Upper Limit of the Periodic Table and Synthesis of Superheavy Elements

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For the first time, using the heaviest possible element, the diagram for known nuclides and stable isotopes is constructed. The direction of search of superheavy elements is indicated. The Periodic Table with an eighth period is tabulated.

1 Shell construction of a nucleus, magic numbers

The nucleus of an atom is the central part of the atom, consisting of positively charged protons (Z) and electrically neutral neutrons (N). They interact by means of the strong interaction.

If a nucleus of an atom is consider as a particle with a certain number of protons and neutrons it is called a nuclide. A nuclide is that version of an atom defined by its mass number ($A = Z + N$), its atomic number (Z) and a power condition of its nucleus. Nuclei with identical numbers of protons but different numbers of neutrons are isotopes. The majority of isotopes are unstable. They can turn into other isotopes or elements due to radioactive disintegration of the nucleus by one of the following means: β-decay (emission of electron or positron), α-decay (emission of particles consisting of two protons and two neutrons) or spontaneous nuclear fission of an isotope. If the product of disintegration is also unstable, it too breaks up in due course, and so on, until a stable product is formed.

It has been shown experimentally that a set of these particles becomes particularly stable when the nuclei contain "magic" number of protons or neutrons. The stable structure can be considered as shells or spherical orbits which are completely filled by the particles of a nucleus, by analogy with the filled electronic shells of the noble gases. The numbers of particles forming such a shell are called "magic" numbers. Nuclei with magic number of neutrons or protons are unusually stable and in nuclei with one proton or other than a magic number, the neutron poorly binds the superfluous particle. The relevant values of these numbers are 2, 8, 20, 28, 50, 82, and 126, for which there exists more stable nuclei than for other numbers. Calculations indicate existence of a nucleus with filled shell at $Z = 114$ and $N = 184$ ($^{298}114$) which would be rather stable in relation to spontaneous division. There is experimental data for the connexion of magic numbers to a nucleus with $Z = 164$ [1, 2]. J. Oganesyan [3] has alluded to a Rutherford-model atom which assumes existence of heavy nuclei with atomic numbers within the limits of $Z \sim 170$. At the same time there is a point of view holding that superheavy elements (SHEs) cannot have $Z > 125$ [4]. In October 2006 in was reported that element 118 had been synthesized in Dubna (Russia), with atomic weight 293 [5]. (It is known however, that this weight is understated, owing to technical difficulties associated with the experiments.)

2 The N-Z diagram of nuclei, islands of stability

The search for superheavy nuclei, both in the Nature and by synthesis as products of nuclear reactions, has intensified. In the 1970's 1200 artificially produced nuclei were known [6]. Currently the number is $\sim$3000, and it is estimated that this will increase to $\sim$6500 [7].

In Fig. 1 the neutron-proton diagram of nuclei of stable and artificial isotopes [8–10] is presented.

Light stable or long-lived nuclei which arrangement can be arranged in a valley of stability as shown by small circles. The top set of border points represents a line of proton stability and bottom a line of neutron stability. Beyond these limits begins the so-called, "sea of instability". There is apparently only a narrow strip of stability for which there exists a quite definite parity, N/Z. For nuclei with atomic weight below 40, the numbers of protons and neutrons are approximately identical. With increase in the quantity of neutrons the ratio increases, and in the field of $A = (N + Z) = 250$ it reaches 1.6. The growth in the number of neutrons advances the quantity of protons in heavy nuclei, which in this case become energetically more stable. To the left of the stable nuclei are proton excess nuclei, and on the right neutron excess nuclei. These and others are called exotic nuclei.

The diagram terminates in the last element from the table IUPAC [11] at No. 114, with mass number 289, while scientists suspect nucleus No. 114–298. Such isotopes should possess the increased stability and lifetime of superheavy elements.

This diagram is specially constructed, only on the basis of tabulated data, but augmented by the theoretical upper limit of the Periodic Table [12]. Up to the Z$\sim$60 the line of trend approaches the middle of a valley of stability, with $N/Z \sim 1.33$. Furthermore, N/Z increases steadily to $\sim$1.5 up to $Z \sim 100$. The equation of the line of trend represents a polynomial of the fourth degree. It is noteworthy that this implies rejection of the upper magic number for neutrons heretofore theoretically supposed.

It is particularly evident from Fig. 2, in which small fragment of the N–Z diagram is amplified and augmented with

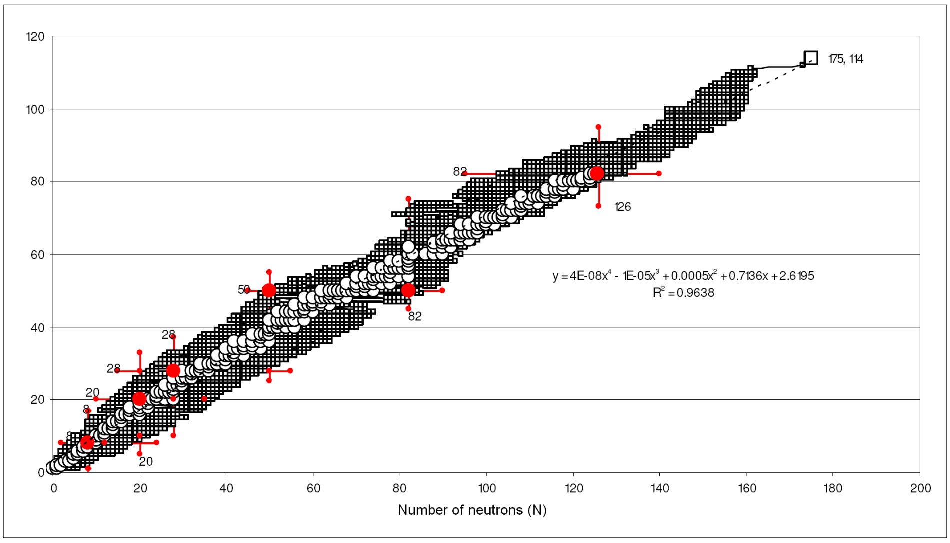

Fig. 1: N–Z diagram of nuclides.

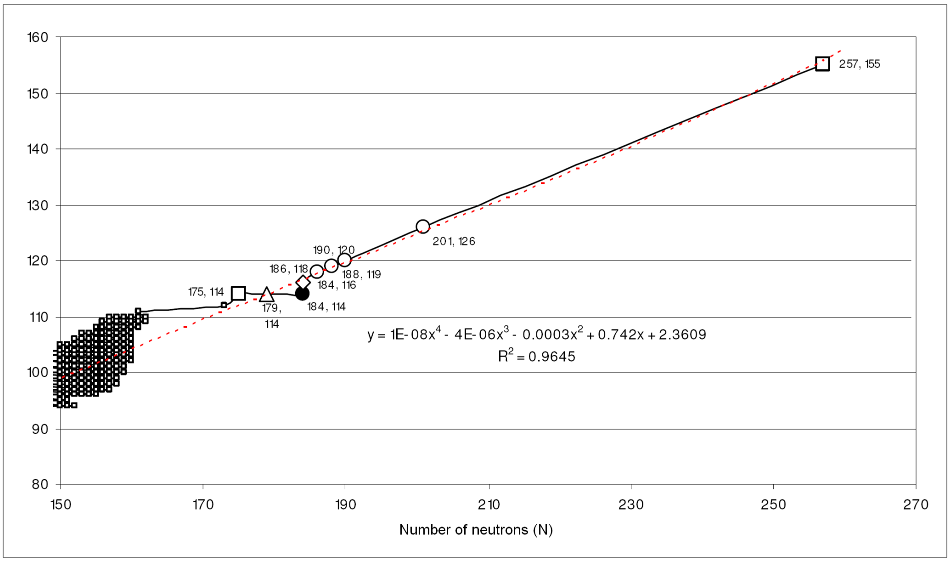

Fig. 2: N–Z diagram of nuclides with elements. For increase in scale the diagram is reduced after carrying out of a line of a trend.

some theoretically determined nuclei, including the heaviest element Z = 155, that the equations of lines of trend and the values of R^2 are practically identical in both Figures. When the line of trend for Fig. 1, without element 155, is extrapolated beyond Z = 114, it passes through the same point in Fig. 2 for Z = 155, indicating that element 155 is correctly placed by theory.

The predicted element No. 114–184 is displaced from the line of a trend. With a nuclear charge of 114 it should have 179 neutrons (A = 293) whereas 184 neutrons has atomic number 116. In the first case there is a surplus 5 neutrons, in the second a deficit of 2 protons. For an element 126 (on hypothesis) the mass number should be 310, but by our data it is 327. The data for mass number 310 corresponds to Z = 120.

It is important to note that there is a close relation between the mass number and the atomic weight. The author's formulation of the Periodic law of D. I. Mendeleev stipulates that the properties of elements (and of simple compounds) depend upon periodicity in mass number. It was established in 1913, in full conformity with the hypothesis of Van den Brook, that the atomic numbers of the chemical elements directly reflect the nuclear charge of their atoms. This law now has the following formulation: "properties of elements and simple substances have a periodic dependence on the nuclear charge of the atoms of elements".

In the Periodic Table the last, practically stable element is bismuth, Z = 83. The six following elements (No.'s 84 to 89) are radioactive and exist in Nature in insignificant quantities, and are followed by the significant radioactive ele-

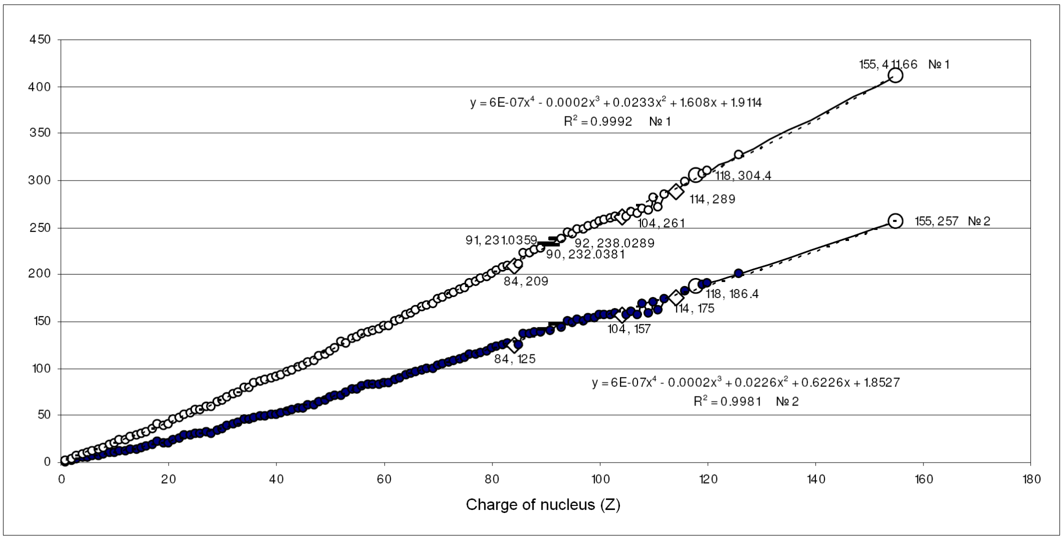

Fig. 3: Dependence of element mass number (1) and corresponding numbers of neutrons (2) on the atomic number in the Periodic Table.

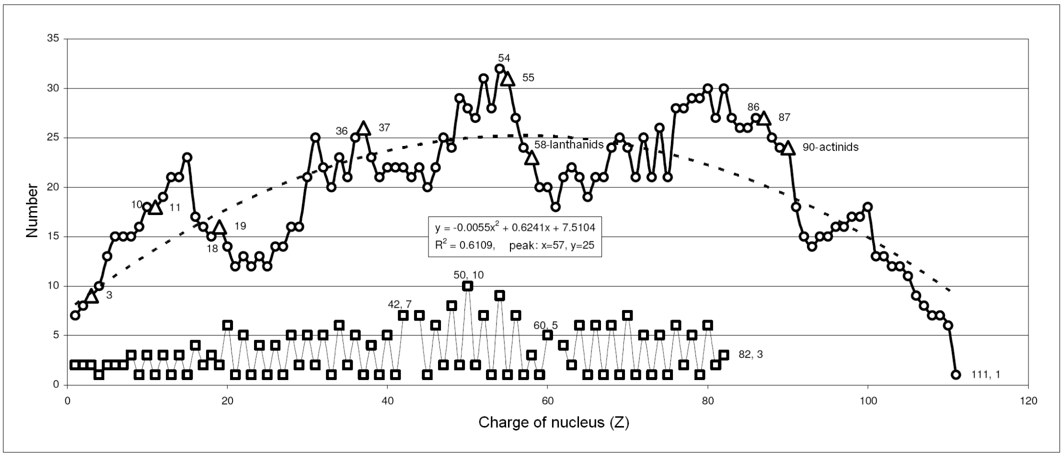

Fig. 4: Dependence of total isotopes (circle) and stable elements (square) on atomic number. The triangle designates the beginning of the periods.

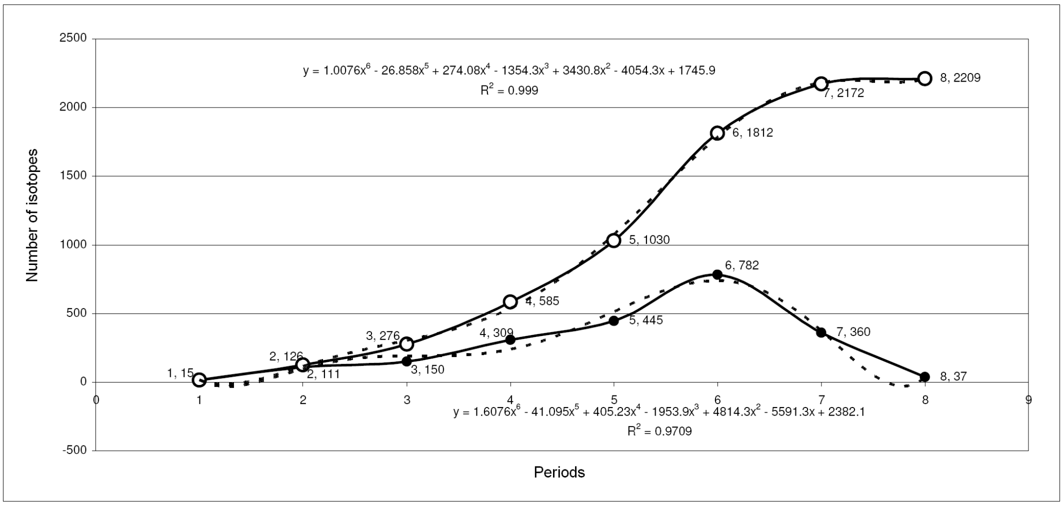

Fig. 5: Distribution of isotopes on the periods: an S-shaped summarizing curve, lower-quantity at each point.

1 H	2A 2											3A 13	4A 14	5A 15	6A 16	7A 17	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	3B 3	4B 4	5B 5	6B 6	7B 7	——— 8	8 9	——— 10	1B 11	2B 12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116	117	118

Table 1: The standard table of elements (long) with addition of the theoretical eighth period.

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Table 2: Lanthanides (upper line) and actinides (lower line).

122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139
		140	141	142	143	144	145	146	147	148	149	150	151	152	153		

Table 3: The eight period: super actinides (18g and 14f elements)

119	120	121	154	**155 Kh**

Table 4: The eight period: s-elements (No. 119, 120), g–elements (No. 121), d–elements (No. 154, 155). Element No. 155 must be analogous to Ta, as Db.

119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136
137	138	139	154	**155**													

140	141	142	143	144	145	146	147	148	149	150	151	152	153

Table 5: Variation of the Periodic Table of D. I. Mendeleev with heaviest element in the eighth period. A structure for super actinides is offered in a series in work [2].

ments thorium, protactinium and uranium (Z = 90, 91, and 92 respectively). The search for synthetic elements (No.'s 93 to 114) continues. In the IUPAC table, mass numbers for elements which do not have stable nuclides, are contained within square brackets, owing to their ambiguity.

It is clear in Fig. 3 that the reliability (R^2) of approximation for both lines of trend is close to 1. However, in the field of elements No. 104 to No. 114, fluctuations of mass number, and especially the number of neutrons, are apparent.

According to the table, the most long-lived isotope of an element violates the strict law of increase in mass number with increase in atomic number. To check the validity of element No. 155 in the general line of trend of elements for all known and theoretical [12] elements, the two following schedules are adduced:

1. For element numbers 1 to 114, $y = 1.6102\, x^{1.099}$ at $R^2 = 0.9965$;
2. For element numbers 1 to 155, $y = 1.6103\, x^{1.099}$ at $R^2 = 0.9967$.

Upon superposition there is a full overlapping line of trend that testifies to a uniform relation of dependences. Therefore, in analyzing products of nuclear reactions and in statement of experiment it is necessary to consider an element No. 155 for clarification of results.

3 The eighth period of the Periodic Table of elements

Our theoretical determination of the heaviest element at Z = 155 allows for the first time in science a presentation of Mendeleev's Table with an eighth period. Without going into details, we shall note that at the transuranium elements, electrons are located in seven shells (shells 1 to 7 inclusive), which in turn contain the subshells s, p, d, f. In the eighth period there is an 8th environment and a subshell g.

G. T. Seaborg and V. I. Goldanski, on the basis of the quantum theory, have calculated in the eighth period internal transitive superactinoid a series containing 5g-subshells for elements No. 121 to No. 138 and 6f subshells for No. 139 to No. 152. By analogy with the seventh period, No. 119 should be alkaline, No. 120 a alkaline ground metal, No. 121 similar to actinium and lanthanium, No. 153 to No. 162 contain a 7d subshell, and No. 163 to No. 168 an 8p subshell [2]. The latter class resulted because these scientists assumed the presence not only of an 8th, but also a 9th periods, with 50 elements in each.

However, distribution of isotopes depending on a atomic number of the elements (Fig. 4) looks like a parabola, in which branch Y sharply decreases, reaching the value 1 at the end of the seventh period. It is therefore, hardly possible to speak about the probability of 100 additional new elements when in the seventh period there is a set of unresolved problems.

Our problem consisted not so much in development of methods for prediction of additional elements, but in an explanation as to why their number should terminate No. 155. Considering the complexities of synthesis of heavy elements, we have hypothesized that their quantity will not be more than one for each atomic. Then, from Fig. 5 it can be seen that the S-figurative summarizing curve already in the seventh period starts to leave at a horizontal, and the eighth reaches a limit. The bottom curve shows that after a maximum in the sixth period the quantity of isotopes starts to decrease sharply. This provides even more support for our theoretical determination [12] of the heaviest possible element at Z = 155.

In July 2003 an International conference took place in Canada, resulting in publication [13], wherein it is asked, "Has the Periodic Table a limit?"

The head of research on synthesis of elements in Dubna (Russia), J. Oganesyan, has remarked that the question of the number of chemical elements concerns fundamental problems of science, and therefore the question, what is the atomic number of the heaviest element?

Despite the fact that hundreds of versions of the Periodic Table have been offered of the years, none have designated the identity of the heaviest element. The heaviest element is offered in Tables shown in Page 107.

4 Conclusions

With this **third paper** in a series on the upper limit of the Periodic Table of the Elements, the following are concluded.

1. As the fact of the establishment of the upper limit in Periodic Table of Elements until now is incontestable (on October, 25th 2005 appeared the first publication on the Internet), it is obviously necessary to make some correction to quantum-mechanical calculations for electronic configurations in the eighth period.
2. In modern nuclear physics and work on the synthesis of superheavy elements it is necessary to consider the existence of a heaviest element at Z = 155 with the certain mass number that follows from the neutron-proton diagram.
3. For discussion of the number of the periods and elements in them it is necessary to carry out further research into the seventh period.
4. From the schedules for distribution of isotopes, it is apparent that the end of the seventh period of elements is accounted for in units because of technical difficulties: No. 94 to No. 103 have been known for 20 years, and No. 104 to No. 116 for 40. Hence, to speak about construction of the Table of Elements with the eighth and ninth periods (100 elements), even for this reason, is not meaningful.

5. The variants of the Periodic Table of Mendeleev constructed herein with inclusion of the heaviest element No. 155 opens a creative path for theoretical physicists and other scientists for further development of the Table.

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