Upper Limit of the Periodic Table and the Future Superheavy Elements*

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Controversy surrounds the isolation and stability of the future transactinoid elements (after oganesson) in the periodic table. A single conclusion has not yet been drawn for the highest possible atomic number, though there are several theoretical as well as experimental results regarding this. In this article, the scientific backgrounds of those upcoming superheavy elements (SHE) and their proposed electronic characters are briefly described.

Introduction

Totally 118 elements, starting from hydrogen (atomic number 1) to oganesson (atomic number 118) are accommodated in the modern form of the periodic table comprising seven periods and eighteen groups. Total 92 natural elements (if technetium is considered as natural) are there in the periodic table (up to uranium having atomic number 92). In the actinoid series, only four elements—actinium, thorium, protactinium and uranium—are natural. The rest of the eleven elements—from neptunium (atomic number 93) to lawrencium (atomic number 103)—are synthetic. Elements after actinoids (i.e., from rutherfordium) are called transactinoid elements. These are also called superheavy elements (SHE) as they have very high atomic numbers. Prof. G T Seaborg had a very distinct contribution in the field of transuranium element synthesis. For this, Prof. Seaborg was awarded the Nobel Prize in 1951. Moreover, the element with atomic number 106 is named after him (seaborgium). It is interesting to note that seaborgium was the first element named after a living scientist. Oganesson (atomic number 118) is named after the Russian scientist Yuri

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Oganessian who is also alive. Now, a total of 26 synthetic elements are known. In 2016, the International Union of Pure and Applied Chemistry (IUPAC) named [1] the four latest elements of the periodic table. These are nihonium (Nh, 113), moscovium (Mc, 115), tennessine (Ts, 117) and oganesson (Og, 118). Here it should be stated that nihonium is the only element in the periodic table, named after an Asian country (Japan). Japanese people call their own country 'Nihon', which means the "country of the rising sun".

A very pertinent question often arises in the context of the periodic table. What will be next to oganesson? or how far will the periodic table be extended? Chemists are seriously thinking about the upper limit of the periodic table. Several theoretical calculations exist. Besides this, simple consideration of the Aufbau principle nicely predicts the electronic character of these future SHEs yet to be discovered.

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Future SHEs

The seventh period of the periodic table has been completed after the discovery of oganesson. Now, if elements 119 and 120 are discovered, they will be placed in Groups 1 and 2, respectively, in the newly constructed eighth period. From their position in the periodic table, it can easily be predicted that elements 119 and 120 will be s-block elements. The electronic characters of the next elements may be assumed using the Aufbau principle (*Figure* 1).

Electronic configuration of oganesson is $[Rn]5f^{14}6d^{10}7s^{2}7p^{6}$. So here, 7p orbital is completely filled up. Next to this electrons will enter the 8s orbital. As s orbital can accommodate 2 electrons, elements 119 and 120 will be s-block elements. Further, if we consider elements 121 and beyond, we have to think about the g orbital, because now electrons will start to enter 5g orbital. As the azimuthal quantum number of g orbital is 4, so (2l + 1) = 9, i.e., a total of 9 g orbitals are possible. As each orbital accommodates 2 electrons, a total of 18 electrons will be housed in the

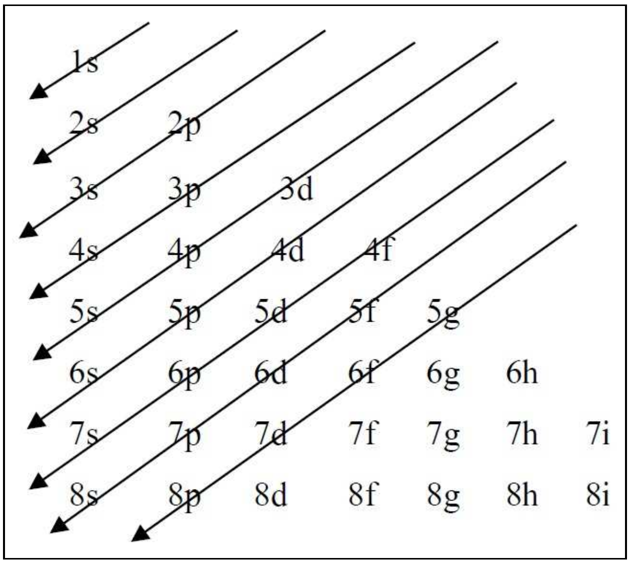

Figure 1. Electron feeding in elements according to Aufbau principle.

g orbitals. This means that elements from 121 to (120 + 18 =) 138 will be g-block elements. After 5g orbital, according to the Aufbau principle, electrons will enter into 6f orbitals. A total of 14 electrons will be accommodated in 6f orbitals (seven f orbitals housing 2 electrons each). Hence elements from 139 to (138 + 14 =) 152 will be f-block elements. Next, d-block elements appear, followed by p-block and so on. Considering all these future elements, Prof. Seaborg has suggested a new periodic table, which is popularly known as the Mendeleev–Seaborg periodic table (*Figure* 2) [2].

In the modern form of the periodic table, there is a controversy about the position of the lutetium and lawrencium, which are generally known as the final elements of lanthanoid and actinoid series having electronic configurations [Xe]$4f^{14}5d^{1}6s^{2}$ and [Rn]$5f^{14}6d^{1}7s^{2}$, respectively. From electronic configurations, it is clear that these elements should be regarded as the first elements of 5d- and 6d-blocks instead of final elements of 4f- and 5f-blocks. This problem is well-addressed in the Mendeleev–Seaborg periodic table, where (*Figure* 2) these two are included as the first elements of 5d- and 6d-blocks, respectively.

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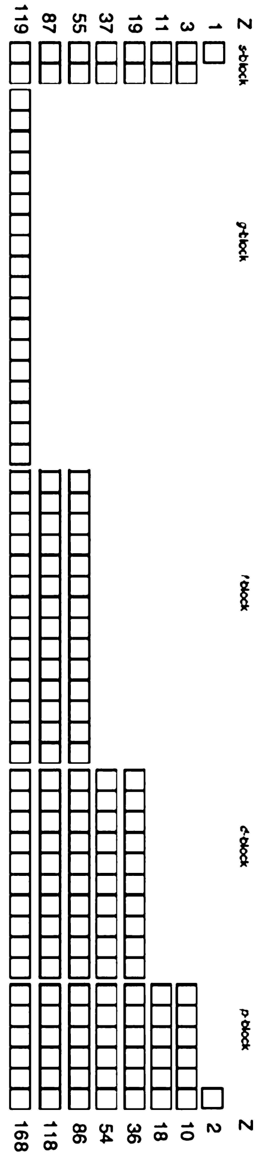
Figure 2. Mendeleev–Seaborg periodic table [2].



The Upper Limit

A very well-known calculation, known as Feynman's calculation exists in the context of the upper limit of the periodic table. If the mass of an electron, its charge, velocity, the radius of the first Bohr orbit, and the number of protons in the nucleus are m, e, v, r and Z, respectively, then the centrifugal force on the electron is $\frac{mv^2}{r}$. The centripetal force, according to Coulomb's law, is $\frac{Ze^2}{4\pi\epsilon_0 r^2}$ (ϵ_0 = permittivity of the medium). So,

$$\frac{mv^2}{r} = \frac{Ze^2}{4\pi\epsilon_0\, r^2},$$

or,

$$mv^2 = \frac{Ze^2}{4\pi\epsilon_0\, r},$$

or,

$$v^2 = \frac{Ze^2}{4\pi\epsilon_0\, mr}. \tag{1}$$

According to Bohr's theory, $mvr = \frac{nh}{2\pi}$ (n = principal quantum number, h = Planck's constant),

or,

$$mr = \frac{nh}{2\pi v}.$$

Substituting the value of mr in (1),

$$v = \frac{Ze^2}{2\epsilon_0\, nh}.$$

Multiplying the velocity of light (c) in the numerator and denominator of the above relation,

$$v = \frac{Ze^2 c}{2\epsilon_0\, nhc},$$

or,

$$v = \frac{Z\alpha c}{n} \text{where, } \alpha = \frac{e^2}{2\epsilon_0\, hc} = \frac{1}{137.157} \approx \frac{1}{137},$$

where $h = 6.626 \times 10^{-34}$ J.s, $c = 3 \times 10^8$ m s^{-1}, $e = 1.602 \times 10^{-19}$ C, $\epsilon_0 = 8.854 \times 10^{-12}$ (vacuum).

From this, it is clear that if $Z > 137$ (for $n = 1$), the velocity of electron (v) will be $> c$, which is not obeying Einstein's relativity theory. So, according to this calculation, elements having the atomic number (maximum of) 137 can exist. This value may be quite higher if the medium is not vacuum (then ϵ_0 will be higher).

Niels Bohr, in one of his calculations, showed that the maximum possible atomic number is 100. In 1955, mendelevium (atomic number 101) was synthesized by Seaborg, proving the idea of Bohr experimentally incorrect. In a recent calculation, it has been shown that the most probable highest atomic number is 172.

Niels Bohr, in one of his calculations, showed that the maximum possible atomic number is 100 [3]. In 1955, mendelevium (atomic number 101) was synthesized by Seaborg [4], proving the idea of Bohr experimentally incorrect. In a recent calculation [5], it has been shown that the most probable highest atomic number is 172.

But here, it needs to be mentioned that the condition $Z \leq 137$ being the limit is for a point nucleus. The limit of $Z = 172$ considers the finite size of the nucleus. At this limit, the most tightly bound electron (K shell) dives into the Dirac vacuum, and spontaneous emission of positrons take place. Observation of positrons in experiments would be a test of the theory.

Conclusion

The possibility of synthesizing an element with the maximum possible atomic number is not yet definite. Prof. Seaborg wrote in his famous book [6], "... there is no limitation on the existence of such heavy elements from the standpoint of extranuclear electronic structure of such atoms; the limitation comes as a result of nuclear instability". In a recent paper [7] it has been observed that the possibility of fruitful formation of a nucleus depends on its stability. It should be stable for a minimum of 10 femtoseconds. If it lasts lesser than this, the nucleus cannot grow along with its surrounding electrons to form an atom. This means that Prof. Seaborg's long-proposed idea is echoed in very recent research. Moreover, at high values of Z, the nucleus becomes unstable due to fission. But around $Z = 120$, 126 and N (number of neutrons) = 184, the nuclei are expected to be more stable than their neighbours due to shell closure (magic numbers for the stability of atomic nucleus) [8]. This is driving the current research for the production of superheavy elements.

Suggested Reading

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