Coulomb Breakup of One-neutron halo nuclei on Heavy Targets

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The production of high energy beams of neutron/proton rich nuclei by the projectile fragmentations in high energy heavy-ion collisions was the beginning of new era in the field of nuclear physics. The experiments performed using these beams have revealed the existence of a neutron/proton halo structure in some isotopes. Because of the very small binding energy of last nucleon(s) the halo nuclei breakup into the halo nucleon(s) and the remaining core under the electromagnetic field of heavy targets is an important reaction channel and represents a very useful tool to investigate their structure. Besides the structural information these reactions also provide very useful source of astrophysical studies. In order to obtain the reliable value of astrophysical S-factor for various radiative capture reactions at low energies the contribution of higher order multipole transition in particular that of E2 and E1-E2 interference terms has to be studied separately. The contribution of E2 transitions in the total Coulomb breakup cross section is found 3% of E1 while E1-E2 terms contribute nothing towards total cross section[1]. Among various observables of the Coulomb breakup reactions the longitudinal momentum distribution (LMD) of the outgoing core fragments, being independent of the reaction mechanism, is very suitable for analyzing the structure of halo nuclei.

Here, we have investigated the structural aspects of ^{19}C and ^{11}Be through Coulomb breakup reactions. The coulomb breakup of halo nuclei at high energies is conveniently described using Eikonal approximation approach. According to this approach, the differential cross section for any electric multipolarity is given by [2]

$$\frac{d\sigma}{d\vec{q}} = \frac{Z_t^2\alpha^2}{2\pi} \sum_{\substack{M,l_1,l_2,m_1,m_2 \\ \lambda_1,\lambda_2,\upsilon_1,\upsilon_2}} i^{m_1-\lambda_1}(-i)^{m_2-\lambda_2}\, \hat{L}\hat{l}_1^{2}\,\hat{l}_2^{2}\,\hat{\lambda}_1^{-1} \times \hat{\lambda}_2^{-1} \left(\frac{\omega}{c}\right)^{l_1+l_2-2} Z_{l_1}^{eff} Z_{l_2}^{eff} G_{El_1m_1} G_{El_2m_2}^{*} f_{m_1m_2} \times I_{Ll_1\lambda_1} I_{Ll_2\lambda_2} Y_{\lambda_1\upsilon_1} Y_{\lambda_2\upsilon_2}^{*} C_{000}^{Ll_1\lambda_1}\, C_{000}^{Ll_2\lambda_2}\, C_{Mm_1\upsilon_1}^{Ll_1\lambda_1}\, C_{Mm_2\upsilon_2}^{Ll_2\lambda_2} \qquad (1)$$

All the symbols are same as defined in Ref.[2,]. A simple mathematical exercise leads to the following explicit expressions for the cross sections differential in longitudinal momentum distribution corresponding to different multipole transitions for for s-and d-wave function as[3,4]

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

$$\frac{d\sigma_{E2}}{dq_z} = \int_{|q_z|}^{\infty} \frac{Z_t^2(Z_2^{eff})^2\alpha^2}{105\gamma^2\beta^4}\left(\frac{\omega}{c}\right)^2 \xi^2 I_{022}^2 \Bigg[\frac{4}{\xi^2}K_1^2(7-10P_2+3P_4) + (K_1^2-K_0^2)(28+20P_2+57P_4)+(7+5P_2-12P_4)\gamma^2 \times (2-\beta^2)^2\left(\frac{2}{\xi}K_0K_1-(K_1^2-K_0^2)\right)\Bigg] q\,dq \qquad (3)$$

$$\frac{d\sigma_{E1E2}}{dq_z} = \int_{|q_z|}^{\infty} \frac{4Z_t^2Z_1^{eff}Z_2^{eff}\alpha^2}{5\gamma^2\beta^3}\left(\frac{\omega}{c}\right)\xi^2 I_{011}I_{022} \times \left[(K_1^2-K_0^2)(2P_1+3P_3)+[\frac{2}{\xi}K_0K_1-(K_1^2-K_0^2)](P_1-P_3)\gamma^2(2-\beta^2)\right] \times q\,dq \qquad (4)$$

$$\left(\frac{d\sigma_{E1}}{dq_z}\right)_{L=2} = \int_{|q_z|}^{\infty} \frac{4Z_t^2 (Z_1^{eff})^2 \alpha^2}{75\gamma^2\beta^2}\xi^2$$
$$\times \left[5\left\{\left(\frac{2}{\xi}K_0K_1-(K_1^2-K_0^2)\right)\gamma^2+\left(K_1^2-K_0^2\right)\right\}\left(2I_{211}^2+3I_{213}^2\right)\right.$$
$$+\ 2P\left\{-2\left(K_1^2-K_0^2\right)+\left(\frac{2}{\xi}K_0K_1-\left(K_1^2-K_0^2\right)\right)\gamma^2\right\}$$
$$\left.\times\left(-\frac{1}{2}I_{211}^2+9I_{211}I_{213}-6I_{213}^2\right)qdq\right] \qquad (5)$$

All the symbols are same as defined in Refs.[3,4].

The major ingredient in our calculations is the radial part of the ground state wave function of the projectile, which has been obtained by solving the radial part of Schrodinger equation in Woods-Saxon potential. The depth of the Woods-Saxon potential has been determined to reproduce the ground state binding energy of the projectiles (for ^{11}Be it is 0.504MeV and for ^{19}C it is 0.530MeV).

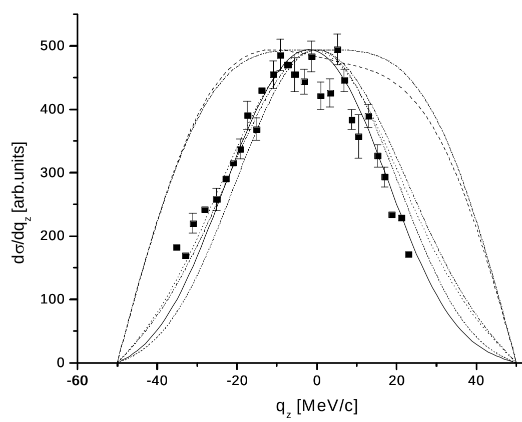

Fig.1. Longitudinal momentum distribution of ^{10}Be coming out from the Coulomb breakup of ^{11}Be on U target at 63AMeV beam energy. The calculations corresponding to $0^+ \otimes 2s_{1/2}$, $2^+ \otimes 1d_{5/2}$, and (0.77) $0^+ \otimes 2s_{1/2}$ + (0.18) $2^+ \otimes 1d_{5/2}$ configurations shown by solid, dashed and dotted line respectively taking into account the effects of *E1-E2* interference while those shown by short-dash, short-dash-dot and dash-dot-dot curves without taking into account these effects.

The results of the calculations are shown in figures 1 and 2 along with the corresponding data taken from Refs.[5,6]. The results for ^{11}Be corresponding to different neutron core coupling scheme are shown in Fig.(1). It has been observed that the agreement between the data and predictions improves when the effects of E1-E2 interference transitions are incorporated with $0^+ \otimes 2s_{1/2}$ configuration. It clearly indicates that the role of E1-E2 transition can not be neglected in the analysis of the Coulomb breakup of ^{11}Be. While a noticeable difference between predictions and data is still lies in the peak region of the spectrum. However we succeed to reproduce the experimental results in case of ^{19}C by considering the excited states of ^{18}C and results so obtained are depicted in Fig.2. Conclusively, it is found that the ground state of ^{19}C is well described by the state in which a $2s_{1/2}$ neutron is coupled to the core in excited state.

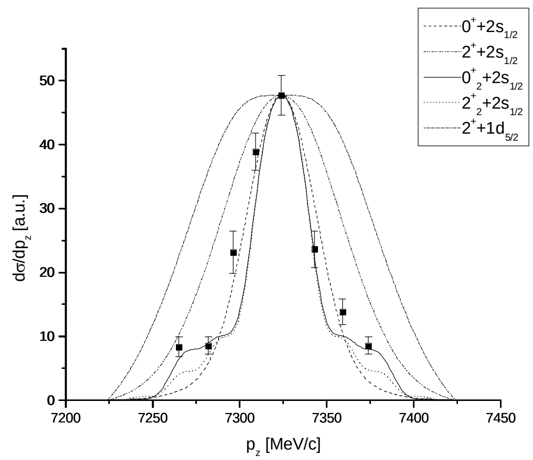

Fig.2. Longitudinal momentum distribution of ^{18}C emitted in ^{181}Ta(^{19}C, ^{18}C+n)^{181}Ta Coulomb breakup reaction at 88AMeV beam energy corresponding to different core neutron spin coupling schemes.

References

[1] Rajesh Kharab, Pardeep Singh et al. Chin. Phys. Lett. 24 (2007) 656.

[2] E. Sauvan et al. Phys. Rev. C 69 (2004) 044603.

[3] Rajesh Kharab, Pardeep Singh et al. Int. Jour. Mod. Phys. E 17(2008)693.

[4] Pardeep Singh, Rajesh Kharab et al. Nucl. Phys. A 802 (2008) 82.

[5] J H Kelley et. al., Phys. Rev. Lett. **74** (1995) 30.

[6] D Bazin et al., Phys. Rev. C **57** (1998) 2156.