Coulomb Nuclear interference in breakup reactions

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Introduction

After the discovery of radioactive ion beams (RIB) in 1985 a great interest has emerged, theoretically as well as experimentally, in the breakup reactions involving these beams. The main attraction for these studies is ascribed to the involvement of these species in various astrophysical nuclear reactions where direct measurements are difficult. So far, the breakup reactions of neutron rich nuclei have been fairly well understood while the proton rich nuclei lying close to proton line are still under investigations.

In light of our earlier work [1] here, we have analyzed the proton and neutron breakup reactions of ^{10}Be and ^{16}C on ^{9}Be target at 77.8 and 75 AMeV energies respectively. We have investigated exclusively the nuclear diffraction and Coulomb breakup and also their interference effects.

Theoretical formalism

The Coulomb breakup mechanism is studied using well known semi classical method that treats the full Coulomb interaction to all orders [1-5]. Where Coulomb potential causing the 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

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

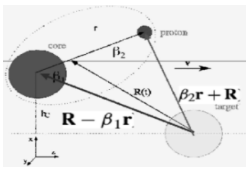

Fig. 1 Coordinate system

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]

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

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

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

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

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

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

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 $S_{c\,t}(\vec{b_c})$ is the core target S-matrix, which is parameterized such as to give a smooth-cut-off with strong absorption radius 5.82 fm and 6.36 fm. The projectile (^{10}Be and ^{16}C) are 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 and neutron separation energies. 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 nuclear diffraction dissociation and Coulomb breakup reaction mechanism in proton breakup and neutron breakup reactions, we have calculated the breakup cross section by integrating the parallel momentum distributions. The results for the proton breakup reactions are listed in Tables 1 & 2, while those for neutron breakup reaction are listed in Tables 3 & 4. In case of proton breakup, interference of Coulomb and nuclear diffraction dissociation is found constructive and cross section increased approx. ~7-9 %.

Table 1: Calculated Proton breakup cross section for reaction considered here.

Reaction	E_{lab} (MeV/n)	B.E. (MeV)	σ^{diff} (mb)	σ^{Coul} (mb)	$\sigma^{diff+diff}$ (mb)
$^{10}Be_4+^{9}Be$	77.8	22.33	1.6642	0.0248	1.821
$^{16}C_6+^{9}Be$	75	22.56	1.10242	0.02658	1.2298

Table 2: Coulomb nuclear diffraction interference in case of proton breakup

Reaction	$\sigma^{diff}+\sigma^{Coul}$ (mb) cal. separately and sum (**A**)	$\sigma^{diff+diff}$ (mb) cal. together (**B**)	(**A-B**) (mb)	% increase
$^{10}Be_4+^{9}Be$	1.689	1.821	0.132	+7.8
$^{16}C_6+^{9}Be$	1.129	1.2298	0.1008	+8.9

on the other hand, in case of neutron breakup, interference is observed to be destructive and cross section decreases approx. from ~3-6%.

Table 3: Calculated neutron breakup cross section for reactions considered here.

Reaction	E_{lab} (MeV/n)	B.E. (MeV)	σ^{diff} (mb)	σ^{Coul} (mb)	$\sigma^{diff+Coul}$ (mb)
$^{10}Be_4+^{9}Be$	77.8	6.81	4.796	0.1589	4.765
$^{16}C_6+^{9}Be$	75	4.25	8.7484	0.6184	8.827

Table 4: Coulomb nuclear diffraction interference in case of neutron breakup

Reaction	$\sigma^{diff}+\sigma^{Coul}$ (mb) cal. separately and sum (**A**)	$\sigma^{diff+diff}$ (mb) cal. together (**B**)	(**A-B**) (mb)	% increase
$^{10}Be_4+^{9}Be$	4.9549	4.765	0.1899	-3.8
$^{16}C_6+^{9}Be$	9.3668	8.827	0.5398	-5.8

Conclusion

It has been observed that in the case of proton breakup from ^{10}Be and ^{16}C on a ^{9}Be target, the interference of nuclear diffraction and Coulomb breakup is constructive from ~ 7-9%, while in case of neutron breakup case, interference is destructive from~3-6%, similar to what we found in our recent papers [1, 2]. We hope that the present study will be helpful for interpreting the experimental results involving exotic nuclei.

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References

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