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Presence of Coulomb Diffraction Interference in ^{9}Be(^{11}Be,^{10}Be)X Reaction

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Abstract
The presence of Coulomb nuclear diffraction interference in single neutron removal reaction ^{9}Be(^{11}Be,^{10}Be)X has been investigated using Coulomb interaction to all orders and nuclear diffraction by eikonal approximations. The sensitivity of interference and its effect on single neutron breakup cross section with incident energy (40-150 MeV/nucleon) have been studied. The obtained results show that Coulomb diffraction interference is constructive for all the considered incident energies, which enhances the single neutron breakup cross-section by 2.6%. The obtained results are quite informative for understanding of breakup mechanisms and also helpful for a clear interpretation of ^{11}Be breakup on ^{9}Be target.
Keywords: *Coulomb Nuclear Interferences, Halo Nucleus, Breakup reaction.*

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I. INTRODUCTION

The study of exotic nuclei lying close to the neutron or proton drip line has been an exciting topic in nuclear physics after their discovery in 1985[1]. The excess number of neutrons or protons in these nuclei exhibit low binding energy, large matter radii, violation of traditional magic numbers, inversion of nuclear states and formation of halo nuclear structure, are a few commonly found novel features in these nuclei. In such nuclei, basically due to very low binding energy the valence nucleons spatially extend from the core through quantum mechanical tunneling effect and form a core plus single or double nucleon nuclear structure, which is also known as Halo structure [2,3]. The study of these nuclei is not only interesting because of their novel structural features but also for their key role in Astrophysical nucleosynthesis reactions [4-6]. These nuclei are very difficult to form in the laboratories however because of advancements in RIB accelerators and detection technologies these days we have a large number of neutron and proton rich nuclei lying close to the drip line and many of them have confirmed halo character [7]. The breakup reactions are frequently used as a tool for structural investigations wherein the measurement of single nucleon breakup cross-section and FWHM width of core longitudinal momentum distribution (LMD) is the key observables that gives clear information about the nuclear structure of the projectile nucleus. The breakup of such nuclei occurs due to both nuclear interaction and Coulomb repulsive interaction between the projectile and target nucleus. The dominating reaction mechanism causing the breakup depends upon the atomic number of the target i.e. in the case of a low atomic number target(light target), Coulomb repulsion is small and breakup occurs dominantly due to nuclear interaction while in high atomic number target (heavy target) the Coulomb interaction dominates over nuclear interaction. Also, many theoretical works have shown that these Coulomb and nuclear diffraction dissociation mechanisms interfere constructively or destructively with each other during the reactions, and affect the experimental observables in significant magnitude and magnitude of interference depending on atomic number of the target and incident energy [8-14].

Therefore, in present work, I have examined the presence of Coulomb diffraction interference in a single neutron knockout reaction ^{9}Be(^{11}Be,^{10}Be)X in a 40-150 MeV/nucleon incident energy regime. Here it is important to mention that ^{11}Be isotope is a well-known neutron rich nucleus having core(^{10}Be) plus a valence neutron halo nuclear structure and the binding energy of valence neutron is very small i.e. (S_n= 0.54 MeV) [15-16]. So it is quite interesting to investigate the effect of interference on a single breakup cross-section, and also its sensitivity with the incident energy of projectile. The brief theoretical formalism is discussed in section-2, and obtained results and conclusions are discussed in section-3 and section-4.

II. Theoretical formalism:

Here, it is presumed that the projectile nucleus is a two-body system and breakup is caused by both the nuclear diffraction and Coulomb dissociation mechanisms. Theoretically, the core fragment longitudinal momentum distribution (LMD) and single neutron breakup cross-section, are calculated, in the nuclear diffraction dissociation mechanism using eikonal approximation while in Coulomb dissociation mechanism using all orders in Coulomb interactions is used, as discussed in ref. [11-14, 17-18], Here, the Coulomb repulsive potential acts between core and target nuclei only since valence nucleon is a neutron, so the Coulomb potential which causes the breakup is

$$V(\vec{r},\vec{R}) = \frac{V_C}{|\vec{R}-\beta_1 \vec{r}|} - \frac{V_C}{R} \qquad (1)$$

Where, $V_c = Z_c Z_t e^2$ and Z_c, Z_t are the core, target charge number and $\vec{R}$ is the position vector from the target nucleus to the center of mass of the projectile. The coordinate system of the projectile and target is shown in Fig.1 [11].

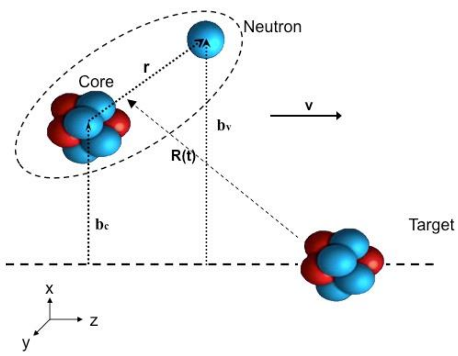

Fig.1 Coordinate system

In Coulomb breakup, the core-target Coulomb scattering amplitude g^{Coul}(also known as $g^{Recoil}(b_c)$) in all orders formalism [11,17,18] is

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

and nuclear diffraction scattering amplitudes (g^{Diff}) in eikonal approximation is respectively

$$g^{Diff} = \int d\vec{r}\, e^{-i\vec{k}.\vec{r}} \phi_i(\vec{r}) \left| S_{nt}(\vec{b}_v) - 1 \right| \qquad (3)$$

and using these scattering amplitudes, the core longitudinal momentum distribution in Coulomb and diffraction dissociation mechanism is calculated by

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

and the single-neutron breakup cross-section is calculated by integrating the core longitudinal momentum distribution over all the longitudinal momentum distribution. Here, b_c, b_v are the core and valence nucleon impact parameters and $S_{ct}(b_c)$, $S_{nt}(b_v)$ are the core-target and neutron–target s-matrices, calculated using MOMDIS code with Hartree-Fock nuclear density forms of core and target nucleus [19,20], and $\phi_i(\vec{r})$ is the projectile nucleus bound state wave function, calculated by numerical solving the Schrodinger wave equation by fitting the depth of nuclear potential to the binding energy of the valence neutron (S_n=0.54 MeV).

III. RESULTS AND DISCUSSION

Using the above theoretical formalism, I have calculated a single neutron breakup cross-section exclusively for nuclear diffraction and Coulomb mechanism separately as well as together to clearly observe the interference among Coulomb and diffraction mechanisms. The study is performed for the medium incident energy range i.e. 40, 70 and 150 MeV/nucleon because mostly the breakup reactions are performed at these incident energies and it would be interesting to examine the presence of Coulomb diffraction interference and its effect on breakup cross section. Here, ^{11}Be nucleus is assumed to have a ground state core(^{10}Be) plus valence neutron structure having ground state configuration [J^{+}=1/2+]. The calculated single neutron breakup cross sections are shown in Table 1, for the sake of simplicity, the spectroscopic factor is taken unity throughout these calculations.

Table 1: Calculated single neutron breakup cross section exclusively for Coulomb, diffraction and both dissociation mechanism together

Reaction Mechanism	E_{lab}(in MeV/nucleon)		
	40 MeV/ nucleon	70 MeV/ nucleon	150 MeV/ nucleon
σ^{Diff} (in mb)	72.89	54.13	27.47
$\sigma^{Coul.}$ (in mb)	7.01	4.78	2.87
$\sigma^{Coul.} + \sigma^{Diff}$ (Simple sum) (in mb) [A]	79.90	58.91	30.34
$\sigma^{Coul.+Diff}$ Calculated together (in mb)[B]	82.09	60.28	30.95
% Enhancement in cross section ([B]- [A]) / [A]X100%	**+2.6 %**	**+2.27%**	**+1.97%**

It is clear from the table that a single neutron breakup cross-section when calculated with both the breakup mechanisms together gives little higher breakup cross section than that of the simple sum of both the mechanisms when calculated independently. This enhancement in the breakup cross-section indicates that both Coulomb and diffraction dissociation mechanisms are interfering constructively during the breakup reaction and enhances the breakup cross-sections approximately 2.6%, 2.27% and 1.97% for 40, 70 and 150 MeV/A incident energies respectively. Also, the percent enhancement in breakup cross section due to interference is found slightly sensitive to the incident energy of projectile and it decreases slightly with the increase in incident energy that is due to the reason that with increase in incident energy the Coulomb interaction time between core and target decreases and so the interference between Coulomb diffraction mechanisms decreases. The obtained results are consistent with the results reported by ref. [11-13]. I, believe that the obtained results are informative for the theoretical understanding of ^{11}Be breakup on ^{9}Be target reaction and further it would be interesting to study this kind of study for heavy target cases generally used in exotic nuclei breakup reactions.

IV. CONCLUSION

The single neutron removal from ^{11}Be nucleus using ^{9}Be target has been studied for Coulomb diffraction interference investigation using the eikonal approximation and sudden approximation to all order in nuclear and Coulomb breakup mechanisms. The obtained results show the presence of constructive interference among Coulomb and diffraction breakup mechanisms, which enhances the magnitude of breakup cross-section by 2.6%. The effect of Coulomb diffraction interference is observed slightly sensitive to the incident energy of the projectile. With these findings, I believe that the breakup of ^{11}Be has been investigated for the first time using an all-order formalism for the Coulomb and diffraction interference study and its impact on a single neutron breakup cross section. The obtained results lead to a better understanding of the reaction mechanism and lucid interpretation of experimental data.

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