not occur for the lightest isotopes of even nuclei in the specific zones.

19. The next feature is the increased stability of the isobars in the specific zones, as reported in reference 8.

In general, the absolute value of binding energy of an isobar increases with Z, but the opposite takes place in the specific zone: the difference between the energies of the isobars with larger and smaller Z starts to decrease at the beginning of the specific zone, and in the center of the zone the isobar with smaller Z has a higher binding energy than the isobar corresponding to the larger Z. This is clearly pronounced in the first and second specific zones, as shown in the Table. Unfortunately, the binding energies are unknown for the remaining specific zones, but the same is expected to hold there although it has not yet been observed.

20. The last feature is the fluctuation in the specific zones of the Z_A numbers and of the lower point of the Bethe-Weizsaecker parabolas of the isobars, as reported by I. Curie[9]. The author of this reference gives a curve of Z_A versus Z and versus A. The value of Z increases almost linearly but fluctuates widely (sinusoidally) in several regions. These regions are the Z intervals 16-21, 29-35, 42-43, 48-52, 61-64, 66-68, 56-58 and 71-81. These regions are the specific zones, regions near unstable Z, or regions containing naturally radioactive isotopes. I. Curie's associates[10] have replaced the single isobar parabola in these regions with two intersecting parabolas to obtain a smoother plot for Z_A. There is no doubt, however, that in the specific zones the fluctuations of Z_A are partly related to the nineteenth feature. The specific zones do not exhibit any unique behavior with respect to such important nuclear quantities as the spin and quadrupole moment. In fact, for odd Z up to $Z = 43$ the maximum spins lie at the upper bounds of the specific zones. Beyond $Z = 43$, the maximum spins are observed at both boundaries of the specific zones. The same can also be

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[7] M. A. Levitskaia and L. P. Rapoport, Dokl. Akad. Nauk SSSR **74**, 953 (1950)

[8] M. A. Levitskaia, Tr. VGU (Reports pf Voronezh State University), Phys. Math. Collection, 1954

[9] I. Curie, J. Phys. et Radium **6**, 209 (1945)

[10] R. Bouchez, J. Robert and J. Tobailem, J. Phys. et Radium **14**, 281 (1953)

Binding Energies of Isobars and Their Differences

Isobar	Binding Energy	Difference	Isobar	Binding Energy	Difference
S^{32}_{16}	271,71	2,23	Cr^{51}_{24}	444,91	—0,85
Si^{32}_{14}	269,48		Ti^{51}_{22}	445,76	
A^{36}_{18}	306,14	—1,5	Fe^{54}_{26}	469,27	—4,...
S^{36}_{16}	307,64		Cr^{54}_{24}	473,...	
Ca^{40}_{20}	340,40	—1,22	Ni^{58}_{28}	500,543	—3,82
A^{40}_{18}	341,62		Fe^{58}_{26}	504,360	
Ti^{46}_{22}	397,32	2,...	Zn^{64}_{30}	553,219	—9,031
Ca^{46}_{20}	(395,...)		Ni^{64}_{23}	562,250	
Ti^{48}_{22}	416,73	3,...	Ge^{70}_{32}	554,31	—10,00
Ca^{48}_{20}	413,...		Zn^{70}_{30}	604,31	
Cr^{50}_{24}	435,30	1,02	Se^{74}_{34}	640,192	—3,325
Ti^{50}_{22}	434,28		Ge^{74}_{32}	643,517	

said concerning the quadrupole moments, as it follows from the Gordy curve (see Fig. 1 in reference 11).

It is next necessary to describe the behavior of the energy in the specific zones. The average binding energy for a single particle hardly means anything in view of the large number of isotopes for even Z. Let us plot the energy of combination of one proton and one neutron, inasmuch as this is made possible by the existing tables of atomic masses.

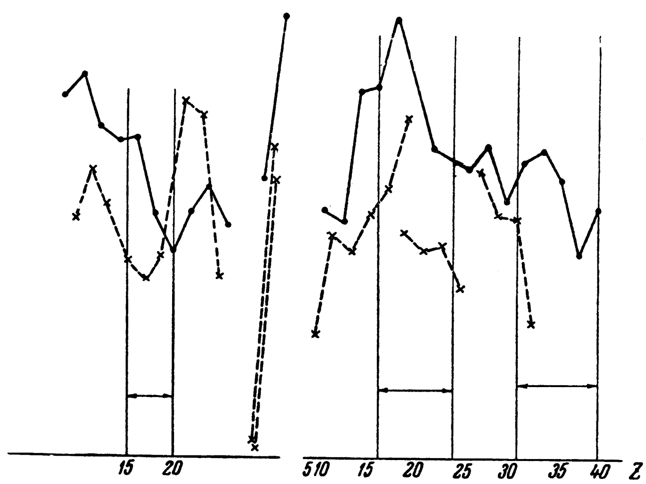

FIG. 5. *a* -- combining energy of one proton plotted as a function of Z; *b* -- combining energy of a single neutron.

[11] M. A. Levitskaia, Dokl. Akad. Nauk SSSR **74**, 37 (1950)

Figure 5*a* shows the energy of combination of a proton as a function of Z. A solid line joins the even-protonpoints and a dotted line joins the odd-proton points (crosses). We see that the energy of combination of the proton drops off in the first specific zone and has a deep minimum at the upper end of the zone for both odd and even protons. Figure 5*b* shows the energy of combination for one neutron. It is difficult to draw solid curves because the energy has several values for the same number of neutrons. The first zone contains the 16th to 26th neutrons, the second zone from the 30th upward. We see again a drop in the energy of combination in the first specific zone and relative maxima at $Z = 18$, 28 and 34.

The value of the combining energy is closely related to the question of nucleon shells and evaluation of these quantities should be the topic of a separate investigation.

All the characteristics indicated in this article are convincing proof that the "specific" zones represent regions of abrupt nuclear changes associated with an increase in the stability of the nuclei, and the magic numbers are apparently a result of these zones.

Translated by J. G. Adashko
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