SRC Model for Nuclear Structure

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Abstract: A new approach for the nuclear structure is suggested which is based upon the idea that the nucleons are not moving independently inside the nuclei, but are forming Short Range Correlated (SRC) quasi-particles. The existence of SRCs inside nuclei has been verified by many experiments [1-3] and is considered to be underlying reason behind the EMC effect [4]. Using few assumptions, a SRC based model for the nuclear structure is proposed. The model is equivalent to the liquid drop model for consideration of the nuclear binding energy and is equivalent to the shell model if the shell structure of SRC quasi-particles is considered. Equivalence of the present model to the cluster model for specific applications is also highlighted. Further, this model provides insights for the symmetric/asymmetric nature of spontaneous fission and Giant Resonances.

1. Introduction:

The various nuclear observables like binding energy, size, spin, quadrupole moments, excitation states and excitation energy etc. are described by using large number of nuclear models [5]. These models have their limited application area and are often based upon very different, sometime contradictory, assumptions [6]. For example, nucleons are assumed to be stationary and interacting with the neighbours only in liquid drop model while they are assumed to be moving almost independently in the mean field in the independent particle shell model. The liquid drop model, which is very successful in explaining the binding energy, can not be used to predict the spin of nuclei, while the shell model has considerable difficulties in explaining the binding energy curve, rotation/vibration levels and spontaneous fission mass distributions [6]. The cluster model of nuclei is based upon the idea of local clustering of 2n and 2p in form of the alpha structures while independent particle shell model insists on the well defined shell structure for the individual nucleons. Moreover, there are many important nuclear phenomena like appearance of new magic numbers far from the stability line, spontaneous fission mass distribution and giant resonances where limitations of the above nuclear models are glaring[6].

Most of these nuclear models were constructed in initial days of nuclear physics and do not incorporate the more recently observed nucleon interaction subtleties. A very important observation about the significant change in the quark distribution for the bounded nucleons, compared to the quark distribution of free or loosely bound system like deuteron, was made by the European Muon Collaboration and is known as EMC effect [4]. This was an unexpected result since in independent particle shell model, nucleons are considered to be moving independently in effective mean field and hence, the quark distribution of nucleons in the tightly bounded nuclei must be similar to that of the free nucleons (apart from some Fermi motion effect). The classical independent particle picture of shell model was further dented by the direct observations of short ranged spatial correlation between nucleons, particularly between protons and neutrons [1-3]. Further, analysis of observed short ranged correlation (SRC) between the nucleons and analysis of the EMC effect have established the direct relation between these two independently observed phenomena [7].

The EMC effect and SRC measurements have highlighted the shortcoming of the independent particle shell model approach and are directly suggesting a different approach for nuclear structure based on the SRC formation of nucleons. Any new approach for the nuclear structure must be based upon the observed nucleon-nucleon interaction (through scattering experiments) and must be able to account for the EMC effect and SRC observations naturally. Also, the new approach should be equivalent to the present set of successful nuclear models in their respective specific application regions.

In the present work, a new model based upon the short ranged correlation of nucleon is discussed. Different motivations for the model are discussed in section 2.1 while layout of the model is given in section 2.2. The equivalence of proposed approach with some of the widely used models along with some of new insights obtained by the proposed model is discussed in section 3.

2. Motivation and layout of SRC model

2.1 Motivation for the SRC model

There are numerous observations which are advocating for the fresh approach for nuclear structure. First of all, there is irritant mismatch between observed nucleon-nucleon interaction obtained through the systematic scattering experiments and the effective nuclear potential used for the shell model calculations [5-6]. The short range nuclear potential used to describe the nuclear forces between nucleons is not used to calculate the observed nuclear levels and, instead, long ranged phenomenological potentials (without any repulsive core) are used to come up with reasonable ground state spin values. Moreover, such phenomenological potentials, along with several other inconsistencies [8], can not explain the near constant value for the BE/A as observed from ${}^{4}_{2}He$ to heaviest possible nuclei.

In contrast to the independent particle model where the nucleon-nucleon interaction is assumed to generate a spherical mean field, for a realistic description of nuclear structure, an actual spin dependent short range nuclear interaction (obtained from the scattering experiments) along with the long range coulomb interaction must be considered. The short range interaction between the nucleons is due to the interaction of their quarks and it consists of repulsive core along with the attractive potential well with minima around 0.8 fm [9]. The shape of short range nuclear potential is related to the quark pressure inside the nucleon and has been recently confirmed for proton by measurement of quark pressure by deeply Compton Scattering in Jafferson Lab [10]. In this measurement, a strong outward directed pressure is observed from centre of proton indicating a repulsive core while a lower and extended inward pressure is observed near the proton periphery indicating an attractive component of nucleon-nucleon interaction. The deep attractive component of nuclear interaction would lead to the formation of short ranged correlated (SRC) quasiparticles which would move in cumulative Coulomb potential well due to all other SRCs. The overall Coulomb potential well would enhance the localization of the proton containing SRCs and thus, would lead to the better coupling of the nucleons into SRCs, similar to the α clustering of nucleons [11].

The presence of nucleons inside the nuclei in the SRCs form, rather than independently moving nucleons in the mean field as envisaged in the shell model, has been directly observed by the deep inelastic scattering measurements using the electron and proton beams [1-3, 12]. It was observed [2] that the removal of protons from C^{12} nuclei with missing momentum above 275 MeV/c resulted in emission of recoil neutron in $92^{8}_{18}\%$ of events, indicating the strong dominance of np SRCs inside nuclei compared to the nn or pp SRCs. It is expected that the formation of closely spaced SRCs would alter the quark structure function of nucleon when they are present inside the nuclei and thus may account the observed EMC effect [4]. A close correlation between EMC effect and SRC formation inside nuclei has been already reported [7] which validats the above arguments.

Now, it has been proposed that, at a given instant, only small fraction of nucleons ($\sim 20\%$) inside nuclei would be involved in the SRC formation [7] and rest of the nucleons are moving as independent particles. On the other hand, EMC observations and observed “collision-free” smooth nucleonic motion in the nuclei indicate that, all of the nucleons must be forming stable SRCs as argued below;

1. The correlation between EMC effects and SRC measurements have been established beyond doubts [7]. If, at a given time, only a small fraction of the nucleons in a nucleus are involved in close contact forming SRCs, the EMC effect would have been possible for those nucleon only. Since rest of the nucleons, at a given time, are moving as independent entities, their quark configuration must be similar to that of independent particles resulting in no EMC effect for them. The EMC effect observation clearly indicates that the parton configuration of all the nucleons, rather than about one fifth of the nucleons, is significantly altered inside the tightly bound nuclei [4,7].
2. The continuous formation and destruction of SRCs inside the nuclei would change the directions as well as kinetic energy of nucleons significantly, making it impossible for nucleons to have a well defined wavefunction.

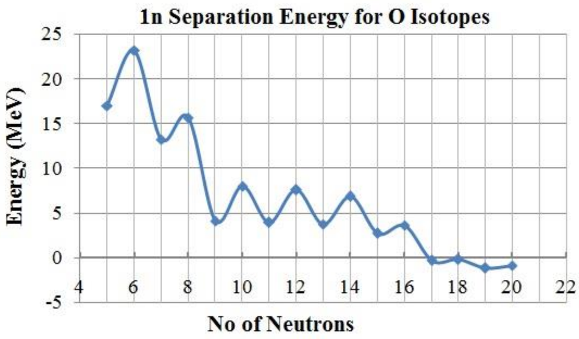
Hence, it can be concluded from above arguments that, instead of the anticipated free particle picture of nucleons in shell model, nucleons are arranged in short ranged, spatially correlated pairs or SRCs inside nuclei. The major contribution to the binding energy of nucleons would be coming from formation and pairing of these SRCs which are moving in the overall Coulomb potential. Moreover, the structure of these SRCs would be very similar (since it dependents mainly on nucleon-nucleon interaction inside the nuclei) from He^{4} to heavy nuclei, the binding energy per nucleon should be nearly equal across the periodic table. This could be a straightforward explanation of observed BE/A curve.

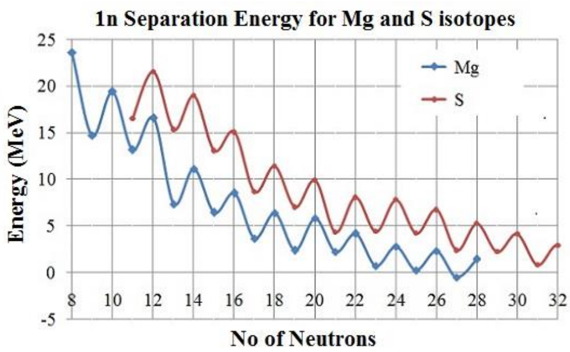
The case for the stable SRCs rather than independent nucleons in nuclei is further strengthened by the observed cross-section of high energy photons for different nuclei. Since the average binding energy per nucleon for most of the nuclei is about 8 MeV, a strong peak must be observed in absorption spectra of energetic photons around this value if independent particle shell model is the correct picture for the nuclei. No such peaks are observed around this value, instead, broad absorption peaks along with nucleonic emission are observed [13] above 12 MeV (which is about double of the BE/A energy value) along with the secondary peaks at higher energy, across the periodic table and is known as Giant Dipole Resonance (GDR). The observation of GDR at energy about the double of the binding energy per nucleons for wide range of nuclei makes a strong case against the independent particle shell model. On the other hand, these observations are directly indicating the presence of tightly bound two nucleon and three nucleon SRCs (such that, most of the nucleonic binding energy is due to the SRC formation), hence, dissociation or breakup of each SRC would require about twice or thrice of average binding energy value.

The formation of SRCs inside the nuclei is reflected in the nucleonic separation energy plots too. For example, it has been observed that there is an extra stability for $N = Z$ even-even light nuclei, similar to observed in the shell closure, at least upto Ti^{44} nuclei [14]. Though the extra stability of $N = Z$ even-even nuclei is attributed to the α-clustering, the observed extra stability in these nuclei can be attributed to the pairing of np SRCs into different orbitals. For example, 1n separation energy plots for the Oxygen, Mg and S nuclei are shown in the fig. 1 where a large kink in 1n separation energy curve is observed for the neutron number equal to 8, 12 and 16 respectively, indicating an extra stability for the $N = Z = even$ configuration. In Oxygen isotopes, 1n separation energy variation for O^{16} is even stronger, indicating the shell closure (s p) for condensed np SRCs. It must be observed that the lightest bound nucleus deuteron contains 1n and 1p and is loosely bound with BE/A of about 1.1 MeV only. The addition of one more np to deuteron i.e. formation of He^4 results into drastic increment of BE/A to 7.2 MeV. It point out the critical role played by the overall Coulomb potential well which in He^4 leads to localization and better coupling of neutron-proton wavefunction in np SRCs and thus, results into much better stability.

Similar to the formation of two nucleonic np SRCs (with total spin 1), grouping of three nucleons into npn and pnp configurations is also possible (with total spin ½). The lightest three nucleon bound system H^3 and He^3 are the example of unpaired npn and pnp SRCs respectively. Apart from somewhat lower binding energy due to extra Coulomb energy component in He^3 system, these nuclei have very similar BE/A (2.83 MeV and 2.57 MeV). Similar to the case of np SRC where a drastic increment of BE/A is observed from unpaired single np for deuteron to paired np SRCs for the He^4, increment of BE/A can be seen for the single npn to paired one (2.83MeV for H^3 to 4.89 for He^6) and for the single pnp to paired one (2.57MeV for He^3 to 4.49MeV for Be^6) due to better coupling of nucleonic wavefunction in overall Coulomb potential well.

There are some other independent indicators of the above discussed three nucleon npn and pnp SRCs inside the nuclei. For example, there is another unexpected distinct kink in 1n separation energy curve for Oxygen isotopes at $N = 24$ typically seen in shell closure. This kink in 1n separation energy indicates a magic configuration [15] and can be interpreted as manifestation of shell closure by 8 npn SRCs in "*s p*" orbitals. In case of odd-even (Z-N) nuclei near stability line, the last proton would be in the unpaired npn SRC while in even-odd nuclei, the last neutron would be in the unpaired pnp SRC. The presence of almost equal number of stable odd-even and even-odd isotopes reflects the equality of npn and pnp binding energy inside these nuclei. Another interesting implication of almost equal binding energy of npn and pnp SRCs is for the mirror nuclei. Since the excitation of odd-even and even-odd mirror nuclei will be due to the last unpaired SRC (each with spin ½), mirror nuclei will have very similar excitation levels in energy as well as spin (apart from additional coulomb factor for pnp SRC).





3.2 Layout of the SRC model

Considering the limitations of current models as well as old and new observations about nuclei, layout for a new approach for the nuclear structure can be drawn. The basic ingredients of this new approach, named here as SRC model are summarized below;

1. Nucleons inside the nucleus are always arranged in the form of short ranged correlated quasi-particles (SRCs) formed by the short ranged nuclear potential. The major fraction of nucleonic binding energy is contributed by the formation of SRCs which is further moderated by the coulomb energy and shell effects.

2. The formation and number of np, npn, pnp (or even more exotic SRCs in nuclei far from stability line) will be driven by the availability of number of neutrons and protons as well as by the minimization of total potential energy of system. The overall Coulomb potential well due to all the nucleons would help in better coupling of the nucleon wavefunction into SRCs and results in higher binding energy. Different SRCs will be paired off in various orbitals for even-even nuclei resulting in zero spin for them. For even-odd, odd-even and odd-odd nuclei, nuclear spin and magnetic moments will be decided by the last unpaired SRC. For example, C^{12} would have 6 np SRCs, C^{13} would have 5 np along with 1 npn SRC, C^{11} would have 4 np along with 1 pnp SRC while C^{14} would have 4 np and 2 npn SRCs.

The presence of npn and pnp SRCs would be helpful in stabilizing the nuclear configuration. Due to the positive Q value for α-decay in most of the heavy nuclei (since α particle or paired np SRCs are very tightly bound in isolation too), they have significant tunnelling probabilities from overall Coulomb potential well of nuclei. On the other hand, paired npn or pnp SRCs almost always have negative Q value of separation owing to their low BE/A in isolation, leading to no tunnelling probability for them. Hence, presence of npn or pnp SRCs, particularly in outer shells, would be helpful in containing the condensed α particles in various orbitals. This can be directly observed in α decay systematic where, apart from shell effects, Q value decreases with increasing the neutron number for different isotopes for a given Z. As an example, α decay in Th^{218} has Q = 9.85MeV with half life time of $1.0 * 10^{-7}$sec. while for α decay in Th^{232}, the observed Q value is 4.08 MeV with half life time of $1.4\text{x}10^{10}$ years (a factor of about 10^{24} change in half life time !).

3. In the odd-odd, odd-even or even-odd (Z-N) nuclei, there would be at least one unpaired np, npn and pnp SRC respectively. The magnetic moments of such nuclei would be due to these unpaired SRCs in different shells. Similarly, nuclear quadrupole moments will be generated by these unpaired SRCs along with the nuclear deformation.

3. Results and implications of SRC model

There are large number of very important direct implications of the proposed model and can be used to understand many of the nuclear phenomena like EMC effect, SRCs observations, spontaneous fission mass distribution and GDR. It can be used to understand the perplexing success of various nuclear models based upon very different assumptions in explaining the nuclear observables. Equivalence of the current model to the various leading nuclear models is discussed below.

3.1. Equivalence to the α cluster model

The SRC model can be considered as extension of α-cluster model. In cluster model, nucleons are clubbed into α-particles and for the $N = Z$ even-even nuclei, there can be $\frac{Z}{2}$ α-particles at a given time and dynamics of those α-particles is studied at high temperature or excitation energy [16]. However, in the current model, for the $N = Z$ even-even nuclei, formation of Z np SRCs takes place which are paired in the $\frac{Z}{2}$ sub-shells. Each of these filled sub-shells would have zero spin and very high BE/A similar to the α-particles. *So, for the $N = Z$ even-even nuclei, SRC model is equivalent to a non-localized cluster model where various α-particles are condensed into different sub-shells or orbitals.* At high temperature, these paired np SRCs may appear as individual α-particles [16]. For even-even nuclei with $N \neq Z$, along with the np SRCs, there could be npn and pnp SRCs paired into sub-shells forming structures similar to the ${}^{6}_{2}He$ or ${}^{6}_{4}Be$. But, unlike α-particle, the BE/A for ${}^{6}_{2}He$ and ${}^{6}_{4}Be$ is not very high hence probability of survival for these cluster structures at high temperature would be low. The ${}^{6}_{2}He$ cluster rotational band in ${}^{12}_{4}Be$ were proposed by Freer et al. [17] and was subsequently confirmed too. As discussed above, the ${}^{6}_{2}He$ cluster can be consider as paired pnp SRCs, hence, the observation of ${}^{6}_{2}He$ clusters further validates the proposed SRC approach. In short, in α-cluster model, nucleons are considered to be clustered in localised α-particles only, but in SRC model, $\alpha,\ {}^{6}_{4}He,\ {}^{6}_{2}Be$ clusters are formed in different sub-shells by pairing of np, npn and pnp SRCs respectively, and thus, are non-localized.

3.2 Equivalence to the Liquid Drop Model

Using the SRC model of nuclear structure model, which is discussed in section 2, one can formulate an expression for the total binding energy of nuclei. This formulation will be similar to the Liquid Drop Model (or LDM).

3.2.1 SRC Formation Energy: Since a given proton/neutron inside a nucleus can be in any of the np, npn or pnp SRCs, the contribution of the given nucleon to the total binding energy will depend upon type of SRC itself. If a_{np} is one half of binding energy of np configuration (i.e. binding energy of proton or neutron when it is in n-p configuration) and a_{npn} (or a_{pnp}) is one third of npn (or pnp) binding energy, then, the total binding energy of nucleus due to the formation of SRCs would be;

BE_{SRC} = a_{np}*No of neutrons and protons in np SRC + a_{npn}*No of neutron and protons in npn SRC + a_{pnp}*No of neutrons and protons in pnp SRC 3.1

This term is similar to the volume energy term in LDM. Here, different coefficient values are used for neutrons/protons constituting np, npn and pnp SRCs, hence, there would not be any need to include the Asymmetric energy term (as used in LDM model) which itself is contained in lower values for the a_{npn}/a_{pnp} compared to the a_{np} coefficient.

3.2.2 Coulomb Energy Term: The coulomb energy term for the SRC model will be similar to the corresponding terms in LDM and hence, can be written as;

$$\text{Coulomb energy term} = a_c \frac{Z(Z-1)}{A^{1/3}} \qquad 3.2$$

3.2.3. Pairing Energy Term: The pairing energy term would be dependent upon the type of SRC and number of protons in SRCs as this would affect the depth of coulomb potential harbouring the SRCs.

With these contributory terms to total binding energy along with the realization that SRC binding energy would depend upon the overall coulomb potential well, it can be seen that the current approach is equivalent to the liquid drop model.

3.3. Equivalence to the Shell Model

In SRC model, instead of free protons and neutrons, nuclear sub-shells are filled by the paired np/npn or pnp SRCs (except the last unpaired SRC in case of odd-even or even-odd and odd-odd nuclei) which are confined in overall Coulomb potential well due to all others SRCs. Consequently, certain nuclei for which shells are completely filled by these SRCs would be extra stable and thus, would lead to the observed magic behaviour for them. The magic configuration of the nuclei must be produced without invoking the assumption of spin-orbit interaction since magnetic moments of nucleons are lower to the magnetic moments of the electron by about three orders of magnitude.

The binding energy values for pnp and npn SRCs is almost equal (except for small coulomb factor for pnp). Hence, if a configuration of different filled shells (due to paired np, npn and pnp SRCs) results in a magic configuration for protons, the further addition of neutron would be in the paired np orbitals, converting them into npn SRCs, leaving rest of the configuration unchanged. As an example, O_8^{16} is a magic structure with “s p” configuration filled by the np SRCs, further addition of neutrons would leads to the formation of npn SRCs progressively, ultimately forming another magic structure for O_8^{24} where “s p” configuration is filled with npn SRCs. Interestingly, this scheme also provides a simple explanation for the observed magic behaviour of Oxygen for $N = 16$. Similarly, for neutron magic configuration of nuclei, further proton addition may take place to the paired np SRCs, resulting in formation of the pnp SRCs.

Although the major fraction of nucleonic binding energy is due to the SRC formation inside the nuclei, it is the overall coulomb potential well which decides the shell structure of nuclei. The presence of similar shape orbitals would leads to higher coulomb energy to the system (for example if 2p and 3p shells are filled, they would have significant spatial overlap). Hence, higher order orbitals may not be favourable (like 2s, 3s, 4s… 2p, 3p… etc). Moreover, extra stability to the configuration, achieved by the complete shell filling, may alter the precedence in shell filling for example, in case of C_6^{12}, it would be more economical to have a completely filled “p” shell rather than fully filled “s” and partially filled “p” shell.

Since the shape of the potential well does not alter the sequence of energy level significantly, hence, for a qualitative discussion, sequence of level scheme obtained using the Wood-Saxon potential is used. As mentioned above, higher order orbitals (2s, 3s… 2p, 3p.. etc.) are discarded on ground of higher coulomb energy. To shorten the discussion, possible qualitative reasons are given for the magic number 50, 82 (for protons and neutrons) and 126 for neutrons only. As the filling of shells is discussed in terms of SRCs, the following notation is used for the shells filling by the different type of SRCs.

x – shell filled by np
$x_{\#}$ – shell filled by npn
$x^{\#}$ – shell filled by pnp

For magic number of 50 for protons, np and npn SRCs (each with one proton) have a completely filled configuration of shells from “s” to “g” shells, resulting in magic number 50 for protons.

$$s\ p\ d\ f\ g = 2+6+10+14+18 = 50\ proton$$

The neutron number in the above configuration can vary (resulting in different numbers of npn). For example, stable Sn isotopes have mass no 112 to 124 (with npn = 12 to 24). On the other hand, absence of any stable isotope for nucleus Z=43 can be understood by the argument that if 42 protons are to be filled, they can be filled in *"d f g"* shells as np and npn SRCs, 43^{rd} proton would have to go in s or p shells as single np or npn, leading to lower stability.

For neutron magic number 5o, the number of proton is always equal to or less than 50, for which possible shell configurations are given below,

$$s_{\#}\ p_{\#}\ d_{\#}\ f = 4n+12n+20n+14n=50n \quad or \quad f\ g_{\#} = 14n+36n = 50 \ or\ p_{\#}\ d\ f_{\#} = 12n+10n+28n=50$$

The number of protons in the above configuration of neutron magic number 50 can vary, converting *np* SRCs to *pnp* SRCs.

The addition of "h" shell (with possible accommodation of 22 fermions) to the magic configuration of Sn (i.e. "s p d f g") would take the number of proton for next magic configuration to 72. But, as it is already mentioned that apart from a small additional coulomb energy factor, binding energy of the pnp SRCs is very similar to that of the npn SRCs. This is also reflected in the observed presence of neutron magic numbers (50, 82 and 126) for even-even nuclei where additional pairs of protons are added to the paired np SRCs converting them to the paired pnp SRCs leaving the magic configuration of neutrons intact. Now, if possibility of a pnp filled "d" shell is considered, then it can account the proton magic number equal to 82 as given below.

$$s\ p\ d^{\#}\ f\ g\ h = 2+6+20+14+18+22 = 82$$

Such a possibility of pnp filled "d" shell is supported by two different indirect implications too. First, it can provide an argument for the observed absence of any stable isotope for Z = 61 nucleus as addition of a proton to Z = 60 ($s\ p\ d^{\#}\ f$ g = 2+6+20+14+18 = 60) nucleus would disrupt the symmetry of configuration, making it less probable. Second, the above configuration for the magic number of proton equal to 82 can be used to understand the magic number 126 for neutron (where npn SRCs in "d" shells are avoided as it is filled with pnp SRCs) as;

$$s\ p\ d\ f_{\#}\ g_{\#}\ h_{\#} = 2+6+10+28+36+44 = 126$$

For the doubly magic nucleus Pb_{82}^{208}, the proton and neutron configuration would be,

$$s\ p\ d^{\#}\ f_{\#}\ g_{\#}\ h_{\#} = 82\ protons + 126\ neutrons$$

For neutron magic number 82, a possible configuration may be,

$$s\ p\ d\ f_{\#}\ g_{\#} = 2+6+10+28+36 = 82n$$

or another possible configuration may be, *s# p# d# f# g = 4+12+20+28+18 = 82n*

After Pb and Bi, occurrence of many short lived nuclei take place which is followed by the island of stability around nuclei Th^{232} ($T_{1/2}\sim 1.4 * 10^{10}$) and U^{238} ($T_{1/2}\sim 7.04 * 10^{8}$). The possible reason behind the stability of these nuclei may be the fully filled "i" shell. Now, increasing the number of protons may increase the importance of coulomb repulsion energy since it is Z^2 dependent term (for example, % change in coulomb energy between Pb to Th is about $\frac{(92^2-82^2)}{82^2} * 100 = 20.46\%$). The increasing coulomb factor for heavy nuclei may reduce the possibilities of pnp SRCs. A possible configuration for U^{238} nucleus may be;

s d f# g# h# i = 2np+10np+14npn+18npn+22npn+26np = 92p + 146n

And for the Th^{232} nucleus, possible configuration may be;

s# p f# g# h# i = 2pnp+6np+14npn+18npn+22npn+26np = 90p + 142n

3.4. Production of Giant Resonances

The interaction of high energy photons with nuclei has been widely studied experimentally. Huge Lorentz resonance type single absorption peaks after 12 MeV for spherical nuclei (Pb^{208} study is one of the classical result with absorption peak about 13.5 MeV) and more than one peaks for the deformed nuclei like Gd^{160} have been observed. A recent compilation of GDR data can be found in ref. [13]. The absorption of photons is accompanied by the emission of nucleons too [13]. These absorption peaks are interpreted as due to the collective oscillation of all of the protons with respect to neutrons in nuclei and are termed as Giant Dipole Resonances or GDR.

As pointed above, no such resonance has been observed around the mean nucleonic binding energy, though it should have been there if the independent particle shell model is the correct picture of nuclei. In terms of SRC model, the interpretation of GDRs is straightforward. Since nucleons are in the form of np, npn or pnp SRCs inside the nuclei, there must be photon absorption resonances resulting in the breaking of the corresponding SRCs into free nucleons. The peak of resonance should be around the double of the nucleonic binding energy as disintegration of at least two nucleons (in np SRCs) is happening in nuclear environment. In case of the deformed nuclei, nuclear shells oriented along the deformation axis would have different coulomb potential well and thus, these shells will have different binding energy value for the filled SRCs too. That would result in secondary peaks in deformed nuclei. In short, observed Lorentz resonances or GDR in nuclei are due to the breakup of SRCs into free nucleons.

3.6. Spontaneous fission

Spontaneous fission of heavy nuclei is one of the well studied nuclear reaction since its discovery in 1938. The consistent efforts by the theoretical nuclear physicists in last 80 years have not resolved the various anomalies regarding the fission mass distribution of different heavy nuclei in a satisfactory way [6]. The application of liquid drop model leads to the prediction of symmetric mass distribution for the two separating fission mass fragments while some modifications of the mass distribution due to magic nuclei are expected in shell model framework. But, the dominating mode of spontaneous fission for most of the Actinide nuclei is observed to be asymmetric fission in which fission fragments are of unequal mass. The larger fission mass fragment contains about 140 nucleons while the remaining nucleons, except few of the ejected neutrons, are contained in the smaller mass fragment. The most probable number of protons in larger fission mass fragments is from 52 to 56 (with a small contribution of less than 5% from isotopes of Sn). Reducing the number of neutrons in the actinide nuclei results in higher number of symmetric fission mass distribution events and a transition from the asymmetric to symmetric fission, with decreasing number of neutrons has been observed [18]. For example, a systematic transition, from the dominating symmetric fission to asymmetric fission has been observed (shown in the figure 3 of [18]) for Pa^{224} (with 133 neutrons) to Pa^{232} (with 141 neutrons) isotopes. The symmetric fission fragments mass distribution has been observed for the Hg^{198} nucleus, along with many other pre-Actinide nuclei [18]. Though, application of some of the current models predicted symmetric fission mass distribution for the Hg^{180} nucleus, strongly asymmetric nature in fission mass distribution has been observed for this nucleus [19]. The observed asymmetric mass distribution in many of the nuclei going though spontaneous fission which resists even the possible outcome of magic configurations in the fission fragments is a strong indicator of the underlying nuclear substructures (before fragment separation) that survive the stochastic and chaotic nucleonic rearrangements during the nuclear fission events.

The SRC model may be used to predict the fission fragments mass distribution without any additional assumption. Since in the present framework, the nuclei are composed of mainly n-p and n-p-p SRCs, any low energy excitation will initiate the collective oscillations of these SRCs in nuclear medium with different oscillation frequency as their masses are different. That would result in the formation of the np and npn SRC blobs which could exchange nucleons before complete separation. Since the spontaneous fission process is quite slow process compared to the nucleon orbital time, nucleonic exchange between the np and npn SRC blobs would happen before the complete separation of blobs. The exchange of neutrons is not hindered by the presence of coulomb barrier between the n-p and n-p-n SRC blobs, resulting in transfer of neutrons from the neutron rich n-p-n SRC blob to the neutron poor n-p SRC blob, while only few protons will move from the proton rich n-p SRC blob to the neutron rich n-p-n SRC blob. Further, transfer of protons from proton poor npn blob to proton rich np SRC blob and transfer of neutrons from neutron poor np to neutron rich npn SRC blob would be much less probable.

As an example, lets us consider excited nucleus U^{236} (U^{235} excited by one neutron capture) which can have 52 n-p-n quasiparticles (with total mass number 156) and 40 n-p quasi-particles (with total mass number 80). The collective oscillations of np and npn SRCs in this nucleus would result in the formation of n-p-n and n-p q SRC blobs, connected by neck formation. Many neutrons would flow from n-p-n to n-p blobs and only few protons can be transferred from n-p to n-p-n blob (due to Coulomb barrier between blobs). Now, the most stable isotopes for the nuclei having proton number 36-40 have about 10-14 more neutrons compared to the number of protons while most stable isotopes for the nuclei with 52 to 56 protons have 20-26 extra neutrons. Hence, neutrons transfer from npn to np blobs would take place, along with evaporation of few neutrons, until neutron equilibrium is not reached while only few protons would transfer from n-p to n-p-n SRC blob. Being a statistical process, this would result in the atomic number of heavier fragments about 52 or more and atomic number of lighter fragment about 40 or less. Considering the availability of extra neutrons and range of the atomic number for the heavy fission fragment, it can be seen that the mass of heavy fragment would be very near to the observed mass value.

These simple arguments can account for the presence of nuclei with Z = 52 to 56 predominantly in the heavier fission mass fragments along with the asymmetric nature of spontaneous fission in U^{235} nucleus. Moreover, the presence of small fraction of Sn isotopes in fission fragments can be understood, despite expected from the extra stability of Sn isotopes, as transfer of proton from proton poor npn SRC would be much less probable.

Similar arguments can be implemented to understand the fission process outcome for other nuclei as well as transition from asymmetric to symmetric mass distribution for actinides with decreasing neutron number. The decreasing neutron numbers would decrease the number of npn SRCs, resulting in decreasing (increasing) the atomic number as well as mass number for npn (np) SRC blob, resulting in more symmetric fission mass distribution

The symmetric or asymmetric fission mass distributions for most of the nuclei below the Actinide nuclei can be understood by similar arguments. In Hg^{198} nucleus, there would be about 38 n-p-n SRCs along with 42 n-p SRCs. The shift of few protons from n-p blob would result in symmetric distribution of fission mass fragments. On the other hand, the Hg^{180} nucleus would have only 20 n-p-n SRCs along with 60 n-p SRCs, resulting in asymmetric fission as observed recently [19].

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