Analysis of ^{208}Pb(^{15}C, ^{14}C+n) ^{208}Pb and ^{181}Ta(^{15}C, ^{14}C+n) ^{181}Ta Coulomb Breakup reactions Data

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The inimitability in the structural features of the neutron/proton drip lines nuclei has attracted much attention of scientific community during last few decades. The work done involving these nuclei has established a novel structure referred to as halo [1, 2]. Thus far, various nuclei owning halo structure have been identified and the most popular among these are ^{11}Be, ^{19}C, ^{6}He, ^{11}Li, ^{8}B, ^{23}Al and ^{20}Mg.

But the Carbon isotopic chain ^{15,17,19}C offers more than one possible candidates for halo structure and hence it has been studied widely[3-8]. During these studies ^{19}C has been established as a one nucleon halo system with $[0^{+} \otimes 2s_{1/2}]_{½+}$ as the predominance core-neutron spin coupling in ground state. On the other hand the possibility of halo structure in ^{17}C was discarded.

However, $1/2^{+}$ ground state spin parity was suggested for ^{15}C in ref [9] and the possible ground state configurations corresponding to $J^{\pi} = 1/2^{+}$ are $0^{+}\otimes 2s_{1/2}$ and $2^{+}\otimes 1d_{5/2}$. The subsequent work carried out involving ^{15}C strengthen its candidature for halo structure with ^{14}C$(0^{+})\otimes 2s_{1/2}$ as the ground state configuration but with different values of spectroscopic factors [4, 5]. Although, yet the possibility of occupation of d-wave was not fully discarded.

Hence in the present work the orbital occupancy of valence neutron in ^{15}C has been investigated through the ^{208}Pb(^{15}C, ^{14}C+n) ^{208}Pb and ^{181}Ta(^{15}C, ^{14}C+n) ^{181}Ta Coulomb breakup reactions at 68AMeV and 85AMeV beam energies respectively within the theoretical framework of eikonal approximation.

In this approach the expression for calculating different observables of Coulomb breakup reaction is given as [10, 11]

$$\frac{d^2\sigma}{q^2 dq \sin\theta\, d\theta} = \frac{Z_t^2\alpha^2}{\sqrt{4\pi}} \sum (-1)^{(2L+S+l_1+\lambda_2+m)}(-1)^{(\lambda_2-\lambda_1+l_1-l_2)/2}$$
$$\times (2l_1+1)(2l_2+1)\sqrt{2\lambda_1+1}\sqrt{2\lambda_2+1}\frac{1}{\sqrt{2S+1}}\left(\frac{\omega}{c}\right)^{l_1-1}$$
$$\times \left(\frac{\omega}{c}\right)^{l_2-1} Z_{l_1}^{eff} Z_{l_2}^{eff}\, \overline{G}_{l_1 m}\overline{G}_{l_2 m}\overline{K}_m(\xi) I_{Ll_1\lambda_1}(q) I_{Ll_2\lambda_2}(q)$$
$$\times \langle Ll_1 00|\lambda_1 0\rangle \langle Ll_2 00|\lambda_2 0\rangle \langle \lambda_1\lambda_2 00|S0\rangle \langle l_1 l_2 m -m|S0\rangle$$
$$\times W(Sl_1\lambda_2 L : l_2\lambda_1)\, \overline{Y}_{S0}(q),$$

The notations used here having same meaning as in ref [10, 11]. Since the electric quadrupole term does not contribute significantly, only dipole term is considered here [12, 13]. Now the explicit expressions for calculating relative energy spectrum and longitudinal momentum distribution of nuclei having s and d-wave valence neutron are obtained by setting L = 0 and 2 in above equation and may be expressed as [7, 14]

$$\left(\frac{d\sigma_{E1}}{dE_{rel}}\right)_{L=0} = \int_0^{\infty} \frac{4Z_t^2 (Z_1^{eff})^2\alpha^2}{3\gamma^2\beta^2}\xi^2 I_{011}^2$$
$$\times\left[(K_1^2-K_0^2)\{(1+2P_2)-(1-P_2)\gamma^2\}+\frac{2}{\xi}K_0K_1(1-P_2)\gamma^2\right]$$
$$\times\sqrt{2E_{rel}\left(\frac{\mu}{\hbar^2}\right)^3}\sin\theta\, d\theta$$

$$\left(\frac{d\sigma_{E1}}{dE_{rel}}\right)_{L=2} = \int_0^{\pi} \frac{4Z_t^2 (Z_1^{eff})^2\alpha^2}{75\gamma^2\beta^2}\xi^2$$
$$\times\left[5\left\{\left(\frac{2}{\xi}K_0K_1-(K_1^2-K_0^2)\right)\gamma^2+\left(K_1^2-K_0^2\right)\right\}\right.$$
$$\times\left(2I_{211}^2+3I_{213}^2\right)+2P_2\left\{-2\left(K_1^2-K_0^2\right)+\left(\frac{2}{\xi}K_0K_1-\left(K_1^2-K_0^2\right)\right)\gamma^2\right\}$$
$$\left.\times\left(-\frac{1}{2}I_{211}^2+9I_{211}I_{213}-6I_{213}^2\right)\right]\sqrt{2E_{rel}\left(\frac{\mu}{\hbar^2}\right)^3}\sin\theta\, d\theta$$

$$\left(\frac{d\sigma_{E1}}{dq_z}\right)_{L=0} = \int_0^{\infty} \frac{4Z_t^2 (Z_1^{eff})^2\alpha^2}{3\gamma^2\beta^2}\xi^2 I_{011}^2$$
$$\times\left[(K_1^2-K_0^2)\{(1+2P_2)-(1-P_2)\gamma^2\}+\frac{2}{\xi}K_0K_1(1-P_2)\gamma^2\right]$$
$$\times q\, dq$$

$$\left(\frac{d\sigma_{E1}}{dq_z}\right)_{L=2} = \int_0^{\pi} \frac{4Z_t^2 (Z_1^{eff})^2\alpha^2}{75\gamma^2\beta^2}\xi^2$$
$$\times\left[5\left\{\left(\frac{2}{\xi}K_0K_1-(K_1^2-K_0^2)\right)\gamma^2+\left(K_1^2-K_0^2\right)\right\}\right.$$
$$\times\left(2I_{211}^2+3I_{213}^2\right)+2P_2\left\{-2\left(K_1^2-K_0^2\right)+\left(\frac{2}{\xi}K_0K_1-\left(K_1^2-K_0^2\right)\right)\gamma^2\right\}$$
$$\left.\times\left(-\frac{1}{2}I_{211}^2+9I_{211}I_{213}-6I_{213}^2\right)\right]q\, dq$$

respectively. As the valence neutron in ^{15}C may occupy s- and d-orbital corresponding to $0^{+}\otimes 2s_{1/2}$ and

$2^+\otimes 1d_{5/2}$ configuration therefore here both possibilities are considered and the corresponding wave functions has been generated by solving the radial part of Schrodinger equation for Woods-Saxon potential. The depth of the potential is adjusted to reproduce the effective binding energy (S_n^{eff}) which represents the sum of single-neutron separation energy and the excitation energy of the core state while the geometrical parameters of the potential are adjusted locally. The S_n^{eff} values for $0^+\otimes 2s_{1/2}$ and $2^+\otimes 1d_{5/2}$ configurations are 1.218 MeV and 8.228 MeV respectively. These wave functions are used for further calculations and results so obtained are given in figure 1 and 2. In fig. 1 the calculated relative energy spectrum for ^{208}Pb(^{15}C, ^{14}C+n) ^{208}Pb reaction at beam energy of 68AMeV along with data is presented. As the different values of spectroscopic factors, 0.91, 0.87, 0.73 are quoted in literature for $0^+\otimes 2s_{1/2}$ core-neutron coupling for ^{15}C [6, 8, 15] but here only two extreme values i.e. 0.91 and 0.73 have been considered. The results corresponding to $2^+\otimes 1d_{5/2}$ configuration are multiplied by a factor of 10^3 for the sake of clarity. It can be observed clearly from the figure that the results corresponding to 0.91 as the value of spectroscopic factor are in good matching with data which is also favored by the calculated χ^2 values which are 0.68, 0.22 and 0.24 corresponding to 0.73, 0.91 and 1.0 as the values of spectroscopic factors respectively. While the results for $2^+\otimes 1d_{5/2}$ configuration are very far from the data and the corresponding χ^2 value, 101, is also very high. Fig. 2 shows the longitudinal momentum distribution of ^{14}C coming out from the Coulomb breakup of ^{15}C on Ta target at 85 AMeV beam energy corresponding to $0^+\otimes 2s_{1/2}$ and $2^+\otimes 1d_{5/2}$ states.

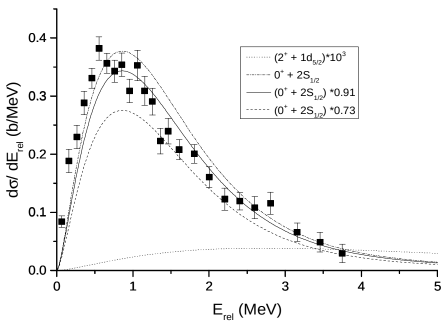

Fig. 1. Relative energy spectrum of ^{14}C and n coming out from the reaction ^{208}Pb(^{15}C, ^{14}C+n) ^{208}Pb. Data points are taken from ref [8]

It is observed from the figure that the results obtained by considering the configuration wherein valence neutron residing in s-orbital are in well agreement with data except only in tail region. While the results for $2^+\otimes 1d_{5/2}$ configuration are very far from the data.

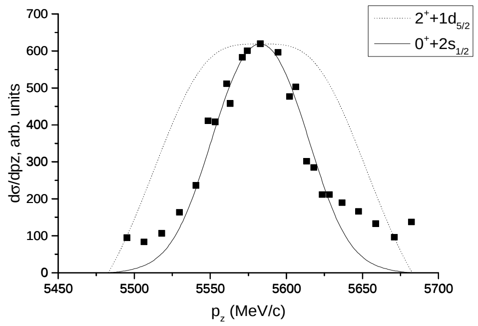

Fig.2. Longitudinal momentum distribution of core fragments coming from the Coulomb breakup of ^{15}C on Ta target at 85AMeV. Solid and dotted lines represent the results corresponding $0^+\otimes 2s_{1/2}$ and $2^+\otimes 1d_{5/2}$ configurations respectively. Data points are taken from ref [3]

In conclusion, present results favor $0^+\otimes 2s_{1/2}$ as the ground state configuration for ^{15}C with 0.91 as the value for spectroscopic factor. While the possibility of occupation of d-orbital by valence neutron is fully discarded. However the departure of predictions from data especially in the tail region of longitudinal momentum distribution demands more work for ^{15}C.

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References

[1] I. Tanihata et al., Phys. Rev. Lett. **55,** 2676 (1985).
[2] P. G. Hansen and B Jonson, Eur. Phys. Lett. **4**, 409 (1987).
[3] D. Bazin et al., Phys. Rev. C **57,** 2156 (1998).
[4] Yu. L. Parfenova et al., Phys. Rev. C **62**, 044602 (2000).
[5] R. Chatterjee et al., Nucl. Phy. A **675**, 477 (2000).
[6] U. Datta Pramanik, Phys. Lett. B **551**, 63 (2003).
[7] Pardeep Singh et al., Nucl. Phys. A **802,** 82 (2008).
[8]T. Nakamura et al., Phys. Rev. C **79**, 035805 (2009).
[9] G. Audi et al., Nucl. Phy. A **729,** 337(2003).
[10] Rajesh Kharab et al., Int. J. Mod. Phys. E **17**, No. 4, 693 (2008).
[11] Pardeep Singh et al., Phys. Atom. Nucl. **71**, 1932 (2008).
[12] Rajesh Kharab et al., Chin. Phys. Lett. **24**, No. 03, 656 (2007).
[13] Pardeep Singh et al., Phys. Atom. Nucl. **77**, 206 (2014).
[14] Pardeep Singh, Phys. Atom. Nucl. (Accepted)
[15] T. Tarutina and M. S. Hussein, Phys. Rev. C **70**, 034603 (2003).