Symmetry based Architectural Model to explain Nucleosyntheses, Fission, Fusion and Emission Processes

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Abstract:

A unique hypothetical model for the nuclear architecture is appended here from simple symmetry considerations bereft of any mathematical intricacies. Quite a number of nuclear models have been developed to describe the arrangement of protons and neutrons inside an atomic nucleus but no concrete proposition has been put forward till today. In the present model a 'core' α- particle is sequentially encircled by all the Platonic solid structures in order of their increasing capacity. This Polyhedral Cage model is the extension of Paulion (p – n) condensation model and can successfully explain the nucleosyntheses of all nuclei especially of higher mass number. The sides of all the polyhedra are built up of p – n pairs (and n – n pairs). Except tetrahedron (the faces of which cannot accommodate nucleons due to its small size and its nearness to the core), faces of other polyhedron are occupied by nucleons in a symmetric fashion to impart stability to the resulting nucleus. Interestingly, on gradual filling up of the polyhedra, certain combinations of protons and neutrons that reach complete filling of each polyhedron (either sides or faces or both) correspond to the so called 'Magic numbers'. The model reflects qualitatively the formation of stable isotopes as described in Segrè Chart and embraces the features of all other presently accepted nuclear models into one qualitative frame. Nuclear reactions such as Fission (both asymmetric and symmetric) and Fusion processes have been logically explained. The so called "neutrino puzzle" in the production of energy in the Sun can be avoided by this model.

Key Words: Architectural model of nucleus, Nuclear Symmetry, Polyhedral Shells, Fission as statistical process, Fusion as Paulion condensation, Magic numbers as logical numbers, Nutrino puzzle

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1. Introduction:

Ever since the discovery of neutron nearly a century ago[1], nuclear scientists are trying tirelessly to affirm a definitive structure for the nucleus that consists of both protons and neutrons. More so they are in the search of an unambiguous mechanism of nucleosynthesis of different elements in nature. Although the α- cluster model[2] is so far the most studied concept especially for the nucleosyntheses of lighter elements, the model fails to explain either the phenomenon of 'Beryllium Bottleneck' or to describe the mechanism of formation of the 'Hoyle's state'[3] of ^{12}C and many more.

In a bid to overcome these shortcomings, a smaller linear unit namely a p – n pair is chosen as a building block instead of a rigid α- particle. The genesis of this unit since termed as Paulion has been critically discussed from theoretical consideration in a previous communication[4]. The nucleosyntheses of lighter elements from Lithium to Oxygen have been discussed on the idea that p – n pair (Paulion) as the acceptable building block which behaves as ideal gas and obey Bose-Einstein Condensation rules. When this condensation occurs, the pairs are arranged obeying simple symmetry rules which are mostly spherically symmetric with small deviation to form prolate or oblate configurations. A nucleus may be considered as a miniature crystal with p – n pair as the main building unit, the total number of which does not exceed 150. Atomic nuclei are protected by a sheath of electrons which prevents any interaction between different nuclei. Thus every nucleus is an independent building with its own characteristic architecture. On the other hand, ordinary crystals of atoms, ions or molecules contain an infinite number of species bonded by ionic, covalent or metallic bonds. Such crystals are systematically studied and they belong to 230 space groups.

While solid crystalline state usually undergoes change from solid to liquid to gas with increase in temperature, the nuclei undergo phase transition at appropriate conditions, and the corresponding change is accompanied by the emission of α, β and γ radiations.

Crystalline states usually involve ionic (NaCl), covalent (diamond), molecular (glucose) or delocalized (metal) forces which holds the units together. These states involve Coulombic interaction with nuclei and are decomposed under comparatively milder conditions. Nuclei, on the other hand, are held by very strong short range π-meson exchange forces and could be condensed or decomposed under vigorous conditions leading to fusion or fission reactions respectively.

2. Scheme of Nucleosynthses of lighter elements:

The possible course of formation of low mass number nucleons from ^{6}Li to ^{16}O has been considered[4] as resulting from condensation of a p – n pair (Paulion) with successive nucleus starting from ^{4}He. This is schematically shown in Fig. 1.

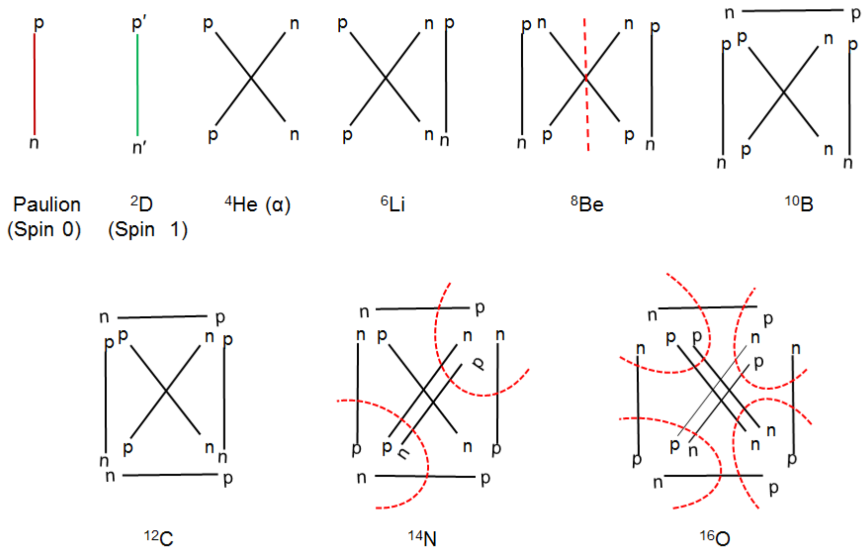


Fig. 1: Scheme of nucleosynthses of lighter elements

Besides ^{2}D (which is shown as p′ - n′ in Fig. 1), of all the known odd-odd nuclei viz., ^{6}Li, ^{10}B and ^{14}N which are included here, only ^{14}N exhibits the formation of virtual α-particles. ^{8}Be is unique in that its formation by condensation of α-particle with two Paulions immediately leads to the decomposition by breakage along the dotted line (Fig. 1) which is known as Beryllium bottleneck.

^{12}C does not fit in the scheme, for which Hoyle's mechanism of formation has been interpreted as the condensation of three virtual α-particles resulting in a spherically symmetric structure conforming to D_3 point group[4]. At ^{16}O the stability of the nuclei is shown by the formation of 4 virtual α-particles with symmetry group depicted as $T_d(\bar{4}32)$.

For heavier nuclei, a bigger framework is necessary to accommodate more and more protons and neutrons in a systematically symmetric fashion. Several models have been put forward to describe the structure of nuclei which are based on the independent existence of protons and neutrons.

3. Architecture of the nucleus:

It is expected that the architecture of the nucleus will be such as to reflect its characteristic properties viz., stability, shape (nearly spherical), emission of α, β, γ rays, etc. The extra-nuclear structure of the atom is made up of only electrons with identical properties and is held by Coulombic interactions with the nuclei. These occupy some stationary states (s, p, d, f etc.) and the change in energy for transition from one state to another is expressed by $E_1 - E_2 = h\upsilon$ which was corroborated by spectroscopic measurements.

On the other hand, nuclei are composed of two different types of particles (protons and neutrons) having their own characteristics and π-meson binding them. These do not appear to be mathematically related by simple equations. γ-ray spectroscopy, which could have supplied some important information about the energetics of the nucleus, seems to be arbitrary and unrelated.

3.1 Nuclear models:

Attempts were made to describe the arrangement of protons and neutrons inside the nucleus by proposing different models. Of these, the most discussed is an independent particle model popularly known as The Shell model[5-7]. This model assumes that protons and neutrons are distributed in a series of discrete energy levels (shells) within the nucleus satisfying certain quantum mechanical conditions without affecting one another although they occupy a tiny sphere of radius 10^{-13} cm.

The shells are analogous to the extra-nuclear electronic stationary states and transition of nucleons from one stationary state to another for stability is accompanied by the emission of γ- rays. Since the energy difference of the shells is quite high, the emitted γ- rays are much harder than x-rays. But all attempts to correlate the frequencies of γ- rays to the energy difference of the shells do not produce any consistent result.

Along with the independent particle model (Shell model), another model namely, Liquid Drop model was proposed by two independent groups of scientists[8,9] for the nucleus which is a statistical one that considers simultaneous interactions of all the nucleons inside the nucleus irrespective of their charges. It treats the nucleus as a homogeneous entity of nucleons in random motion as in a liquid drop and is devoid of any ordered arrangement (cf. Shell model). Like a liquid drop, the nuclei have mobile boundaries and are subject to changes from external and internal forces. The surface tension of the nucleus provides the binding force of the nucleus and balances the Coulombic repulsion of protons. Though the phenomenon of nuclear fission is based on this model yet it faces a setback to explain the formation of asymmetric fission products (*vide infra*). Moreover, the model suffers from the fact that nuclear liquid must have densities million times greater than an ordinary liquid – which seems improbable.

Both Shell model and the liquid drop model have their own merits but there is some apparent antithesis about the supremacy of one over the other. To overcome this dualism, a generalized (Collective) model was put forward[10] in which some major features of the two models are incorporated. It was proposed that when the number of neutrons and protons are equal or very close to the magic numbers, the shell model is applicable but otherwise the liquid drop model describes the nuclear properties better.

At a later date, a lattice model[11] was proposed as a modification of the shell model. It reproduces the nuclear properties from which the development of gaseous phase (shell), liquid phase (liquid-drop) and molecule like (clusters) models took place. This model also exhibits the known symmetries of the quantum numbers that conventionally describes the nucleus.

In Fermi gas model[12], the nucleus is considered as a whole and nucleons are not regarded independently. The nuclear potential well is filled from the bottom resembling a gas at 0°K, the energy levels are filled up completely. On excitation, the nucleons are promoted to higher levels which play a dominant role in nuclear reactions and decay. The Fermi gas model considers the free nucleons above the Fermi level similar to the ideal gases.

In the optical model[13,14], the nucleus is supposed to behave much as a transparent crystal towards neutron which is almost wholly reflected or refracted without being absorbed. Thus the optical model is based on scattering effect of the neutron by the nucleus.

It is seen that all these models are developed on mathematical approach of filling up of nuclear energy levels (Shell model), to explain the indistinguishability of neutrons and protons (Liquid drop model), similarity in behaviour of nucleus with a gas (Fermi gas model) or scattering of neutrons by nucleons analogous to the scattering of light by a crystal (Optical model).

What is striking is that while these theoretical models are capable of explaining several characteristic properties of the nucleus, none of these could predict anything about the architectural arrangement of the nucleons so as to reflect on the rigidity of the nucleus and the possibility of α, β, γ ray emission, the breakage (fission) possibility of nucleus by hammering with neutrons or other projectiles which can explain the experimental mass distribution of fission products. To overcome these deficiencies, a polyhedral model based on the symmetrical arrangement of p – n (Paulion) pair is put forward.

3.2 Concept of Polyhedral Model:

The "Polyhedral model" presented here is the first of its kind that throws light on the comprehensive architecture of the nucleus. The model rests on the following assumptions.

1. Since all the nuclei have the same density and the binding energy per nucleon which is about 8 MeV for most of the nucleons (above mass number 56) it indicates that the nuclei have a common architectural pattern.
2. The p – n pair (^2H) is the building block of all types of nuclei. Although n – n pairing also occurs when there is an excess of neutrons, the p – p pairing are least probable due to their inherent instability owing to violation of Pauli Exclusion Principle.
3. The arrangement of these building blocks is flexible and is such as to maintain as far as possible the spherical symmetry and stability of different isotopes.

The α-particle may be considered as the "core" of the nucleus which is made up of two p – n pairs[4]. In order to conform to the spherical symmetry, Platonic solid structures namely, tetrahedral, cubical, octahedral, dodecahedral and icosahedral are arranged sequentially around the core with increasing size and their capacities of holding p – n pairs (as well as n – n pairs) in a symmetrical fashion. The sides of all the polyhedra are built up of p – n pairs (and n – n pairs). Except tetrahedron (the faces of which cannot accommodate nucleons due to its small size and its nearness to the core), each face of other polyhedra can accommodate a neutron or di-neutron or p – n pair or ^3He or ^4H as the case may be.

Thus the total capacity of nucleons inside the nucleus comes out to be 368 which is made up of α (capacity 4), Tetrahedron (12), Cube (48), Octahedron (56), Dodecahedron (108) and Icosahedron (140). The known stable nuclei (up to A = 228) usually fill up to the dodecahedron. The icosahedron is sparsely occupied by nucleons starting from ^{228}Ra to the actinides and trans-actinide (super-heavy) elements. Fig. 2 shows the schematic diagram of the proposed polyhedral cage architecture of the nucleus.

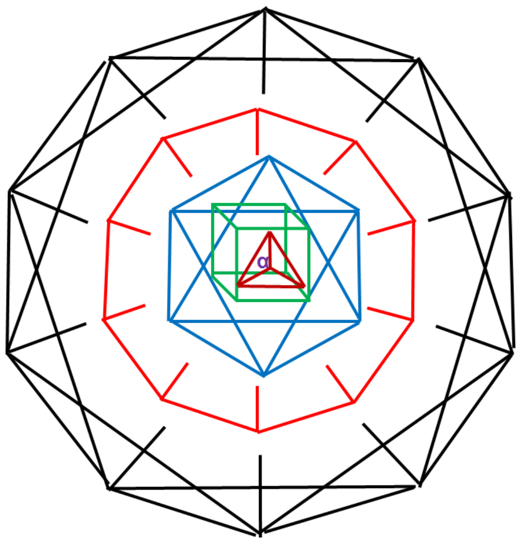


Fig. 2: Arrangement of polyhedral cage structure in the nucleus

The plot of atomic mass of most abundant nuclei of some of the elements against progressive filling up of polyhedra with nucleons is shown in Fig. 3. The abscissa shows the capacity of the spherically symmetric polyhedron in order of increasing volume with nucleon pairs occupying the sides and the faces to form virtual/real alpha particles. The plot is a straight line on which the stable nuclides are shown with R^2 value of 0. 9993. In terms of this model the stable nuclei correspond to the complete or partially symmetric filling up of the polyhedrons that includes automatically some of the so called 'magic numbers'.

It is seen that the plot is a straight line up to ^{56}Fe but after that the plot shows some deviation. Although this deviation is not more than 2%, it is indicative of a defect structure in the skeleton of the nuclei whereby the nuclides become vulnerable to attack by projectiles (neutron, proton, α- particle etc.) so as to result in artificial radioactivity and also for fission reactions.

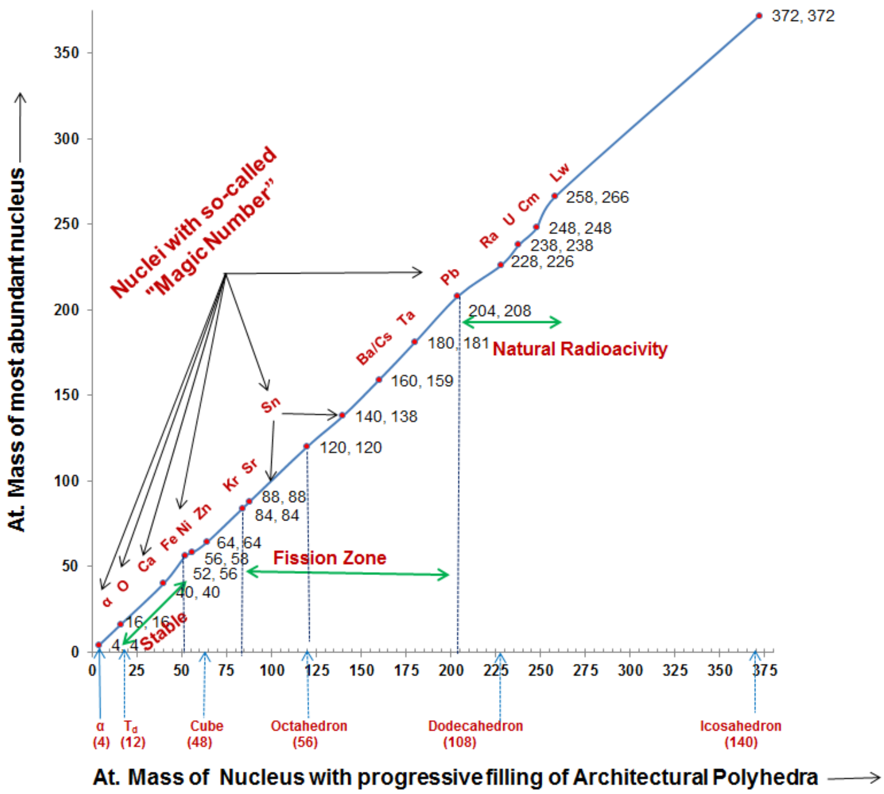


Fig. 3: Plot of Atomic mass against occupancy of nucleons in different polyhedra

The figure is divided into three zones. 1) The stable zone includes nuclei up to ^{56}Fe and shows scant radioactivity (either artificial or natural). In this stable zone nuclei ^{4}He, ^{12}C, ^{14}N, ^{24}Mg, ^{28}Si and even ^{56}Fe have been found to undergo thermonuclear reactions (fusion). Although the fusion (burning) process mostly occurs in stellar medium at a very high temperature (~10^{9}K), fusion of the H atoms to produce ^{4}He is possible in terrestrial conditions also (inside a reactor). 2) The second zone comprises mass number ^{86}Kr to ^{208}Pb and shows artificial radioactivity. 3) Above A = 208 (isobars of Pb and Bi) the elements are naturally radioactive showing disintegration generally accompanied by emission of α, β, γ rays. At A = 120, (the most stable isotope of Sn) the figure shows full capacity of the octahedral configuration.

Table I: Distribution of nucleons of some isotopes in different polyhedral arrangement

	α-core	T_d	Cube		O_h		DoD		I_h	
Capacity / Isotope		S 6	S 12	F 6	S 12	F 8	S 30	F 12	S 30	F 20
	4	12	12+12	12+ 12	12+12	16 + 16	60	48	60	80
^{4}He	4									
^{16}O	4	12								
^{28}Si	4	12	12							
^{40}Ca	4	12	12 +12							
^{56}Fe	4	12	12 +12	12 +**4**						
^{56}Ni	4	12	12 +12	16						
^{64}Zn	4	12	12 +12	12 +8 +**4**						
^{88}Sr	4	12	12 +12	12 +12	12 +**12**					
^{88}Sr**	4	12		**12**			60			
^{120}Sn	4	12	12 +12	12 +12	12 +12	12+**20**				
^{140}Ba	4	12	12 +12	12 +12	12 +12	16+8+**8**	**20**			
^{180}Ta	4	12	12 +12	12 +12	12 +12	16+16	26+ **34**			
^{204}Pb	4	12	12 +12	12 +12	12 +12	16+16	44+**16**	**24**		
^{238}U	4	12	12 +12	12 +12	12 +12	16+16	60	4+**44**	**10**	

** Alternative arrangement

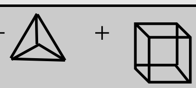
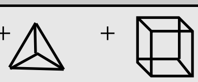
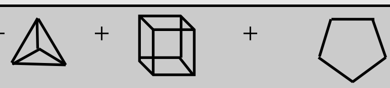
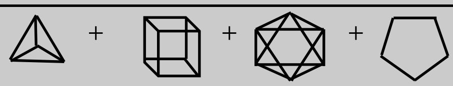
S = Side of the polyhedron ; F = Face of the polyhedron. Bold underlined numbers indicate excess neutron and are present as di-neutrons. Unmarked numbers indicate nucleons in the form of Paulions unless otherwise stated.

The polyhedral model described here is not unique in the progressive filling order proposed. It is quite possible that to gain stability of isotopes in terms of symmetrical arrangement, the sequence of filling up of the polyhedra may take an alternative path. It depends on the availability of protons and neutrons and how they can arrange themselves to make the ultimate polyhedron occupied to approach spherical symmetry as far as practicable. The distribution of nucleons in different polyhedral arrangements for stable isotopes of nuclei is shown in Table I.

3.2.1: Magic numbers

Most recently recognized[15] magic numbers i.e., 2, 8, 20, 28, 50, 82, and 126 can easily be derived by this symmetrical model (Table II).

Table II: Magic Numbers according to Polyhedral model

Magic Number	Number of p and n	Sequence of filling of Polyhedra	Number of nucleons (*proposed)
2	2 + 2 = 4	α	4
8	8 + 8 = 16	α + 	4 +12 = 16
20	20 + 20 = 40	α + 	4 + 12 +24 = 40
28	28 + 28 = 56	α + 	4 + 12 +(24 + 16) = 56
50	50 + 50 = 100	α + 	4 + 12 +24 + 60 = 100
82	82 +126 = 208	α + 	4 + 12 +48 + 56 + (60 +24) = 204*

*The present model could reach a value of 204 (^{204}Tl) in place of the target value of 208 (^{208}Pb).

In addition, the stable isotopes and isobars from Segrè Chart can be represented in the polyhedral model as is shown in Table III.

Table III: Stable isotopes and isobars of some elements from Segrè Chart along with unstable trans-actinides and super-heavies as reflected in the Polyhedral model

Polyhedron (Capacity)	Range	No. of nucleons	Isobars	Distribution of nucleons	Remarks
α (4)	4	4	He	4	
T_d (12)	5-16	16	O	4 + 12	
C (48)	17-64	28	Si	16 +12	¼ filled Cube
		40	Ca	16 +12 +12	½ filled Cube
		52	Fe	16 +24+12	¾ filled Cube
		64	Co, Ni, Cu, Zn	16+ 24 + 24	filled Cube
O_h (56)	65-120	76	Ge, As, Se	64 + 12	¼ filled O_h
		88	Rb, Sr, Y, Zr	64 + 12 + 12	½ filled O_h
		104	Pd, Cd	64 + 24 + 16	½ filled O_h
		120	Sn, Sb	64 + 24 + 32	filled O_h
DOD (108)	121 - 228	140	Ba, La, Ce	120 + 20	1/3 of 60 DOD
		160	Gd, Tb, Dy	120 + 40	2/3 of 60 DOD
		180	Hf, Ta, W	120 + 60	filled DOD
		204	Hg, Tl, Pb	120+ 60 + 24	½ of 48 DOD
		228	Ra, Ac, Th	120 + 60 +48	filled DOD
I_h (140)	229 – 330*	248	Cf	228 + 20	1/3 of 60 I_h
		268	$_{110}^{164}$	228 + 40	2/3 of 60 I_h
		288	$_{112}^{178}$	228 + 60	filled I_h
		308	$_{126}^{184}$	288 + 20	¼ of 80 I_h
		329	$_{125}^{206}$	288 + 40	½ of 80 I_h

* Beyond ^{228}Ra, ^{228}Th and ^{228}Ac, the icosahedral cage starts accommodating the trans-actinides and the super-heavy nuclei up to 330 (Z = 126). The unanimity of theoretical models in predicting the existence of super-heavies with Z = 110, 112, 114, 118 or 126 and N = 164, 178 or 184 has been pointed out[16]. The filling of icosahedral structure as shown above reflects most of these numbers. It is seen that the ‘magic numbers’ occurs automatically. The term ‘magic’ indicates some hidden tricks not easily observed or explained. In the case of nucleus no such magic appears to exist. It is better to replace the term “magical numbers” by “logical numbers”.

3.2.2: Stability and configuration of isotonic nuclei:

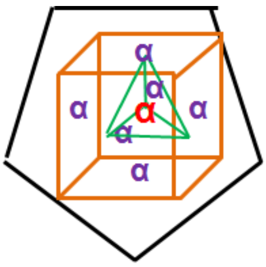
There are altogether 5 observationally stable isotonic nuclei with A – Z = 50 viz., ^{86}Kr, ^{88}Sr, ^{89}Y, ^{90}Zr, ^{92}Mo. The stability of these species has been attributed to the number 50 (magic number) without any attempt to explain the stability from the architectural point of view. Also known are six isotonic nuclei with 82 neutrons, (another magic number) viz., ^{138}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{142}Nd, and ^{144}Sm. A similar isotonic nucleus with 126 (magic number) neutrons occurs in ^{208}Pb and ^{209}Bi. Distribution of nucleons of these isotonic species is shown in Table IV.

From Table IV it is seen that

1) Isotonic nuclei owe their stability mainly to the presence of fully occupied peripheral dodecahedral arrangement (for A – Z = 50 or 82) or icosahedral (for Pb and Bi) with gradual filling up of the faces of the inner cubic core with suitable nucleons.
2) A possible explanation for the stability of A – Z = 50 nuclei can be provided by the application of the polyhedral model by invoking the stability of the dodecahedral peripheral structure which is spherically symmetrical. Thus ^{100}Sn may be expressed by the sequence of filling up the nucleons in the following manner (as shown in Table IV).

   4+12+24+60 = 100 (A) and 2 + 6 + 12+ 30 = 50 (Z)

   The structure of ^{100}Sn nucleus may be represented as in Fig. 4.



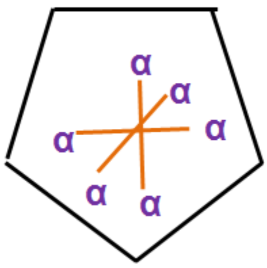


Fig. 4: Schematic filling of ^{100}Sn with nucleons

Table IV: Distribution of nucleons in Isotonic nuclei with A – Z = 50, A – Z = 82 and A – Z = 126

	α-core	T_d	Cube		O_h		DoD		I_h	
Capacity / Isotope	4	S 6 12	S 12 12+12	F 6 12+ 12	S 12 12+12	F 8 16 + 16	S 30 60	F 12 48	S 30 60	F 20 80
$^{86}Kr_{36}$	4	12		**10**			56 + **4**			
$^{87}Rb_{37}$	4	12		**10** + p			56 + **4**			
$^{88}Sr_{38}$	4	12		**12**			60			
$^{89}Y_{39}$	4	12		**11** + 2p			58 + **2**			
$^{90}Zr_{40}$	4	12		**10** + 4			60			
$^{92}Mo_{42}$	4	12		**8** + 8			60			
$^{100}Sn_{50}$	4	12		24			60			
$^{138}Ba_{56}$	4	12	24	8 n +6p	**24**		60			
$^{139}La_{57}$	4	12	24	8n +7p	**24**		60			
$^{140}Ce_{58}$	4	12	24	8n + 8p	**24**		60			
$^{141}Pr_{59}$	4	12	24	8n + 9p	**24**		60			
$^{142}Nd_{60}$	4	12	24	8n +10p	**24**		60			
$^{144}Sm_{62}$	4	12	24	8n +12p	**24**		60			
$^{208}Pb_{82}$	4	12	24	24	**24**		**20** + 40		60	
$^{209}Bi_{83}$	4	12	24	24	**24**		**20** + 40+p		60	

S = Side of the polyhedron ; F = Face of the polyhedron

Bold underlined numbers indicate excess neutron and are present as neutrons or di-neutrons.

Unmarked numbers indicate nucleons in the form of Paulions unless otherwise stated.

The α core is encircled by the tetrahedral structure, which in turn is encircled by an octahedral disposition of α particles placed at the centre of cubical faces, which in turn is encompassed by the dodecahedral cage composed of a total of 30 p – n pairs. On the right in Fig. 4 is presented a simplified picture showing only the peripheral dodecahedron enclosing α- particles arranged in an octahedral disposition.

The structure of ^{100}Sn shows unoccupied sides of the inner cube which can accommodate extra neutrons to yield other isotopes of Sn (a total of 40). It implies that not only the inner vacancies are filled up by neutrons; in addition the vacancies of the peripheral dodecahedron structure may also be filled up by n – n (di-neutron) pairs.

3) The inner cubical core is filled up symmetrically as far as possible by α (^4He), α' (^3He), Paulion (p – n) and di-neutron (n – n) so as to comply with the A and Z values of the isotopes as well as maintaining the spherical symmetry of the structure.

4) ^{87}Rb is a member of A – Z = 50 group but in spite of belonging to this magic group, this isotope is unstable and shows β^- activity with $t_{½} = 4.9 \times 10^{10}$ years. This is reflected in Fig. 5. This isotope contains a p – n pair that may combine with a free neutron to form a triton which is β^- active according to the following equation:

$$p - n + n \rightarrow p - n - n\,(^3H) \rightarrow \beta^- + {}^3He + \nu$$

5) The non-existence of ^{91}Nb in this group as a stable isotope is justified in terms of the proposed model. 12 neutrons and 3 protons (cf. Table IV) are required to be incorporated in the dodecahedron cage which demands the occurrence of at least one Triton which is radioactive.

6) The ^{92}Mo isotope shows a deficit of 4 protons and 4 neutrons from the structure of ^{100}Sn prescribed above and is depicted in the simplified form along with other members of A – Z = 50 nuclei (Fig. 5).

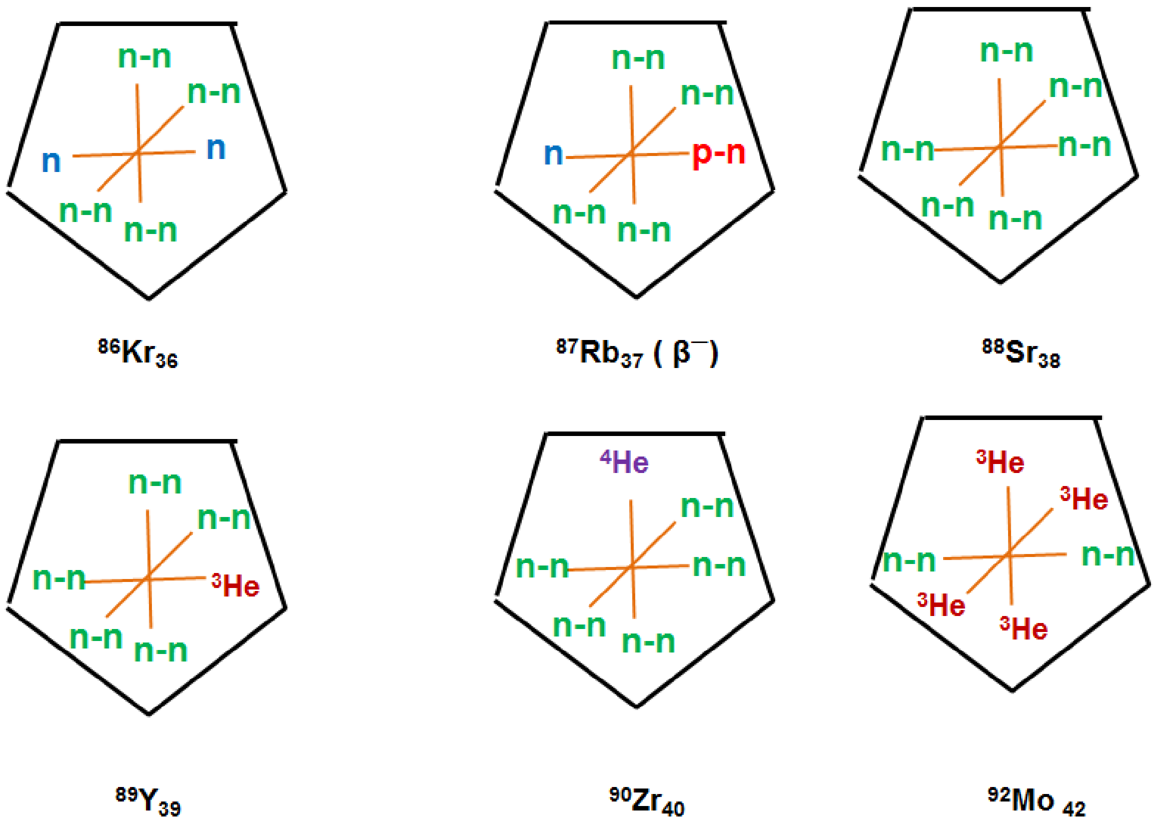


Fig. 5: Arrangement of nucleons of isotones with A –Z = 50

Similarly, the structures of nuclei having neutron and proton difference of 82 are represented in Fig. 6. The nucleons shown here are protected by a shield of 24 di-neutrons in inner octahedron in addition to the peripheral dodecahedral structure (cf. Table 4).

7) Between lead and bismuth, the more massive ^{209}Bi, was long considered to be the paragon of stability amongst all known elements but recently[17] it is found to be a pseudo- radioisotope with a longest half-life of 2.01×10^{19} years. The stability of ^{209}Bi is corroborated in Table IV in which the latter is shown to contain an extra free proton that can further combine with a p – n pair to produce stable α′ (^{3}He) according to the following equation:

$$p + p - n \rightarrow p - p - n\ (^{3}He)$$

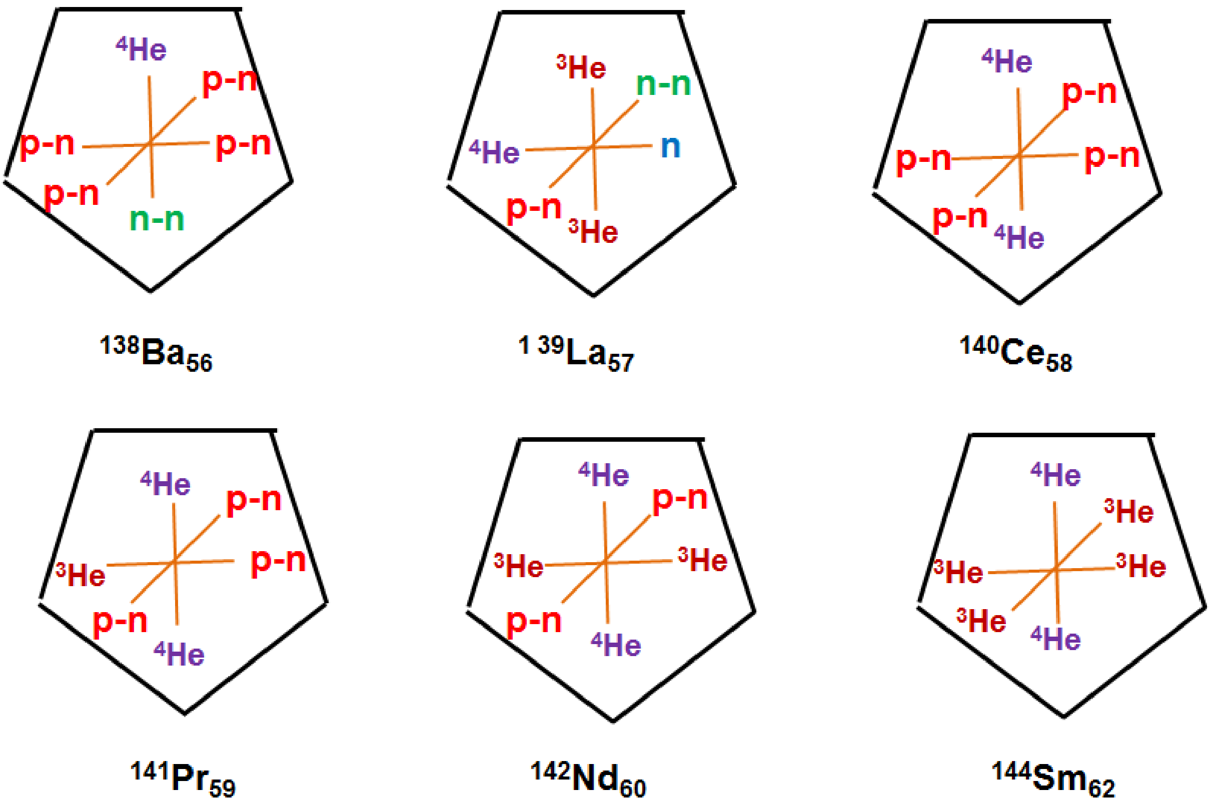


Fig. 6: Arrangement of nucleons of isotones with A –Z = 82

3.2.3: Explanation of α, β, γ emission in terms of the proposed polyhedral model

The polyhedral model shows the arrangement of p – n pairs in tetrahedral, cubical, octahedral, dodecahedral and icosahedral arrangements. All these configurations are spherically symmetrical and are quite stable which accounts for the rigidity and the sphericality of the nucleus. It does not appear to be feasible that a proton or a neutron undergoes transition from one polyhedron to another. In this respect the nuclear transition is completely different from the extra-nuclear electronic transition, for which "electronic spectroscopy" is well documented. Anything like "nucleon spectroscopy" which can systematically analyse emission of α, β or γ rays is, not known till now. It seems that nuclear transition is confined within one particular type of polyhedron. Even then the transitions are specific for a single isotope and no generalization is possible.

α – emission: The Segrè Chart shows that with increasing mass number, the isotopic stability depends on the presence of excess neutron to overcome the Coulombic repulsion among the protons. Thus starting from ^{40}Ca, which shows n/p ratio of 1, the heavy ^{238}U shows n/p ratio of 1.6, and the still heavier nuclei are unstable and show radioactivity. Thus the disintegration of naturally occurring Thorium (4n + 0), Uranium (4n + 2), Actinium (4n + 3) or artificially prepared Neptunium (4n + 1) series show emission of α (along with β and γ rays) to attain stability by converting to different isotopes of Pb[18]. By this process the number of excess proton is diminished. It is suggested that the changes are confined within the icosahedral and dodecahedral peripheral configurations of these isotopes.

β^-– emission: In contrast, β^- emission is far more common among nuclei and are not confined to any particular polyhedral configuration. It is known that a free neutron is converted to a proton by emission of an electron (β^-) along with an anti-neutrino according to the following equation:

$$n \rightarrow p + \beta^- + \bar{\nu}$$

and the energy liberated in the process is distributed in all proportions between β^- and $\bar{\nu}$ so that emitted β^- may have all types of energy value. Even if the neutron is not free but linked to a proton as in a p – n pair, conversion may take place according to the following equation:

$$p - n \rightarrow p - p + \beta^- + \bar{\nu}$$

the p – p pair thus produced may then combine with an n – n pair (from excess neutrons present) to form a pair of p – n (i.e., an α- particle) and the liberated energy of the system is emitted as γ radiation.

β^+– emission: The conversion of a proton to a neutron is believed to occur through the following equation:

$$p \rightarrow n + \beta^+ + \bar{\nu}$$

A closer look reveals that although the charge and energy conservation is maintained in the reaction, it demands the production of a neutron with mass less than that of proton which is unacceptable. The capture of an electron from one of the outermost electronic orbitals (K , L, M) does not solve the problem as this will lead to charge imbalance.

The problem can only be addressed by assuming that the proton reacts with a photon (according to Dirac's suggestion of $\gamma = \beta^+ \beta^-$) which will explain the β^+ emission by the following reaction.

$$p + (\beta^+ \beta^-) \rightarrow n + \beta^+ + \bar{\nu}$$

Simple electron capture (EC) reaction has no role to play in β^+ emission but leads to x-ray emission as a secondary effect due to rearrangement of electrons in the extra-nuclear orbitals of the atom.

In summary, α–emission may occur through escape of peripheral α- particle of the polyhedral cage and is governed by Fermi Gas model. The dynamics of vibrational modes of the polyhedral cage may lead to different half-life values.

β^-– emission occurs through transformation of a neutron to a proton with conservation of mass, energy, spin, angular momentum and parity of the parent and daughter nuclei.

β^+– emission involves the reaction of a proton with a photon.

γ – emission is associated with change of energy of a nuclear configuration from an unstable state to a stable state with conservation of quantum mechanical prescriptions.

3.2.4: Nuclear structure vs. Extra-nuclear electronic structure

Unlike atoms, nuclei are isolated and unbounded among themselves, unaffected by each other even in a crystalline arrangement. While the atomic electronic periphery leads to combination among them to produce crystal structure belonging to 230 different space groups, nuclei are each individual building with its own point group characteristics.

Only similarity among individual atoms and their own nucleus is that they are usually spherically symmetrical which supplies stability to them. Thus Be, Mg, Ca, Sr, Ba, Ra all have spherical s^2 electronic structure. C, Si, Ge, Sn, Pb with spherically symmetrical s^2p^2 (sp^3 hybridized) structure and inert gases having s^2p^6 spherically symmetrical structure, all have stable isotopic nuclei as seen from Segrè Chart and many of them correspond to conventional Magic numbers.

4. Nuclear Fission:

Bombardment of a nucleus by neutrons as projectile was studied during 1934-1938 by different groups [19-22]. When slow neutron impinges on a nucleus, it may 1) be scattered at the surface (elastic scattering). 2) penetrate the nucleus but after sometime is ejected out of the nucleus (compound elastic scattering). 3) directly react with one or more nucleons or 4) form a true compound nucleus which may be unstable emitting α, β, γ rays or undergoes fission reaction. The thermal neutron induced fission occurs with ^{228}Th, ^{230}Th, ^{233}U, ^{234}U, ^{240}Pu, ^{242}Pu, ^{243}Am, ^{246}Cm, ^{250}Cf, ^{252}Cf, ^{255}Es, ^{256}Fm, ^{257}Fm nuclei.

Perhaps the most astounding phenomenon in the field of nuclear science is the discovery of 'fission' that has overriding importance in its vast technological applications.

The theoretical description of the fission process however, is one of the oldest problems in nuclear physics. Much work has been done to understand this process and many aspects have been clarified, but it appears that a consistent description of fission is still very far away[23]. Up till now there is no unique model or theory which can describe all aspects of this phenomenon. The liquid drop model of nuclear fission proposed by Meitner[24] and later supported by Bohr and Wheeler [25] got its credence because of its ability to account for the energy released and the basic energy transformations in the process. However, main lacuna in this model is that it predicts the dominant mode of fission should be symmetrical when the droplet would split into two almost equal halves with comparable masses.

Skeletal structure of nucleus is held by strongest of all known forces. A dense liquid like a globule of mercury on free fall disintegrates into droplets of all sizes from very small to quite large ones. In contrast, breaking of a nucleus shows a definite band of masses (80-140). Not even a trace of iron nucleus which is known to be the strongest (highest binding energy per nucleon) of all known nuclei is obtained in the fragmentation process.

It is a general observation that when fissionable isotopes are bombarded with thermal neutrons (slow), they undergo asymmetric fission with the production of two groups of isotopes.

1) Isotopes of elements with atomic number (Z) from 35 to 43 having masses from 83 to 104 (Br, Kr, Rb, Sr, Y, Nb, Mn, Tc) and
2) A heavier group with Z = 51 – 57 with mass from 130 – 140 (Sb, Te, I, Xe, Cs, Ba, La) with most probable type having mass from 95-140. Curiously enough, the number of protons in the large fragment is consistently found to be 52–56, while the average number of nucleons in the large fragment remains remarkably constant at ~140.

Some text book authors[26] tried to project shell model to explain the asymmetric fission fragmentation but without much concrete logic. The hard core model developed by Wahl[27] also does not seem to be convincing.

With fast projectiles (10 MeV), however, the fragmentation pattern is symmetric and only one group of isotopes of elements with atomic number between 43 and 51 (Ag, Cd, Lu, Sn) are formed.

The approximate distribution of fission fragments (asymmetric and symmetric) along with corresponding percentage yield and filling up of different polyhedral structures is shown in Fig.7.

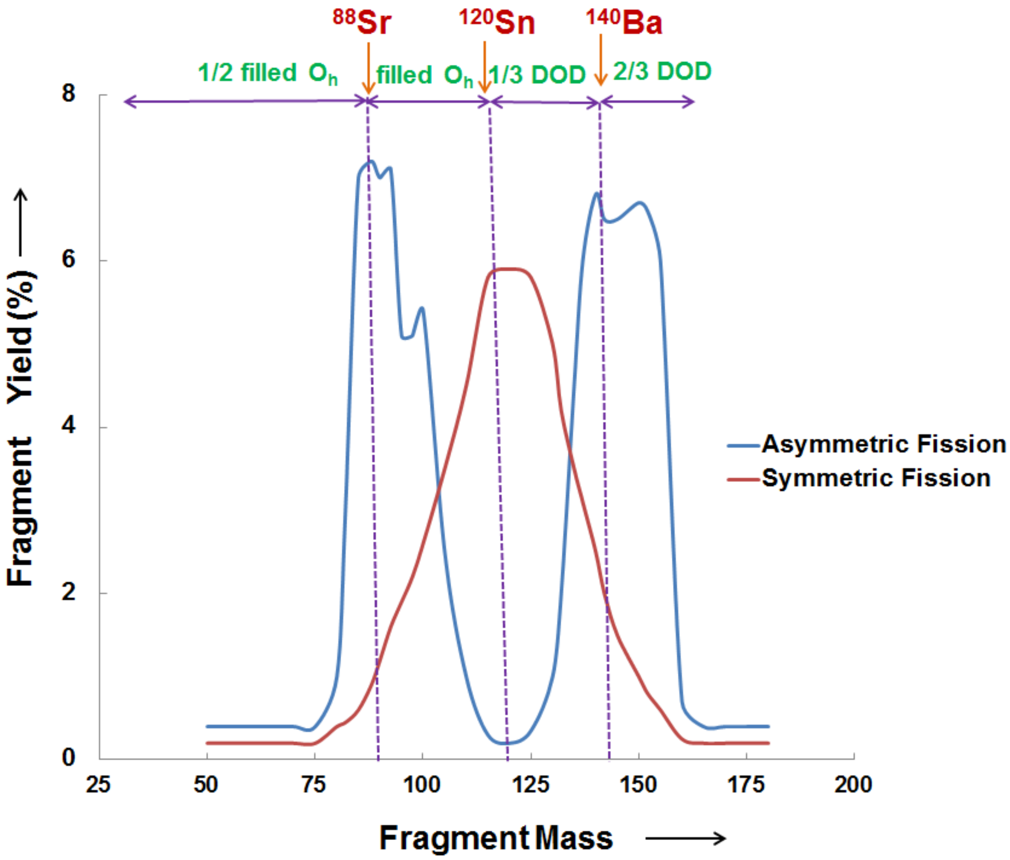


Fig. 7: Schematic distribution of fission fragments with filling up of polyhedra

The peaks of the asymmetric fission are concentrated around mass number 90 and 140. The minimum occurs at 120 which represents ^{120}Sn and is "magically" the main product in symmetric fission process. Till today, it is an unexplained fact that nearly all the fissionable nuclei break in the fragments with mass ratio of about 3:2.

The present polyhedral model of the nucleus involving p – n pairs could successfully explain both the symmetric and asymmetric fission fragmentation pattern. It is considered that the fission process is a statistical one but not of a single nucleus. In a recent study[28], relative yield of ^{235}U fission products were measured in a high level radioactive sludge. Some 42 elements were detected in the mass range of 84-154 and their concentrations were measured through ICP_MS which indicates that a single fissile nucleus is not involved in the fission process. Lowest mass number detected was ^{79}Se of which fission yield is so low that its concentration could not be measured by ICP-MS.

One nucleus on breaking is supposed to produce only one daughter nucleus but not a pair of masses of comparable size. It is hard to believe that one skeleton on breaking could give rise to skeletons of two smaller bodies preserving all its characteristics!

In terms of the proposed model, on bombardment with lower energy neutrons the outermost dodecahedral arrangement is partially broken up to produce a structure with mass number 160 with maximum at ^{140}(Ba/Cs). With more clipping, the whole of the dodecahedral arrangement is broken to reduce it to the octahedral configuration with mass number ^{120}Sn. Further stripping will partially break the octahedral structure to produce mass number of about 80 with maximum at ^{88}Sr (cf. Fig. 7). Thus at ^{88}Sr, the octahedron is ½ filled, at ^{120}Sn it is fully occupied and at ^{140} Ba, the next dodecahedral sides are one third filled up. The peaks occur at 88 and 140 and the ratio of masses is 140/88 = 1.6. This value changes somewhat with different mass numbers which arises from the attainment of stability of isotopes through neutron emission, but in general the ratio of about 3:2 is maintained.

According to this model, the bombarding neutrons enter the fissionable nucleus (say ^{235}U) , and omitting any scattering, forms a compound nucleus which induces clipping of the nucleus (assisted by emission of α, β, or γ radiations) to the ultimate dodecahedron shell. When this shell is completely broken, mass of ~120 (symmetric fission) of Sn nucleus is formed. If the neutron penetrates further, the next inner shell (O_h) is broken and stripping of nucleons produces mass up to ^{84}Kr. The innermost shells of the nucleus are not affected even by high energy neutrons.

The distribution of nucleons in ^{84}Kr, ^{88}Sr, ^{120}Sn, ^{140}Sn and ^{140}Ba/^{140}Cs which are produced by fission of Uranium by clipping / stripping of the nucleons from peripheral dodecahedron and next inner octahedral shells are shown in Fig 8.

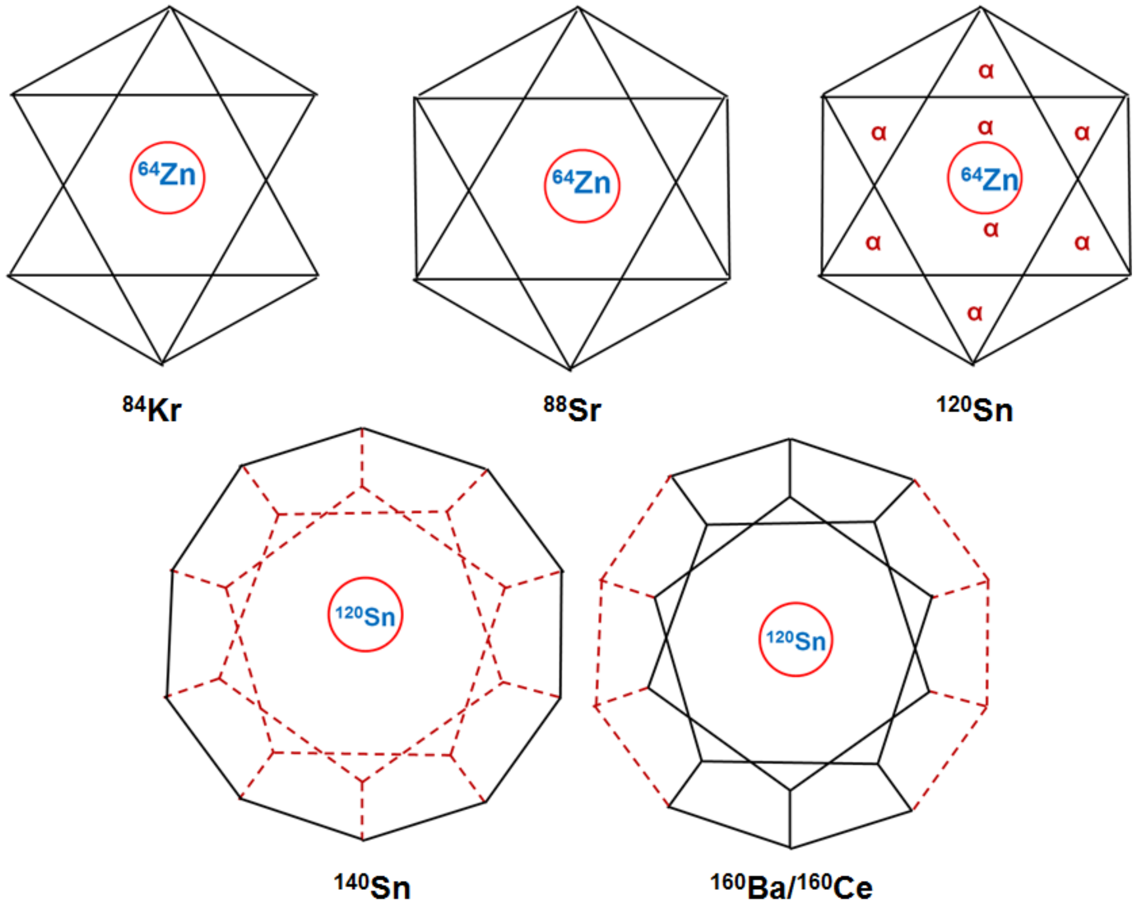


Fig. 8: Arrangement of nucleons produced by clipping of dodecahedron periphery.

Continuing sequentially, the configuration of ^{180}Ta, ^{204}Pb/Tl and ^{228}Ra are shown in Fig. 9. It reveals the occupancy of α- particles on the faces of the dodecahedron in Ra and Pb/Tl. ^{228}Ra is fissionable but besides this, it is also naturally radioactive and by losing α and β particles produces isotopes of ^{204}Tl, ^{208}Pb and ^{209}Bi.

5. Fusion Reaction (Energy production in the Sun)

At the time of evolution of the universe at an initial temperature of ~10^9K, the nucleons started condensation through cooling with time. It is possible that the masses produced are of different dimensions and the rate of fall of temperature of the masses was widely different. It is also possible that in some cases (Sun for example), the temperature is not sufficiently decreased (present temperature 10^7K) and the coagulation of p – n process is still occurring.

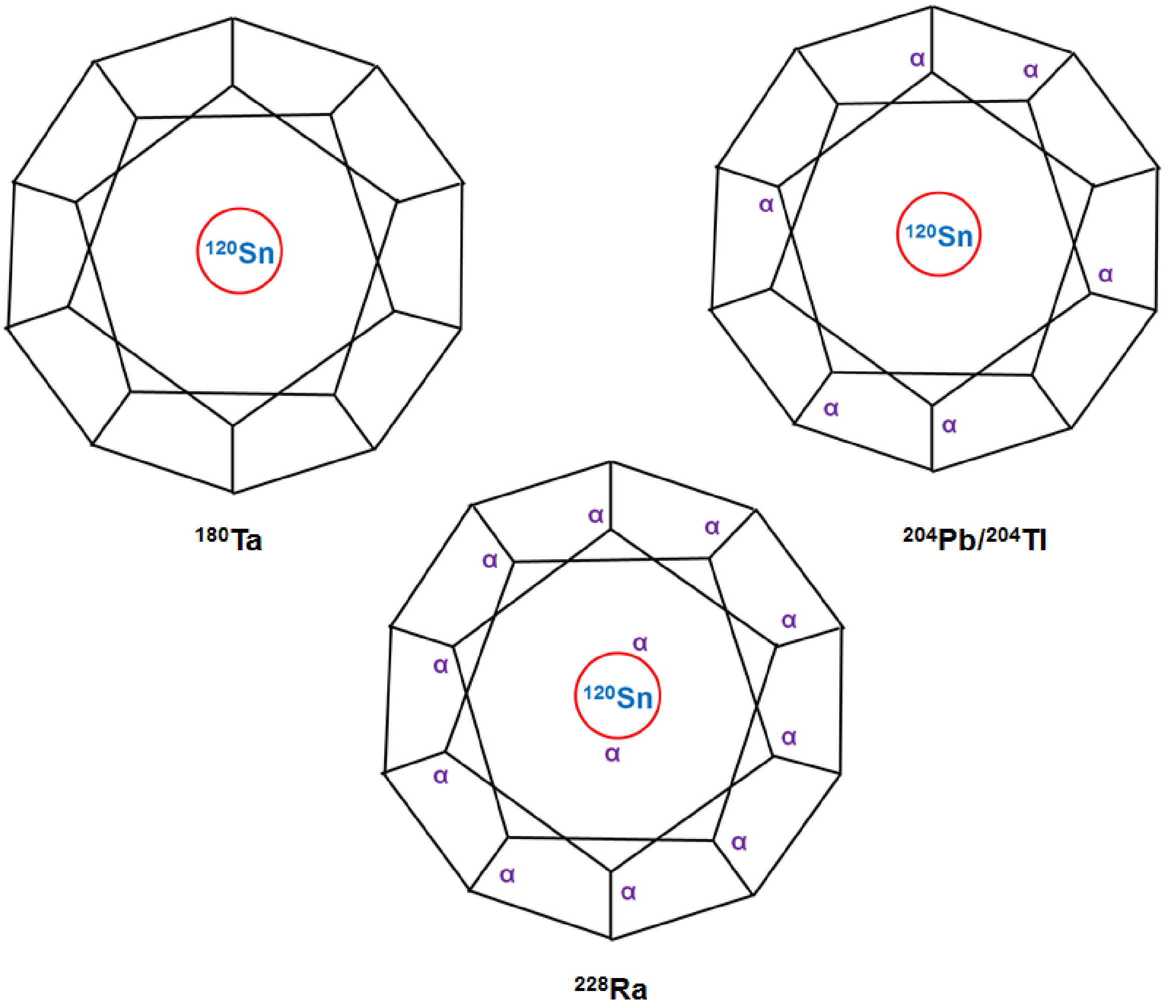


Fig.9: Configuration of ^{180}Ta, ^{204}Pb/Tl and ^{228}Ra

As a result, while for terrestrial conditions the temperature is sufficiently low to sustain life and vegetation, the Sun's temperature is not favorable for any animation to occur. On the other hand, the temperature of the Sun is not decreasing owing to some thermonuclear reactions which continuously generate heat for sustenance of the temperature of the sun for billions of year to come.

The thermonuclear reactions taking place in the Sun result through two mechanisms:

1. The carbon cycle where ^{12}C is the catalyst which condenses with four protons in stages to produce α- particles along with positrons, nutrinos and γ-rays. The initial requirement of energy for the protons to react with ^{12}C was thought to be supplied by quantum mechanical Tunnel effect[29].

$$4\ {}^{1}H \xrightarrow{{}^{12}C} 2\ {}^{4}He + 2\beta^{+} + \gamma + \text{nutrinos}$$

2. Proton – proton reaction[30-32]

$${}^{1}H + {}^{1}H \rightarrow {}^{2}D + e^{+} \qquad Q = 1.44\ \text{MeV}$$

$${}^{2}D + {}^{1}H \rightarrow {}^{3}He + \gamma \qquad Q = 5.49\ \text{MeV}$$

$$2\ {}^{3}He \rightarrow {}^{4}He + 2{}^{1}H + \gamma + \text{nutrinos} \qquad Q = 12.86\ \text{MeV}$$

$$\text{Overall : } 4\ {}^{1}H \rightarrow {}^{4}He + 2\beta^{+} + 3\gamma + \text{nutrinos} \qquad Q = 26.7\ \text{MeV}$$

Both the mechanisms predict that plenty of neutrinos are generated as a result of the proposed reactions, while experimental observations failed to detect these highly penetrating particles in any appreciable amount. This phenomenon is usually known as the “nutriono puzzle” which is still considered as an unsolved problem.

It is proposed here, that the initial reaction producing matter in the early process of evolution is still continuing in the Sun’s interior i.e., proton – neutron pairs (Paulions) are condensing in the following manner.

$$p - n \;+\; p - n \;\rightarrow\; {}^{4}He\ \ (\alpha\text{-particle})$$

The condensation produces only α- particles but no positrons or nutrinos, whereby the neutrino puzzle is automatically eliminated. In case of any neutrino generated from the nuclear reactions, these are absorbed by ^{2}D which is an efficient absorber of neutrinos with high cross section by which ^{2}D is decomposed to protons and neutrons. The condensation reaction produces sufficient energy as a result of these exothermic reactions.

The combination of two Paulions has been theoretically considered previously[4] and the Pauli allowed species has been figured out to liberate approximately ~25 MeV energy which is quite close to the value of 25.7 MeV calculated from shear mass difference of the components. The liberated energy value (Q = 26.7 MeV) in proton-proton reaction and also for CNO cycle for helium production[33] is also quite close.

6: Conclusion

The proposed non-mathematical model of the architecture of the nucleus is based on the foundation of natural symmetry and Bose-Einstein condensation of Pauli allowed p – n pair (Paulion) along with n –n pairs. The lattice of the polyhedral structure thus formed is interposed by α- particles at suitable facial position of the polyhedrons. This model reflects qualitatively the salient features of all the presently accepted models (Shell, Liquid Drop, Composite, Fermi gas and Optical) and is also capable of explaining the fission and fusion processes. It also logically explains the formation of stable nuclei starting from Helium up to Uranium and extends to the formation of unstable trans-actinides and super-heavies. The variation of the predicted values from atomic masses of most stable isotope is less than 2%.

This architectural model of the nucleus is first of its kind and is purely hypothetical one. No experimental verification of the structure appears to be possible but the model is able to explain many of the known properties of the nuclei like shape, stability, prediction of so called magic numbers, process of fission and fusion reactions, neutrino puzzle, stability of isotonic nuclei and emission of α, β and γ- rays. The model, however, is not claimed to be the final say about the problem but might serve as the pointer to the importance of symmetry properties applied to nuclei which may lead to the systematization of the wealth of data collected by nuclear scientists.

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