Study of Interference Effects in Breakup Reaction ^{9}Be (^{15}O, ^{14}N) X at 56 MeV/u.

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Introduction

With the recent progress in the world's rare ion beam facilities, gaining insights into the structure and properties of exotic nuclei has become significantly more feasible. For instance, the isotope ^{15}O is recognized as an exotic nucleus [1]. Researchers frequently employ breakup reactions to investigate these unique exotic Nuclei. However, when analyzing these processes, a potential challenge arises from the potential interference between Coulomb and diffraction-based breakup reactions. Till now, many studies on the interference effect have been done, but coulomb-diffraction and Recoil-Direct Interference effects show a significant change in the breakup cross-section. So, including this effect to reproduce experimental results using the Glauber model in eikonal approximation becomes important as studied in many research papers [3-5].

In this study, we have investigated the ^{15}O breakup with a ^{9}Be target at 56 MeV/u beam energy whose LMD is given [1] and can compare this with theoretically calculated LMD. As ^{15}O is a proton-excess exotic nucleus, the proton separation energy is S_p=7.297 MeV. As we know, ^{15}O nuclei have considerable separation energy, four times larger than the ^{13}O nuclei [2], but the breakup cross-section is two times larger. According to the Glauber model, it should be smaller, so we believe including the interference effect will reproduce their exact behavior. So here we have investigated the two types of interferences in the breakup reaction: one is Coulomb diffraction, and another one is the recoil and direct Coulomb.

Theoretical formalism

The diffraction breakup is studied by using Eikonal approximation, while the Coulomb breakup is studied by treating Coulomb interaction to all orders as discussed in ref [4-7], where the Coulomb potential which causes the breakup is given by

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

Here, $V_c = Z_c Z_t e^2$, $V_v = Z_v Z_t e^2$ and $V_0 = (Z_c + Z_v) Z_t e^2$ while β_1 and β_2 are the mass ratio of valence proton and core to that of the projectile, Z_p and Z_t are the projectiles and the target charge number. The coordinate system used is shown in Fig.1.

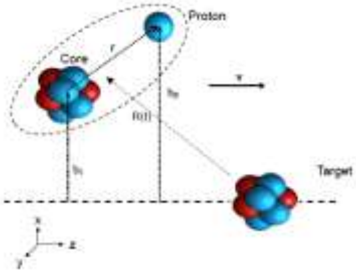

Fig.1 The coordinate system for projectile-target interaction.

The longitudinal momentum distribution in the Coulomb breakup mechanism is calculated by

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

Where $g^{Coul} = g^{Recoil}(b_c) + g^{Direct}(b_v)$, g^{Recoil} as a core-target and g^{Direct} as valence proton-target Coulomb amplitude to all order [3] and are written as

$$g^{Recoil}(b_c) = \int d\vec{r}\, e^{-i\vec{k}.\vec{r}} \emptyset_i(\vec{r}) \left(e^{i\frac{2V_c}{\hbar v} log \frac{b_c}{R_\perp}} - 1 - i\frac{2V_c}{\hbar v} log\frac{b_c}{R_\perp} + i\chi(\beta_1, V_c) \right) \tag{2}$$

$$g^{Direct}(b_v) = \int d\vec{r}\, e^{-i\vec{k}.\vec{r}} \emptyset_i(\vec{r}) \left(e^{i\frac{2V_v}{\hbar v} log \frac{b_v}{R_\perp}} - 1 - i\frac{2V_v}{\hbar v} log\frac{b_v}{R_\perp} + \chi(-\beta_2, V_v) \right) \tag{3}$$

and for nuclear diffraction dissociation we have used the well-known Eikonal approximation which is given as [3,4].

$$\frac{d\sigma}{d\vec{k}} = \frac{1}{8\pi^3}\int d\overrightarrow{b_c}\,\left|S_{ct}\left(\overrightarrow{b_c}\right)\right|^2 \left|g^{Diff.}\right|^2 \tag{4}$$

Where diffraction breakup amplitude is calculated as

$$g^{Diff}(b_v) = \int d\vec{r}\, e^{-i\vec{k}.\vec{r}} \phi_i(\vec{r}) (e^{i\chi_{nt}(b_v)} - 1), \tag{5}$$

b_c and b_v are core and valence nucleon impact parameters and $S_{ct}(b_c)$ and $\chi_{nt}(b_v)$, the core target and proton target S-matrix calculated by t-rho-rho (MOMDIS code [6]) method using Hartree-Fock form of densities of the core and target. Here, the projectile ^{15}O is assumed to have a core plus clustered proton structure, and its radial wave function $\phi_i(\vec{r})$, is obtained by solving the Schrodinger wave equation for $[1^{+} \otimes 1p_{1/2}]$ core-nucleon configuration in Woods-Saxon potential, where the binding energy 7.297 MeV [1] was reproduced by adjusting the potential depth (V_0 = 47.35 fm). The Woods-Saxon potential

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*Electronic address: surender.schphy@dcrustm.org parameters, i.e., radius, diffuseness, as 1.25fm and, 0.7fm respectively.

Results

By using theoretical formalism, we conducted an analysis to calculate the interference effect between Coulomb and diffraction breakup processes, for the reaction ^{9}Be(^{15}O,^{14}N)X at beam energies of 56 MeV/u. Additionally, we calculated the interference effects between the recoil and direct Coulomb breakup cross-sections given by in theoretical formalism. By integrating the differential cross-section, we find the total proton removal cross-section.

The table 1 shows the breakup cross-section for stripping, diffraction Coulomb, simple sum of coulomb and diffraction, and coulomb-diffraction calculated together so due to the coulomb diffraction interference there is change in the breakup cross-section as well as the FWHM of LMD distribution. The percentage change in the breakup cross-section is destructive in nature and decreases the breakup cross-section by approx. 4 %.

Similarly, table 2 shows the breakup cross-section and FWHM of LMD for the Recoil and Direct Coulomb Breakup and their percentage interference effect between recoil and direct coulomb breakup which is found approx. 66 % change in coulomb breakup due to percentage change.

Table 1: Calculated proton breakup cross-section in Diffraction and Coulomb dissociation and their percentage interference effects.

	σ_{-p} (mb)	FWHM (MeV/c)
Stripping	26.04	203.83
Diffraction	13.72	195.65
Coulomb	00.41	121.47
Coul+diff (simple sum)	14.13	192.46
Coul+diff(Cal. Tog.)	**13.53**	**194.04**
% Interference	-4.3 %	+0.8 %

Table 2: Calculated proton breakup cross-section of Recoil and Direct Coulomb and their percentage interference effects.

	σ_{-p} (mb)	FWHM (MeV/c)
Recoil	0.19	98.86
Direct	1.01	108.74
Recoil + Direct (simple sum)	1.20	107.97
Recoil + Direct (Cal. Tog.)	0.41	121.47
% Interference	-66%	+12.49

The calculated FWHM width is approx. 194 MeV/c which lies same as the experimental value 190±10 MeV/c [1]. So, it shows that the calculated result of FWHM of LMD and total breakup cross-section (which include coulomb, Diffraction, and stripping) are good in experimental limit [1,2] so it becomes important to include the interference effect in the breakup reaction.

Conclusion

Here, we studied the interaction of a ^{15}O beam with a ^{9}Be target at a beam energy of 56 MeV/u. We calculated the interference between the Coulomb and diffraction effects, as well as between the recoil and direct breakup reactions. From our results, we conclude that interference is a significant phenomenon in breakup reactions. Specifically, we found that Coulomb-diffraction interference is destructive in nature, reducing the breakup cross-section by up to 4%, while the FWHM of the longitudinal momentum distribution (LMD) shows only a small variation. In contrast, the interference between the recoil and direct breakup reactions is also destructive, decreasing the breakup cross-section by about 66%. When all these effects are included, the width of the FWHM of the total LMD (i.e., the sum of the Coulomb, diffraction, and stripping contributions) is found to closely reproduce the experimental value of 190 ± 10 MeV/c. Thus, incorporating interference effects in breakup reactions is essential for obtaining more accurate results.

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