Breakup of proton halo nuclei

Ravinder Kumar[1] and Angela Bonaccorso[2]
[1]Department of Physics, Deenbandhu Chhoturam University of Science & Technology, Murthal, Sonepat-131039 Haryana, INDIA
[2]INFN, Sezione di Pisa, Largo Pontecorvo 3, I-56127 Pisa, Italy

Introduction

The study of breakup reactions involving loosely bound nuclei, is a method that can help understanding astrophysical nuclear reactions where direct measurements are difficult. Therefore after the discovery of halo nuclei a large interest has emerged worldwide on the measurements of breakup reactions in the medium incident energy range. The breakup reactions of neutron rich nuclei have been studied extensively and they are fairly well understood while the proton rich nuclei lying close to drip line are still under intensive investigations.

In light of our earlier work [1] this time we have analyzed the proton breakup reaction of ^{9}C on ^{9}Be target at 63.8 AMeV energy and studied exclusively the diffraction and Coulomb breakup and also their interference effects.

Theoretical formalism

For Coulomb breakup, we used a semi classical method that treats the full Coulomb interaction to all orders [1-5]. The Coulomb potential causing the Coulomb breakup is given by

$$V(\vec{r},\vec{R}) = \frac{V_c}{|\vec{R}-\beta_1\vec{r}|} + \frac{V_v}{|\vec{R}+\beta_2\vec{r}|} - \frac{V_0}{R}$$

where

$$V_c = Z_c\, Z_t\, e^2, V_v = Z_v\, Z_t\, e^2 \;\; and \;\; V_0 = (Z_v + Z_c)\, Z_t\, e^2$$

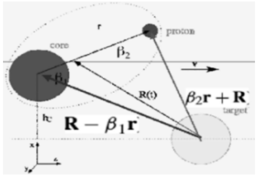

Fig. 1 Coordinate system

while β_1 and β_2 are the mass ratios of the proton and core, to that of the projectile. Z_p and Z_t are the projectile and target proton numbers, respectively. The coordinate system used is shown in Fig. 1. The parallel momentum distributions is given as [2,4]

$$\frac{d\sigma}{d\vec{k}} = \frac{1}{8\pi^3}\int d\overrightarrow{b_c}\left|S_{c\,t}(\overrightarrow{b_c})\right|^2 |g^{Coul.}|^2$$

where $g^{\mathrm{Coul.}} = g^{rec}(b_c) + g^{dir}(b_v)$ are core-target (recoil) and valence proton-target (direct) Coulomb amplitudes to all order [4,5]

$$g^{recoil}(b_c) = \int d\vec{r}\; e^{-i\,\vec{k}.\vec{r}}\, \phi_i(\vec{r}) \left(e^{i\frac{2V_c}{hv}log\frac{b_c}{R_\perp}} - 1 - i\frac{2V_c}{hv}log\frac{b_c}{R_\perp} + i\chi(\beta_1, V_c)\right)$$

$$g^{direct}(b_v) = \int d\vec{r}\; e^{-i\,\vec{k}.\vec{r}}\, \phi_i(\vec{r}) \left(e^{i\frac{2V_n}{hv}log\frac{b_v}{R_\perp}} - 1 - i\frac{2V_n}{hv}log\frac{b_v}{R_\perp} + i\chi(-\beta_2, V_v)\right)$$

For diffraction dissociation we have used the well known eikonal approximation which gives [2].

$$\frac{d\sigma}{d\vec{k}} = \frac{1}{8\pi^3}\int d\overrightarrow{b_c}\left|S_{c\,t}(\overrightarrow{b_c})\right|^2 \left|g^{Diff.}\right|^2$$

Where $g^{Diff}(b_v) = \int d\vec{r}\; e^{-i\,\vec{k}.\vec{r}}\, \phi_i(\vec{r})\left(e^{i\chi_{nt}(b_v)} - 1\right)$

b_c and b_v are core and valence nucleon impact parameter and $S_{c\,t}(\overrightarrow{b_c})$ is the core target S-matrix, which is parametrized such as to give a smooth-cut-off with strong absorption radius 5.71 fm. The projectile (^{9}C) is assumed as two-body object whose radial wave function is obtained by numerical solution of the Schrodinger equation in the Woods-Saxon potentials with depth adjusted to reproduce the experimental proton separation energy of 1.3 MeV. The radius parameter of the Woods-Saxon potential has been taken as 1.25 fm and the diffuseness as 0.7 fm.

Results

In order to study the interference of diffraction dissociation and Coulomb breakup reaction mechanism, we have calculated the parallel momentum distributions and cross section shown in Fig. 2 and Table 1 respectively. Fig. 2 shows that the interference of Coulomb [dot line] and diffraction dissociation [dash line] is constructive, resulting in a total which is larger than the simple sum of the diffraction and Coulomb contributions [dash dot line]. The effect of the core-target recoil due to the Coulomb interaction [dash line] and of the direct proton-target Coulomb interaction [dot line], are shown in Fig. 3. The solid line contains both terms. It is clear that the interference between the two is mostly destructive.

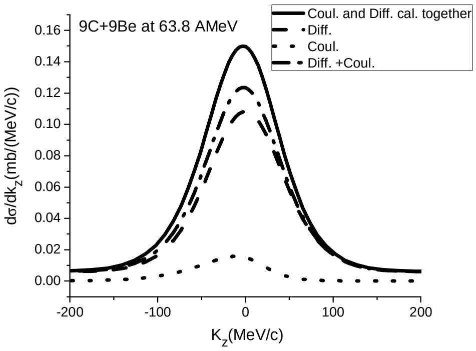

Fig. 2. Interference effect of diffraction and Coulomb breakup mechanism on the parallel momentum distribution in proton breakup.

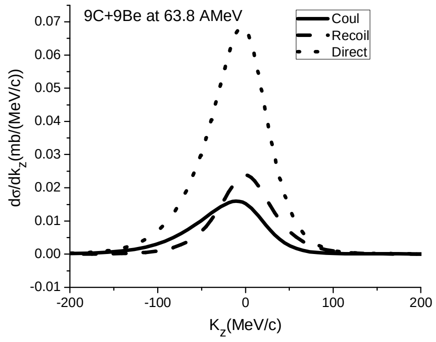

Fig. 3. Interference effect of recoil and direct terms in Coulomb breakup on the parallel momentum distribution in proton breakup.

Table 1: Calculated cross section corresponding to each reaction mechanism.

Reaction Mechanism	Cross section (mb)
$\sigma^{\text{Diff.}}$	14.49
σ^{Direct}	6.022
$\sigma^{\text{Recoil.}}$	1.95
σ^{Coul}	1.613
$\sigma^{\text{Diff.+Coul}}$	19.121

The direct term alone, being proportional to β_2, is indeed always larger in absolute value than the recoil term. However, it is the effect of the interference between the direct and the recoil terms that causes the reduction of the Coulomb breakup in the proton halo case.

Conclusion

From this study it clear that in the case of proton breakup from ^{9}C on a ^{9}Be target, the direct and recoil terms of the Coulomb breakup mechanism give rise to a destructive interference. However, the interference of diffraction and Coulomb is constructive, similarly to what we found in our recent papers [1, 2]. We hope that the present study will be helpful to understand the complicated proton breakup reactions of proton halo nuclei and also the interpretations of the experimental results involving exotic nuclei.

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