Mechanism of nucleosynthesis: Formation of lighter nuclei with proton-neutron pair as the building block

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Abstract

A novel and unique model based on the singlet state of proton–neutron pair as a building block is postulated for nucleosynthesis of different nuclei. The presently accepted alpha cluster model is inadequate for the explanation of the formation of ^{7}Li, ^{8}Be, ^{10}B, their stability and abundance. Problem of Beryllium bottleneck and the explanation of Hoyle's state of ^{12}C appear to be insurmountable by the cluster model.

Proton and neutron combine to form deuteron (spin 1) and another species (isomeric with deuteron, with spin 0) obeying Pauli Exclusion Principle and is termed ***Paulion***. The corresponding element is Christianized as **Paulium (Pl),** hitherto unrecognized isomer of hydrogen. The newly identified species, is capable of formation of alpha particle following Bose-Einstein Statistics.The ***Paulion*** condensation model is applied to build-up different isotopes of Li, Be, B, C, N and O and can resolve the existing puzzle in the nucleosynthsis of stable ^{12}C. It can explain the abundance and the properties of different nuclei.

An empirical equation A = Z (p – n) pair + (A - 2Z) n explains the composition of different nuclei where A is the mass of the nucleus, Z being its number of proton.

Key words: Stellar and Terrestrial nucleosynthesis; α- cluster model; (p – n) pair; isotope of hydrogen and isomer of deuterium; Paulium (P_l)

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1. Introduction

One of the basic problems in nuclear astrophysics is the mechanism of formation of different nuclei of some 80 odd stable chemical elements which are found in samples from stellar, terrestrial, lunar, meteoritic and cosmic sources. The primordial nucleosynthesis from Big Bang recognizes the formation of H, He and a small amount of Li. Elements heavier than ^{4}He have been produced in stellar nucleosynthesis process that started through hydrogen burning leading to the formation of ^{4}He by fusion of four ^{1}H nuclei [1]. The fusion process to form a nucleus (so called alpha process) in the form of helium burning, carbon burning etc. is thought to be the mechanism by which the heavy nuclei were formed in steps at a temperature of 10^8 K and above [2]. But the formation of higher mass number nuclei is strongly hindered by beryllium bottleneck in terrestrial as well as in stellar systems such as nova, super-nova, dwarfs, neutron stars and black holes.

In spite of all geochemical, geological and biochemical changes over a time span of some billions of years, the stable nuclei retain their integrity (along with stable and radioactive isotopes). Although the explanation of the formation of all these species is a Herculean task, some notable attempts have been made towards the goal. One such attempt is the alpha cluster model which assumes that different nuclei are formed by the conglomeration of alpha particles. Carbon being the backbone of existence of life in the universe has drawn maximum attention of nuclear scientists for its mechanism of formation. Various theoretical as well as experimental researches have been made keeping in pace with its abundance and rate of formation. Throughout the history of nuclear physics, the idea of α-particle clustering has been present.

It was pointed out [3] that effective element-building inside stars must proceed in absence of hydrogen, by triple α-particle collisions as starting point resulting in ^{12}C with the release of gamma rays. These considerations were further developed and it was suggested [4] that ^{12}C is produced by a non-resonant two- step process, the first step being the combination of two α-particles forming a short-lived ^{8}Be followed by capture of another alpha to form ^{12}C which undergoes radiative transition forming a stable ^{12}C. The non-resonant capture process, however, fails to corroborate with the actual abundance of stable ^{12}C in the universe. In order to account for the amount of ^{12}C and ^{16}O in the universe, Sir Fred Hoyle surmised that an accelerating mechanism is mandatory and he put forward his astounding prediction for the existence of a resonance in ^{12}C, 300 KeV above the 3 α threshold, required to increase the cross section by seven orders of magnitude [5]. The existence of this state (excitation energy 7.68 ± 0.03 MeV) was since discovered experimentally [6].

There have been a number of recent reviews on the growing and vibrant fields of nuclear clustering in which a balanced description of up to date theoretical models and the experimental findings are given [7-13]. The exceptional stability of the alpha particle coupled with the fact that only this particle is ejected from radioactive materials (besides beta and gamma rays) led to the idea that alpha particles might be the building block of atomic nuclei.

In spite of enormous and exhaustive researches still going on in this field, the exact details of α interactions and the extent to which their underlying fermion structures play a role is not yet fully understood. The nuclear scientists conclude that ‘there still remain many open questions and challenges to be solved in near future’.

The shortcomings of the α-cluster model lies in the fact that this can predict the formation of only those nuclei (n-alpha nucleus) with mass numbers which are multiple of 4. The most stumbling fact is that two alpha particles do not form ^{8}Be and three of these are reluctant to form ^{12}C. Also, the model does not usually explain the formation of Li, Be and B. Curious is the fact that an extra neutron can bind α-particles to form stable isotopes of ^{7}Li (abundance 92.5%), ^{9}Be (100%) and ^{11}B (80.1%). All these factors pose some doubt on the so far accepted theory of nucleosynthesis considering α- particle as building block. It therefore, appears that an alternative species is to be searched which could serve as the building block for nucleosynthesis successfully.

Alpha particle being tetrahedral in nature is quite rigid to interact with each other to enter into alpha-alpha condensation process. To overcome the hindrance, a smaller linear unit consisting of one proton and one neutron (p – n) is being postulated in this article as the new building block obeying Pauli Exclusion Principle. This new model has been able to eradicate the restriction of formation of nuclei smaller or equal to ^{40}Ca which is the heaviest stable n-alpha nucleus.

2. The Concept of Paulion

To understand the mechanism of nucleosynthesis, we start *ab initio* from the combination of a proton with a neutron which is believed to be the starting process of nucleus formation. Omitting the spin of the two Fermions, the Hamiltonian of the system is

$$H = \frac{1}{2m_n}\vec{p}_n^{\ 2} + \frac{1}{2m_p}\vec{p}_p^{\ 2} + V \qquad (1)$$

where V is the potential energy of the system.

Since the two particles are interacting, the centre-of-mass momentum $\vec{p}_{cm}$ and the relative momentum $\vec{p}_r$ are $\vec{p}_{cm} = \vec{p}_p + \vec{p}_n$ and $\vec{p}_r = (m_n\vec{p}_p - m_p\vec{p}_m)/M$, respectively where M = $m_p + m_n$. Putting $\mu = m_p m_n/(m_p + m_n)$ which is the reduced mass, the quantum version of the Hamiltonian becomes

$$H = \frac{1}{2M}\vec{p}_{cm}^{\ 2} + \frac{1}{2\mu}\vec{p}_r^{\ 2} + V \qquad (2)$$

where $\vec{p}_{cm}$ is a constant of motion and $E_{cm} = \frac{1}{2M}\vec{p}_{cm}^{\ 2}$ (energy of the centre-of-mass the value of which is zero).

Now, since $\vec{p}_r = -ih\frac{\partial}{\partial\vec{r}}$, the deuteron Hamiltonian becomes

$$H_D = -\frac{h^2}{2\mu}\nabla_r^{\ 2} + V \qquad (3)$$

Converting the kinetic energy term into spherical coordinates and using angular momentum operator of $\vec{L}^2$ for the reduced potential, the Schrödinger equation becomes

$$\left[-\frac{h^2}{2\mu}\,\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{\vec{L}2}{2\mu r^2} + V\right]\mathit{\Psi}_{n l m r\theta\varphi} = E_n \mathit{\Psi}_{n l m r\theta\varphi} \qquad (4)$$

Using the relation $h^2\, Y_L{}^m(\theta\varphi) = h^2 l\,(l+1)\, Y_L{}^m(\theta\varphi)$ and solving the equation by the method of separation of variables and eliminating $Y_L{}^m$ we get,

$$-\frac{h^2}{2\mu}\,\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\,\Psi_{nl(r)}\right) + \left[V + \frac{h^2 l\,(l+1)}{2\mu r^2}\right]\mathit{\Psi}_{nl(r)} = E_n\mathit{\Psi}_{nl(r)} \qquad (5)$$

Putting $\mathit{\Psi}_{nl(r)} = u_{nl(r)}/r$, the radial part becomes

$$-\frac{h^2}{2\mu}\frac{d^2u}{dr^2} + \left[V + \frac{h^2}{2\mu}\,\frac{l\,(l+1)}{r^2}\right]u(r) = E_n(r) \qquad (6)$$

This is a one dimensional Schrödinger equation with an effective potential (containing centrifugal potential)

$$V_{eff}(r) = V + \frac{h^2 l(l+1)}{2\mu r^2} \qquad (7)$$

Using a nuclear square-well potential of range 2.1fm and depth V_0 = - 35 MeV the plot becomes (Figure 1).

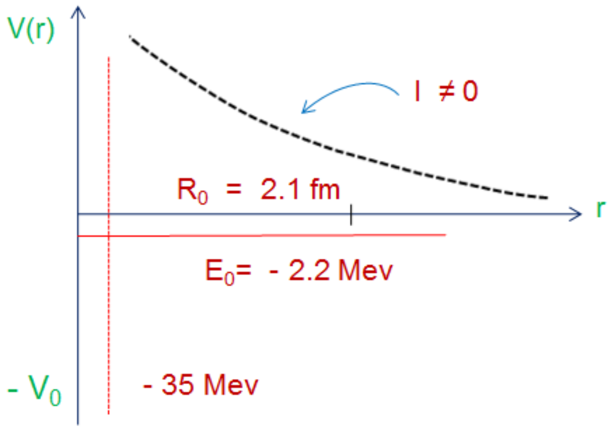

Figure 1. Plot of Effective Square-well potential

With no centrifugal potential $l = 0$, the equation becomes

$$\left[-\frac{h^2}{2\mu}\ \frac{1}{r}\frac{d^2}{dr^2}\ +\ V\right]u_0(r)\ =\ E_0u_0(r) \tag{8}$$

The Eigen functions are

$$u(r) = A\sin(kr) + B\cos(kr) \quad 0 < r < R_0 \qquad \text{and} \quad (r) = Ce^{kr} + De^{kr} \qquad r > R_0$$

On examining the eigenvalues, it is found that a bound state is indeed possible with $E_0 = -2.2$Mev (with $l = 0$). The next odd solution with $k_m = 3k_0$ gives a very high kinetic energy to show as unbound state. With $l > 0$ no bound state is produced indicating that the excited state of deuteron is unbound.

Thus it is seen that deuteron is a bound entity in the ground state with a mean binding energy of 1.1 MeV (as against 7-8 MeV for most of the nuclei). The charge distribution of deuteron is unsymmetrical with a quadrupole moment of 0.00274 b. Two deuterons may not form a compound nucleus $^2H + ^2H \rightarrow\ ^4He$, thus the probability of formation of α- particle is quite small.

Considering the spin of the two nucleons which are both Fermions, we find for the bound deuteron state (with $l = 0$), $\quad S = \vec{S}_p + \vec{S}_n$ (spin ½)

The spin dependent potential $\quad V_{spin} = V_1(r)/h^2\, \vec{S}_p\, \vec{S}_n$

The configurations are either $\quad \vec{S} = 1$ or $\vec{S} = 0$

We write

$$\vec{S}^2 = (\vec{S}_p + \vec{S}_n)^2 = \vec{S}_p{}^2 + \vec{S}_n{}^2 + 2\,\vec{S}_p\vec{S}_n \tag{9}$$

$$\text{Or,}\quad \vec{S}_p\vec{S}_n = ½\,(\vec{S}^2 - \vec{S}_p{}^2 - \vec{S}_n{}^2) \tag{10}$$

$$\text{Then,}\quad < \vec{S}_p\vec{S}_n > \ = \frac{h^2}{2}\left[S\,(S+1) - S_p\left(S_p + 1\right) - S_n(S_n + 1)\right] \tag{11}$$

$$= \frac{h^2}{2}\left[S\,(S+1) - 3/2\right] = \frac{h^2}{4}\ \text{(for a triplet state) or}\ \frac{3h^2}{4}\ \text{(for singlet state)}$$

If $V_1(r)$ is an attractive potential (< 0) the total potential

$$V_{s=1} = V_T = V_0 + \frac{1}{4} V_1 \qquad (12)$$

and
$$V_{s=0} = V_S = V_0 - \frac{3}{4} V_1 \qquad (13)$$

Putting $E_T = -2.2$ MeV and $E_S = 77$ KeV ($\cong 0$) we obtain

$V_T = -35$ MeV [with $V_0 = -32.5$ MeV and $V_1 = -10$ MeV] and $V_S = -25$ MeV

Invoking the spins of proton and neutron (both fermions with spin ½), the ground state of deuteron is a triplet (spin 1) and the excited state is a singlet (spin 0). Since the triplet state is stable, condensation of two deuterons will not form a α-particle which is a boson with spin 0. On the other hand, the excited singlet state is capable of mutual combination to produce a stable α-particle with almost 25 MeV of binding energy (Figure 2).

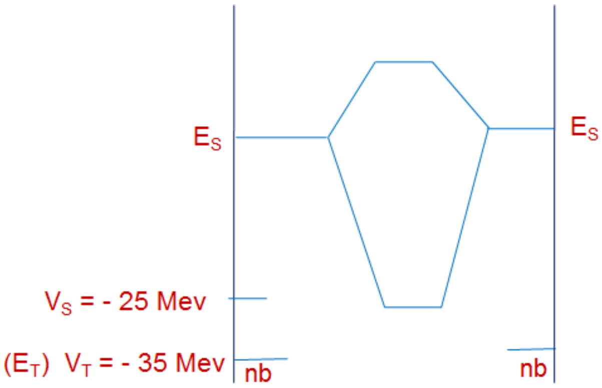

Figure 2. Energy Level Diagram showing bonding of excited level state in comparison to non-bonding ground state of deuteron

The spatial configuration of α-particle is non-planar (tetrahedral). As this singlet state results by the application of Pauli Exclusion Principle, we designate it as ‘Paulion’ (p – n) pair in honour of Wolfgang Pauli. This may be considered as derived from Paulium (with symbol Pl) an unrecognized isotope of hydrogen which is isomeric with deuterium. This Paulion (pl) may be regarded as the fundamental building block in nucleosynthetic processes in preference to α-particle.

The various ways by which neutrons and protons may combine in the nucleus are as follows:

1.	p + n → pl [(p – n)]	Paulion $^{2}H^{+}(0)$
2	p + n → d $[^{2}H^{+}(1)]$	deuteron, $^{2}H^{+}(1)$, isomer of Paulion
3.	pl + pl → α $(^{4}He^{++})$	spin allowed α-particle is produced
4.	d + d → --	spin forbidden, no α-particle is produced
5.	pl + p → $^{3}He^{++}$	stable isotopic nucleus of He
6.	pl + n → t $(^{3}H^{+})$	triton, nucleus of tritium, radioactive
7.	p + p → p – p	di-proton
8.	n + n → n - n	di-neutron

Of these, reactions 1 and 2 have been discussed earlier using quantum mechanical treatment. The reactions 3 and 4 are related to alpha particle formation and are discussed later. Reaction 5 shows the interaction of a Paulion (pl) with a proton to produce $^{3}He^{++}$, a stable isotopic nucleus of helium. According to reaction 6, t (triton), a radioactive nucleus of ^{3}H is formed by the interaction of pl with n which is subsequently converted to $^{3}He^{++}$ (helium nucleus) by emitting β^{-} particle as t → $^{3}He^{++}$ + β^{-} + anti-neutrino (a particle with mass and charge zero having only energy and spin). When we arrive at the elucidation of formation mechanism of any nucleus based on Paulion (p – n) model, it transpires that the number of proton present in the nucleus will combine with identical number of neutrons to form Paulions and the residual neutrons present in the nucleus will club together to form di-neutrons. Thus nuclei having odd mass number will mostly be β^{-} active due to the formation of intermediary tritium nucleus resulting from the interaction of the odd neutron with one pl. Some example of such reactions are ^{87}As → Sr, ^{133}In → Cs, ^{137}Sb → Ba, ^{149}Ba → Sm, all of which are β^{-} active yielding stable fission products [14].

Reactions 7 and 8 show the formation of di-proton with spin (1) and di-neutron with spin (1), respectively. In both the cases, formation of resulting spin (1) state arising from the interaction of proton and neutron with unpaired spin would be contradicted by Pauli Exclusion Principle. It is required that for their existence they must differ in some other quantum number (e.g. orbital angular momentum). However, this will produce a lower binding energy making them comparatively unstable. A nucleus resembles a tiny crystal composed of neutrons and protons. Existence of electrons in the nucleus is forbidden by the de Bröglie principle. Due to their fractional charges and incapability of their independent existence, consideration of quarks as the building block is not ordinarily acceptable. The combination of a neutron and a proton to form a Paulion may be called a ‘quasi-nucleon’ in analogy with “quasi-particle” in the quantum interpretation of a crystalline state. Like quasi-particle, the quasi-nucleon behaves as a perfect gas which obeys the gas laws, and may be either fermions or bosons. Depending on the temperature of the surroundings, these Paulions may condense along with excess neutrons (and/or protons) to produce nuclei of different mass numbers having different isotopes. The process will follow Bose-Einstein condensation laws.

3. The formation of α-particle

A proton and a neutron interact with each other to produce either deuteron or Paulion. A neutron and a proton have almost the same mass but they have different electrical charges. Both are fermions with spin ½. The neutron consists of a proton and negatively charged π-meson. The π-meson which is a boson acts as an attractive force by mutual exchange. The difficulty in explaining the mass transfer accompanying π-meson (300 times heavier than an electron) is overcome by assuming a virtual process and application of Heisenberg uncertainty principle which shows the time of exchange as 10^{-23} sec and the distance traversed as 10^{-13} cm which is within the nuclear dimension. The interaction may be represented as below obeying the Pauli Exclusion Principle (Figure 3).

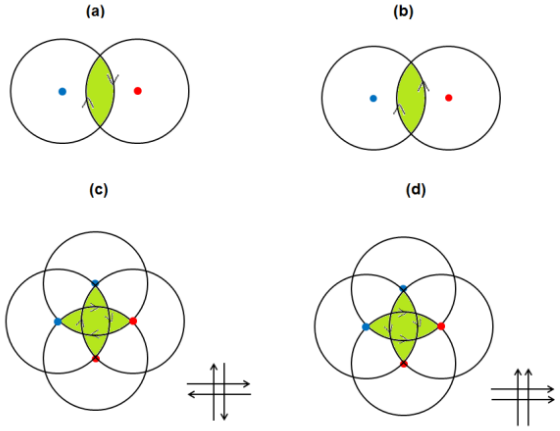

Figure 3. (a) π-meson overlapping n and p, spin is zero producing a Paulion with total spin 0. (b) Spin of n and p are parallel with total spin 1(deuteron) (c) Formation of α (boson) with spin 0 from Paulion. (d) Non-zero spin fails to produce α from deuteron.

This interaction conforms to the characteristic properties of nuclear force, viz., 1) The force is short range, 2) It has saturation properties, 3) It arises from exchange and is independent of electrical charges of the nucleons and 4) It occurs in pairs or pair of pairs. Recently Bose-Einstein condensation mechanism has been applied for studying the reaction rates of fusion of deuterons in Palladium metal, which is extremely slow due to the Gamow factor arising from Coulomb's barrier between the deuterons [15].

4. Nucleosynthsis of Lithium, Beryllium and Boron

Existing theories of nucleosynthesis fail to explain the formation and abundance of ^{6}Li, ^{8}Be, and ^{10}B in cosmic atmosphere as these isotopes decompose at high temperature in the Big Bang process and in the stellar interiors. Spallation reaction mechanism [16] has been proposed in which a target nucleus breaks up in a high energy nuclear reaction to form products which are 10-20 mass units below the target. By far the most acceptable explanation is that these 3 elements are produced by interaction of cosmic rays with nuclei found in the gas or dust clouds of inter stellar medium. Curiously, in the case of these three elements the most abundant isotopes are ^{7}Li, ^{9}Be and ^{11}B. In all these, an extra neutron in excess of the number of protons imparts stability to these isotopes. All these three stable isotopes are proposed to be formed by the condensation of Paulions (p – n) which are bound by an extra neutron as shown in (Figure 4).

In all these cases, the central neutron is enclosed by dotted lines to include two protons and two neutrons producing intertwined virtual α-particles resulting in the stability of these isotopes (Figure 4 a). Three dimensional representation of the structure of these isotopes are shown in (Figure 4 b). If the central neutron in ^{7}Li, ^{9}Be, and ^{11}B is replaced by a proton ^{7}Be, ^{9}B and ^{11}C isotopes are produced respectively.

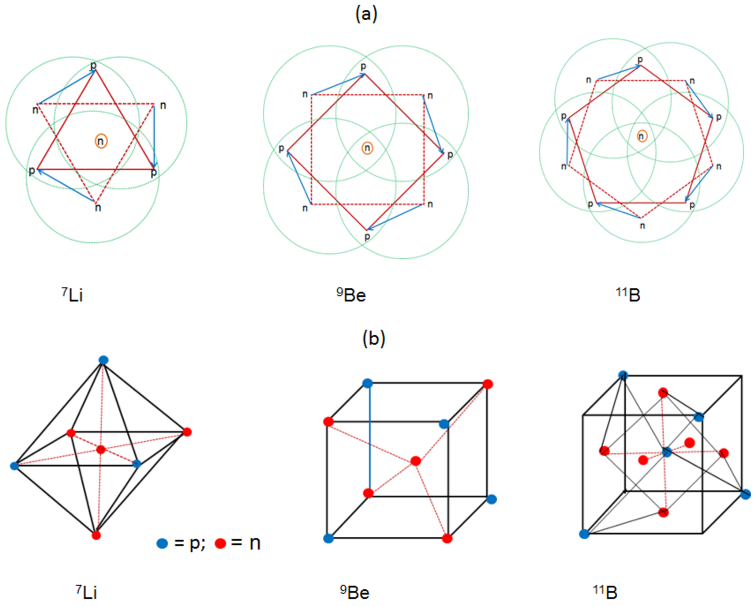

Figure 4. (a) Formation of virtual α-particles in Li, Be, B in two dimension (b) Structural representation of Li, Be, B in three dimension.

5. Nucleosynthesis of Carbon

As discussed earlier, researches are still being continued to understand the precise nature of the element ^{12}C specially the so-called ‘Hoyle state’ which has become a touchstone for nuclear astrophysics, nuclear structure and nuclear forces and is playing a dominant role as a prototype of α-cluster states in lighter nuclei.

Various theoretical models predict different structures of the Hoyle's state. These include molecular structure of different types (linear chains of 3 α-clusters, [17] compact triangular / bent-arm or obtuse triangular configuration of alpha clusters, [18] a finite α- boson gas quite different from that expected in the shell model, [19] α-particle condensate type, [20,21] or a dilute self-bound gas of weakly interacting α- particles resembling the properties of a Bose-Einstein condensate [22]. In a recent research, experimental evidence [23] has been put forward in support for triangular D_{3h} symmetry in the arrangement of the three alpha particles in the ground state of ^{12}C. However, the Hoyle's state of ^{12}C cannot be described unambiguously by any known model of atomic nuclei including the shell model which is inaccurate when it comes in describing the lowest excited state of ^{12}C.

The Hoyle's state is now being considered as a Bose-Einstein condensate (BEC) of Paulion obeying Bose statistics and is represented pictorially (Figure 5) where the p ← n pair is denoted as ←.

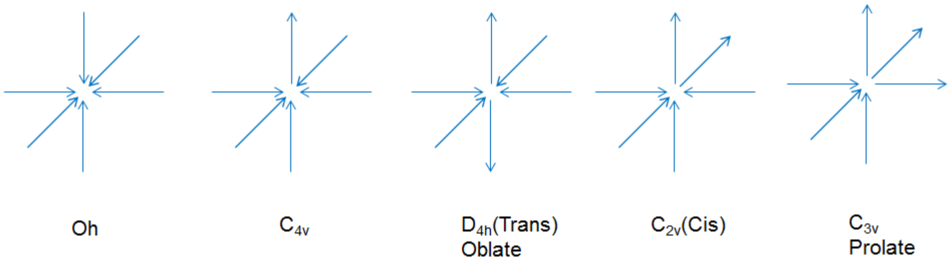

Figure 5. Possible Orientation of Paulions in ^{12}C

Different orientation of six Paulions in the condensation process may produce configurations of different symmetry type viz. O_h, C_{4v}, D_{4h}, C_{2v} and C_{3v} in order of decreasing energy. O_h configuration with highest energy is assumed to be the much debated excited Hoyle's state. This releases its energy via emission of γ-rays by the process in which six Paulions condense to form three alpha particles yielding a spherically symmetrical arrangement with D_3 symmetry (Figure 6).

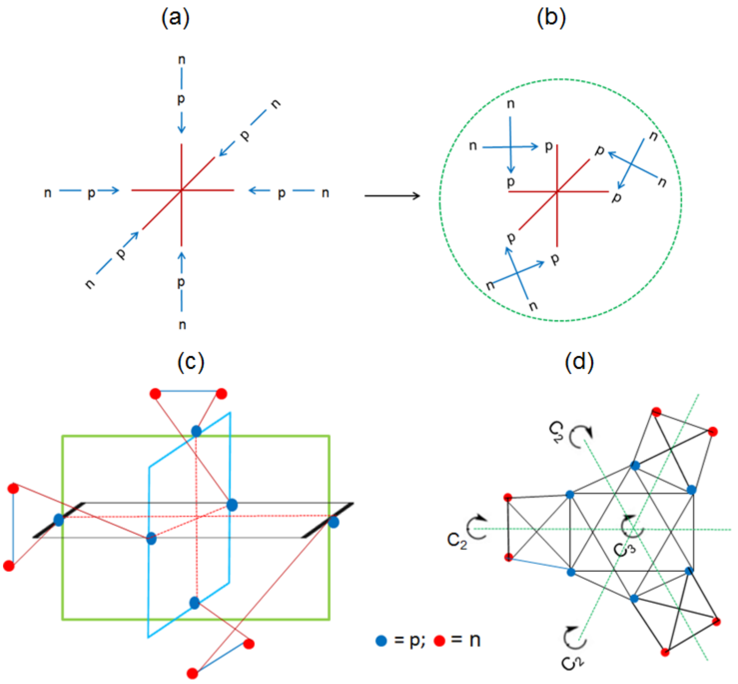

Figure 6. (a) Orientation of Paulions in Hoyle's state. (b) Combination of Paulion to produce 3 α-particles. (c) Orientation of 3 α-particles with respect to three perpendicular planes. (d) Symmetry of ^{12}C nucleus (D_3).

This is analogous to the formation of a tris-chelate chemical (coordination) compound with three bidentate ligands; the difference being that here the three α-particles are intertwined with no central nucleon present. Due to the presence of six protons placed at the end of three perpendicular axes, the net quadrupole moment is zero indicating a spherically symmetrical arrangement in ^{12}C.

6. Nucleosyntheses of Nitrogen and Oxygen

The formation of nitrogen and oxygen nuclei can be proposed in a similar fashion. In case of ^{14}N, the nucleus is formed by condensation of six Paulions to form three virtual alpha particles as shown in (Figure 7 a). The extra proton and neutron gives rise to a spin value of 1. The nucleus shows a quadrupole moment of 2b and is almost spherical with ellipticity of 0.027.

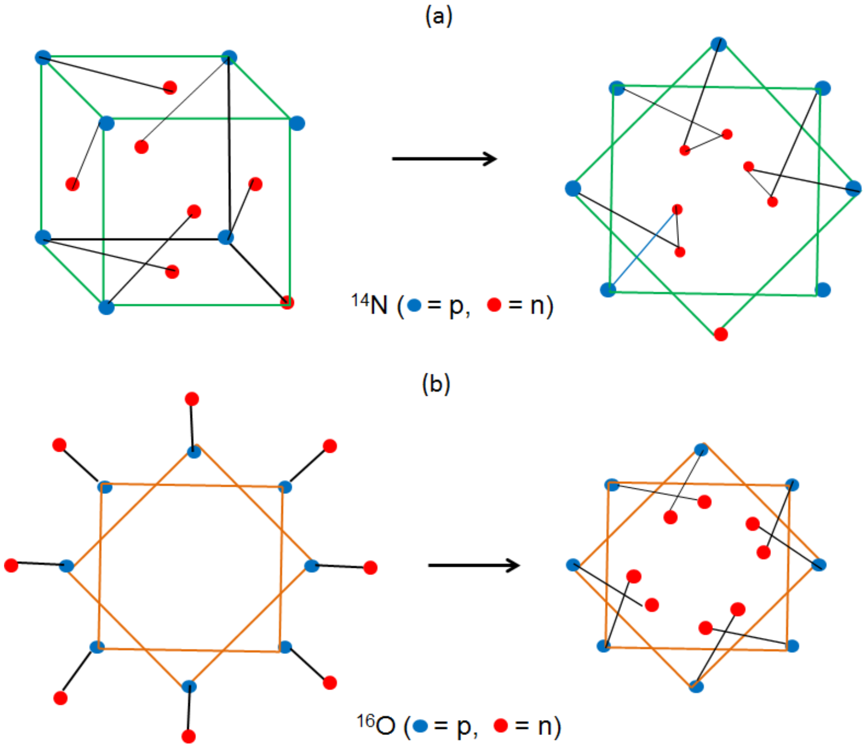

Figure 7. (a) Formation of three alpha particles in ^{14}N by orientation of Paulions (b) Formation of four alpha particles in ^{16}O by orientation of Paulions.

Based on theoretical calculations it was suggested [24] that while in the ground state, the protons and neutrons of ^{16}O nucleus jostle randomly like the molecules of a liquid, in the excited state, the protons and neutrons cluster together to form four alpha particles. These alpha-particles further condense into a single quantum state, similar to that of a conventional Bose–Einstein condensate.

Using algebraic cluster model the low-lying states of ^{16}O is described as rotation-vibration of a 4 α- cluster with T_d symmetry [25]. In terms of Paulion model, the structure of ^{16}O nucleus is comprised of eight Paulions forming four intertwined virtual alpha particles as shown in (Figure 7 b) having spin 0 with spherical disposition of symmetry T_d ($\bar{4}32$) showing zero quadrupole moment.

7. Discussion

In the light of the observation of Goldsmith [26] and Brown, [27] the laws of relative cosmic abundance of the most stable isotopes of known nuclei follows an asymptotic decrease with increase in mass number is shown schematically (Figure 8).

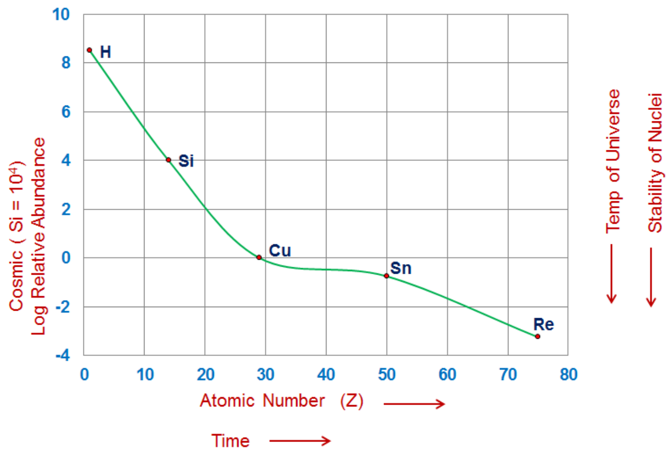

Figure 8. Abundance of nucleus of different mass numbers with respect to time, temperature and stability.

The abundance of the elements depends on the nuclear properties and not on their chemical characteristics. The abundance is maximum with hydrogen (Z = 1) and with passage of time and decrease of temperature, the Paulion condensation sets in with production of nuclei with higher mass number.

The condensation process is believed to take place in a short span of time (less than an hour). As the availability of (p – n) pair decreases accompanying the condensation, the abundance of heavier nuclei goes on decreasing. The curve also represents the stability of the nuclei with increase of Z. The stability decreases as exhibited by the occurrence of radioactivity of the high mass number nuclei (> than 82) in comparison with the very stable nuclei with lesser mass numbers.

In stellar atmosphere, low mass number elements like H, He, Li etc., are easily formed and are most abundant at higher temperature. High mass number nuclei are supposed to be formed by fusion at higher temperature by the process of helium burning etc. In terrestrial condition, no such fusion is possible because of continuous decrease of temperature. As pointed out earlier condensation reaction takes place involving Paulions following the process of Bose-Einstein condensation (BEC).

In the atomic level, such condensation process for gaseous elements (bosons) occurs at ‘low’ temperature below the ‘Degeneracy Temperature’ (DT) which is 10^{-2} K for helium [28, 29]. Later BEC phenomenon was observed directly in dilute vapours of alkali atoms [30-32] at different temperatures in Nano Kelvin region. In nuclear BEC case, very high temperature is required for the purpose [14]. It is therefore, conjectured that different nuclei (along with their isotopes) are formed through condensation of Paulions (along with extra neutron or proton as the case may be) at different ‘degeneracy temperatures’ which may be some hundreds of thousand degrees.

8. Conclusion

In stellar nucleosynthesis, the burning mechanism may produce different nuclei by thermonuclear fusion with rise of temperature in different types of stars but in terrestrial case with decrease of temperature, Paulion model of condensation becomes operative. The temperature of the universe has already cooled down, so nucleosynthesis has been completed once and for all and no further nucleosynthesis is expected. Each of 80 plus known stable nuclei that are found in terrestrial, lunar and meteoritic samples has its own identity and structure which cannot be altered or tailor-made.

Thus the proposed Paulion cluster model is the forerunner of the much discussed and applied alpha cluster model. Contrary to alpha cluster model, this unique model having a smaller unit could be applied to explain the nucleosynthesis of nuclei of all mass numbers.

As a corollary, the mass number (A) of isotopes of any nucleus may be expressed as the summation of Z number of (p – n) and (A - 2Z) number of n; Z being the number of proton. Thus the empirical equation becomes

$$A = Z\,(p - n)\text{ pair} + (A - 2Z)\,n$$

1) In case of even Z, Z/2 alpha particles are formed by condensation of (p – n) pairs and when Z is very high (> 82), formation generally accompanies α-emission (radioactive elements) along with β^- emission for stability.
2) In case of odd Z,
   a) If the number of neutron (A-2Z) is odd then after sorting out the di-neutrons, the 'odd neutron out' will combine with a (p – n) as follows:

      $(p - n) + n \rightarrow t \rightarrow {}^{3}He^{++} + \beta^- +$ anti-neutrino which explains the β^- emission of certain nuclei as discussed in reaction 6 earlier.
   b) If (A-2Z) is even, then the extra neutrons form (n – n) di-neutron pairs of spin 1 (unstable due to violation of Pauli Exclusion Principle).

Prima facie, this Paulion model is able to explain the known properties of nuclei in respect of their shape, magnetic moment, quadrupole moment, ellipticity as well as their terrestrial abundance and their radioactive properties. A Paulion is a theoretical particle, may not have independent existence but it can be applied as well to the formation of high mass number nuclei which will be discussed in a later communication.

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