The Synthesis, Structure and Decay of Super-Heavy Nuclei

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SUMMARY. Super-heavy nuclei are those transuranic nuclei with more than 106 protons . The underlying nuclear structure of super-heavy elements may be visualized as 5 concentric closed layers of alpha particles. This structure is an extension of layered alpha particle models of common nuclei based on Bernal's model of a drop of a monatomic liquid. It will be shown that all super-heavy nuclei with atomic numbers in excess of 107 may be thought of as having a fifth closed layer of 16 alpha particles which decays because of its inherent instability.

1.Introduction

The lighter transuranic nuclei were first artificially synthesized during the 1940s and 50s by using cyclotrons to fuse either fast neutrons, hydrogen or helium nuclei with heavy target nuclei. The heavier transuranic nuclei were first produced in the 50s, 60s and 70s by accelerating boron, carbon, nitrogen or oxygen nuclei with linear accelerators to fuse with curium or californium targets. Since 1981 super-heavy nuclei containing up to 112 protons have been created by fusing chromium, iron, nickel or zinc with lead or bismuth. Recently nuclei with 118 protons have been fused from krypton and lead.by Ninov et al (1)

2. Synthesis

The specific nuclear reactions used to synthesise the lighter, heavier and super-heavy transuranic nuclei are listed below in Tables 1, 2 and 3 respectively

Z (T½)	NAME (Date)	SYNTHESIS
93 24d	Neptunium 1940	n + U238 → γ+β+Np239
94 864y	Plutonium 1941	H2 + U238 →2n+β+Pu238
95 433y	Americium 1945	2n + Pu239 →γ+β+Am241
96 163d	Curium 1944	He4+Pu239 →n+Cm242
97 4.5h	Berkelium 1949	He4+Am241 →2n+Bk243
98 44ms	Californium 1950	He4+Cm242 →n+Cf245
99 20d	Einsteinium 1952	Thermonuclear → Es253
100 20h	Fermium 1953	Thermonuclear → Fm255
101 76m	Mendelium 1955	He4 + Es253 →n+Md256

TableL.ighter trans-uranic elements

Z (T½)	NAME (Date)	SYNTHESIS
102 2.3s	Nobelium 1958	C12+Cm244 →4n+No252
103 4.3s	Lawrencium 1961	B10+Cf251 →3n+Lr258
104 3.4s	Rutherfordium 1969	C12+Cf249 →4n+Rf257
105 1.5s	Dubnium 1970	N15+Cf249 →4n+Db260
106 0.9s	Seaborgium 1974	O18+Cf249 →4n+Sg263

Table 2. Heavier trans-uranic elements

Z (T½)	NAME (Date)	SYNTHESIS
107 102ms	Bohrium 1981	Cr54+Bi209 →n+Bh262
108 1.8ms	Hassium 1984	Fe58+Pb208 → n+Hs265
109 3.4ms	Meitneri um 1982	Fe58+Bi209 →n+Mt266
110 0.2ms	110 1994	Ni62+Pb208 →n+110.269
111	111 1994	Ni64+Bi209 →n+111.272
112 0.2m,s	112 1996	Zn70+Pb208 →n+112.277
114 39ms	114 1999	Ca48+Pu244 →3n+114.289
118	118 1999	Kr86+Pb208 →n+118.293

Table3. Super- heavy elements

3. Nuclear Structure

The underlying nuclear structure of heavy elements may be visualized as 5 concentric layers of alpha particles. This structure is an extension of layered alpha particle models of common nuclei based on Bernal's (2) model of a drop of a monatomic liquid in which hard spheres representing atoms are densely packed. This model successfully explained many properties of such liquids as well as those of metallic glasses. Norman (3) showed how Bernal's model may be used to account for the size, density, quadrupole moment and binding energy levels of many nuclei if the hard spheres are alpha particles. Accordingly an oxygen 16 nucleus is modeled as a single tetrahedral layer of 4 alpha particles. A second layer of 10 alpha particles models nickel 56; a third closed layer of 12 alphas forms the core of all nuclei containing at least 52 protons, and a fourth layer of 12 additional alphas forms a basis for those nuclei with 76 or more protons. Norman (4),(5) has also shown that this latter structure of 38 alphas constitutes the stable end point of the radioactive decay of heavy nuclei such as uranium. Furthermore, when a uranium nucleus undergoes fission induced by thermal neutrons it forms a light fragment with a core of no less than 2 alpha layers and a heavier daughter with a core of rarely less than 3 alpha layers.

The alpha particle models of super-heavy nuclei with 108 or more protons indicate that they have a core consisting of a closed fifth layer of 16 alpha particles surrounding the inner 4 closed alpha layers. This structure is indicated in Figure 1. On the basis of this modeling it would appear that the synthesis of all transuranic elements involves the closure of the fifth layer of alpha particles.

If the inter-nucleon bond between two adjacent nucleons in a nucleus is mediated by the exchange of virtual mesons then the meson bond (MB) energy may be calculated in the following way. Assume that 6 equal meson bonds strongly bind the 2 protons and 2 neutrons of a He4 nucleus (alpha particle) into a tetrahedral structure. The total meson bond energy, Em, of the He4 nucleus is defined as the empirically determined binding energy, Eb, of this nucleus corrected for the Coulomb repulsive energy, Ec, so that: Em = 6 MB = Eb + Ec where Eb = 28.3 MeV and Ec = 0.8 MeV. Therefore 1 MB = 4.84 MeV. The total number of meson bonds in any nucleus is equal to the value of Em for that nucleus divided by 4.84 MeV. The values of Eb, Ec, Em and the number of MB for some transuranic nuclei are provided in Table 4.. The details of the meson bond structure of Hassium (z=108) are given in Table 5.

A	E_b	E_c	E_m	MB
U235	1784	909	2693	553
U236	1790	908	2698	554
U237	1796	907	2703	555
U238	1802	905	2707	556
U239	1806	904	2710	557
Np239	1807	924	2731	561
Pu240	1813	943	2756	566
Pu241	1819	941	2760	567
Am242	1823	960	2783	572
Am243	1830	959	2789	573
Cm244	1836	978	2814	578
Cm245	1841	976	2817	579
Bk246	1845	996	2841	584
Bk247	1852	994	2846	585

Cf248	1858	1014	2872	590
Cf249	1863	1013	2876	591
Es250	1867	1032	2899	595
Es251	1874	1030	2904	596
Fm252	1879	1050	292	601
Fm253	1884	1049	2933	602
Md254	1888	1069	2956	607
Md255	1894	1067	2961	608
No256	1899	1087	2986	613
No257	1904	1086	2990	614
Lw258	1907	1107	3014	619
Lw259	1914	1104	3018	620
Rf260	1918	1125	3043	625
Rf261	1924	1123	3047	626

Table 4. Binding, Coulomb and meson bond energies of transuranic nuclei. Note that 1 more meson bond for each additional neutron and.5 more meson bonds for each extra proton.

Energy Level	**Bonds / Nucleon**	**P**	**N**	**Layer**
$1s_{1/2}$	6	2	2	
$1p_{3/2}$	8	4	4	
$1p_{1/2}$	8	2	2	1
$1d_{5/2}$	7	6	6	
$2s_{1/2}$	6	2	2	
$1d_{3/2}$	6	4	4	
$1f_{7/2}$	6	8	8	2
$2p_{3/2}$	6	4	4	
$1f_{5/2}$	5	6	6	
$2p_{1/2}$	5	2	2	
$1g_{9/2}$	5	10	10	
$1g_{7/2}$	5	8	8	3
$2d_{5/2}$	5	6	6	
$2d_{3/2}$	5	4	4	
$3s_{1/2}$	5	2	2	
$1h_{11/2}$	5	12	12	4
$1h_{9/2}$	5	10	10	
$2f_{7/2}$	5	8	8	
$2f_{5/2}$	2		6	
$3p_{3/2}$	5	4	4	
$3p_{1/2}$	2		2	
$1i_{13/2}$	4	4	14	5
$2g_{9/2}$	1		10	
$1i_{11/2}$	1		12	
$3d_{5/2}$	1		6	
?	1		3	

Table 5. The 5 alpha layers in 108 Hs 157

Note that in Table 5 the number of meson bonds per nucleon is the number of bonds binding that nucleon to separate contiguous nucleons. For this reason the total number of meson bonds in a single energy level is equal to the sum of the products of half the listed number of bonds with the number of protons and neutrons respectively. For example, in the $1s_{1/2}$ level the total number of bonds is = 3x2+3x2=12 bonds.

(a)
(b)
(c)

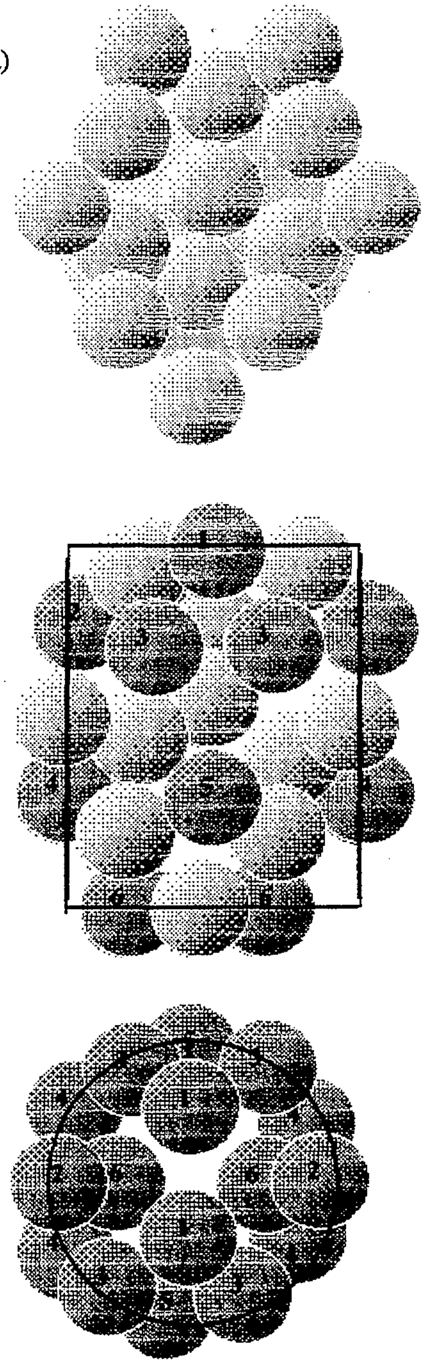

Figure 1. (a) The 38 alphas of Os densely packed as 4 layers. (b) The 54 alphas of Hs consisting of a closed fifth layer of 16 alphas shown in elevation as numbered darker spheres. (c) A plan view of these 16 alphas indicating their cylindrical hexadecapole structure about 3 equivalent orthogonal axes This model conforms with hexadecapole moment data according to V.Ninov (private communication).

4. Radioactive Decay

The decay of super-heavy nuclei usually involves the removal of the fifth layer of alpha particles in a delayed series of alpha and beta emissions as illustrated in Table 6 for element 112 (A=277). By contrast element 114(A=289) undergoes spontaneous fission after losing only 3 alphas.

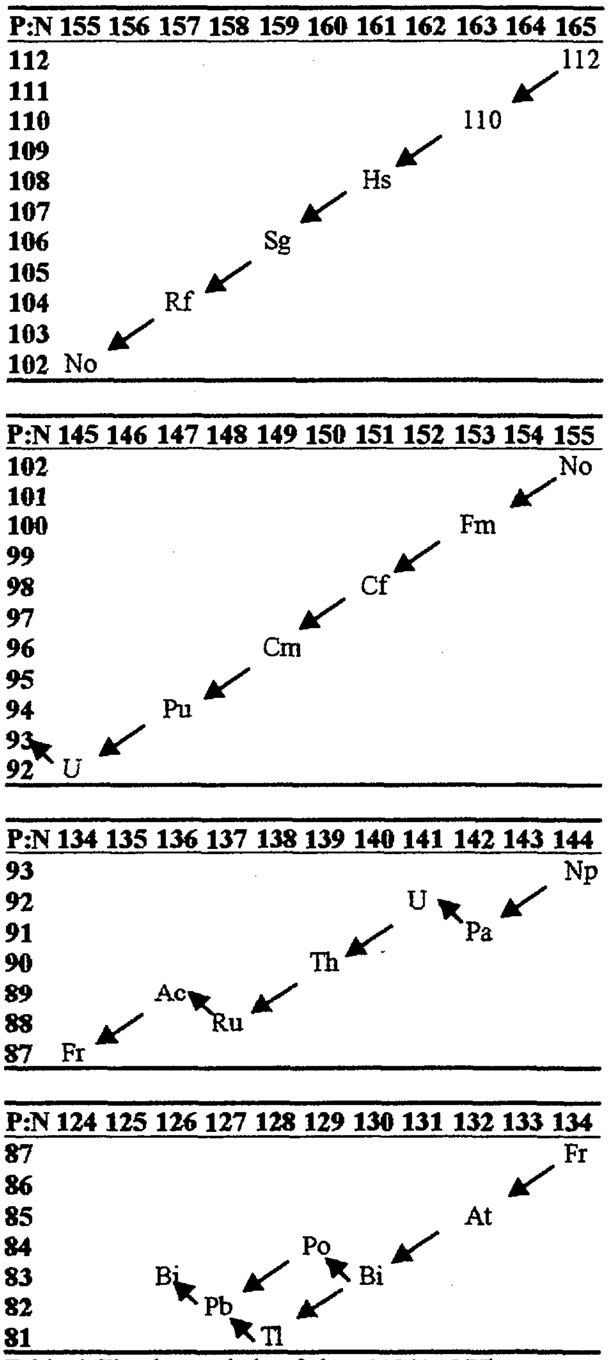

Table 6. The decay chain of elent 112(A=277)

In each **α decay** (↙) the energy released by the decrease in the total Coulomb repulsion energy breaks 6 meson bonds and imparts kinetic energy to the α particle.

In each **β decay** (↖) the increased Coulomb repulsion energy is counteracted by the formation of 4 additional meson bonds and the energy released by the decaying neutron.

5. Conclusion

Super-heavy nuclei are those transuranic nuclei with more than 106 protons . The underlying nuclear structure of super-heavy elements may be visualized as 5 concentric closed layers of alpha particles. This structure is an extension of layered alpha particle models of common nuclei based on Bernal's model of a drop of a monatomic liquid. It has been shown that all super-heavy nuclei with atomic numbers in excess of 107 may be thought of as having a fifth closed layer of 16 alpha particles which decays because of its inherent instability.

6. References

(1) Ninov,V et al.(1999) Phys.Rev.Lett.83,1104.
(2) Bernal,J.D.(1960) Nature, (London),185,68.
(3) Norman,P.(1993)Eur.J.Phys.,(Bristol),14,36.
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7. Appendix

The bond structure of the layered models of nuclei with closed layers compared with the total number of bonds based on calculations of E_m.:

Layer	**1**	**2**	**3**	**4**	**5**
Alphas/ Layer	4	10	12	12	16
MB in Layer	4x6= 24	10x6= 60	12x6= 72	12x6= 72	16x6= 96
MB ex Layer	4x3/2= 6	4x3+6x4 = 36	12x4= 48	12x5= 60	16x6= 96
MB in + ex	24+6= 30	60+36= 96	72+48= 120	72+60= 132	96+96= 192
Closed Nucleus	$_8O_8$	$_{28}Ni_{28}$	$_{52}Te_{76}$	$_{76}Os_{116}$	$_{108}Hs_{157}$
MB N-Z	-	-	24x2= 48	40x2= 80	49x1= 49
MB Core	30	30+96= 126	126+120 =246	246+132 =378	378+192 =570
MB Total (Model)	30	126	48+246 =294	80+378 =458	49+570 =619
MB Total (Data)	29.1	127.1	296	456	646