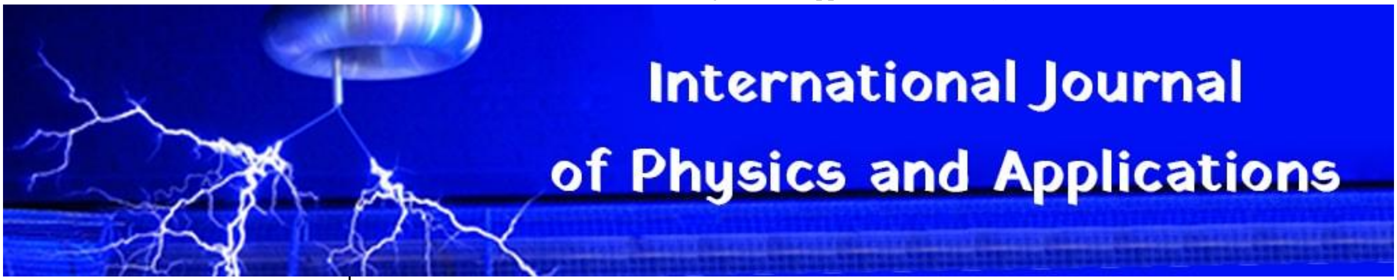

E-ISSN: 2664-7583
P-ISSN: 2664-7575
IJOS 2023; 5(2): 30-32

www.physicsjournal.in
Received: 10-05-2023
Accepted: 15-06-2023

Ravinder Kumar
Department of Physics
Deenbandhu Chhotu Ram
University of Science and
Technology, Murthal, Sonipat,
Haryana, India

Corresponding Author:
Ravinder Kumar
Department of Physics
Deenbandhu Chhotu Ram
University of Science and
Technology, Murthal, Sonipat,
Haryana, India

Effect of Coulomb nuclear diffraction interference in $^{9}Be(^{13}O,^{12}N)X$ breakup reaction

Ravinder Kumar

DOI: https://www.doi.org/10.33545/26647575.2023.v5.i2a.178

Abstract
The effect of Coulomb nuclear diffraction interference on the magnitude of single proton knockout cross section have been examined quantitatively for single proton knockout from ^{13}O nucleus on ^{9}Be targets at 28.5 MeV/nucleon incident beam energy. The Coulomb breakup mechanism is treated with all orders treatment in sudden approximation and nuclear diffraction mechanism is treated using Glauber eikonal approximations. The obtained results shows that interference plays a significant role in ^{13}O knockout reaction, which can enhance the magnitude of knockout cross section approximately 20%. Therefore, I hope that this investigation will be helpful for better interpretation of ^{13}O nucleus structure.

Keywords: Coulomb nuclear interference, halo breakup, knockout reactions

1. Introduction
After the discovery of extended matter distribution among excessive neutron or proton rich nuclei, a tremendous interest has be observed in the field of nuclear physics research [1-3]. These species have novel structural properties which are not normally observed in stable nuclei. These nuclei attracted lot of attention because of their key roles in nucleosynthesis reactions and also for better understanding of nuclear structure and nature of nuclear forces [4-6]. Therefore, so far large number of such exotic nuclei have been discovered in big laboratories worldwide [1-7]. For structural investigations frequently the single nucleon knockout reactions are used in which mainly the valence nucleon breakup cross section and longitudinal momentum distribution (LMD) of core fragment after removal of valence nucleon is measured and magnitude of these observables reveals the structural information of exotic nucleus. In these reactions the breakup of projectile is caused due to nuclear and Coulomb interaction with the target nucleus. The dominancy of breakup mechanism depends upon the atomic number (size of target nucleus) of the participating target nuclei, i.e. for high atomic number targets, Coulomb mechanism remain dominating while in case of small target nucleus, nuclear interactions dominates over Coulomb interaction. But in medium atomic mass number target cases the situation becomes more difficult because both the breakup mechanisms contribute equally to the breakup. In this light few recent theoretical works has shown that during the breakup, the Coulomb and nuclear interactions mechanisms can interfere constructively or destructively with each other and affect the magnitude of breakup observables [8-14]. The effect of interference depends on atomic number of target and also on the incident energy of projectile nucleus.
In this investigation, I examined the effect of Coulomb diffraction interference on the magnitude of single proton breakup cross section in case of ^{13}O nucleus. The effect is examined for frequently used[9] Be targets at 28.5 MeV/nucleon incident energies. The ^{13}O nucleus is a proton rich nucleus, expected to have a halo structure having a core (^{12}N) and a valence Proton [15]. The valence proton is attached with core with binding energy S_p= 1.51 MeV) and as per nuclear shell model predictions valence proton lies in $1p_{1/2}$ state [15]. So this would be interesting to examine Coulomb diffraction interference effects on its single proton breakup cross section. The theoretical formalism is briefly discussed in section-2, whereas obtained results and conclusions are discussed in section-3 and section-4.

2. Theoretical formalism
The ^{13}O nucleus is a proton rich loosely bound system having a two-body structure, containing

a core of ^{12}N nucleus and a valence proton attached with it with small separation energy (S_p= 1.51 MeV). During the interaction with target nucleus, the projectile nucleus breaks because of Coulomb and nuclear interactions between projectile and target nucleus. The dominancy of breakup mechanisms causing the breakup depends on the atomic number of the participating target and impact parameter of the projectile. The nuclear structure of exotic nuclei is frequently studied via single nucleon knockout reactions, the measurement of core fragment longitudinal momentum distribution (LMD) and single nucleon breakup cross-section are the key observables generally used for structural investigations. After following the theoretical formalism of ref [10-14], Here, I calculated the single proton breakup cross section by treating the Coulomb interaction between projectile and target nucleus to all orders and nuclear diffraction mechanism by Glauber eikonal approximation [11-14, 17-18]. The incoming projectile and target nucleus coordinate system used in this work is shown in Fig.1 [11, 12].

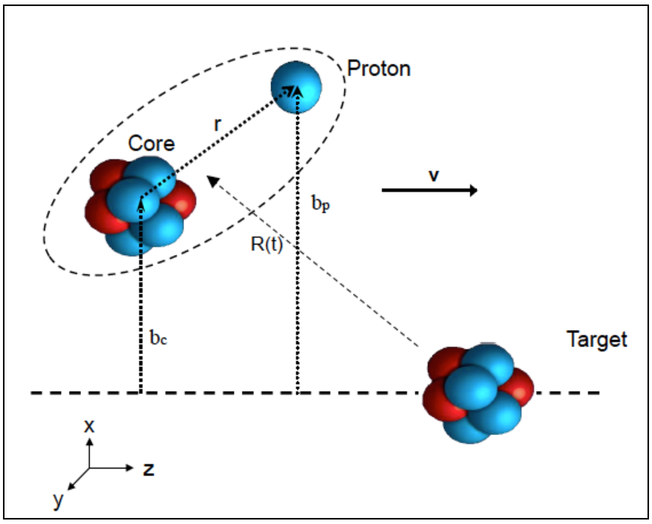

Fig 1: Coordinate Geometry of the interaction

The Coulomb repulsive potential between incoming projectile and target that causes the breakup is

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

here, $V_c = Z_c Z_t e^2$, $V_v = Z_v Z_t e^2$ and $V = Z_p Z_t e^2$ where Z_c, Z_v, Z_t and Z_P are the core, nucleon, target and projectile nucleus atomic numbers, $\vec{R}$ is the position vector from the target nucleus to the center of mass of the projectile.

In all orders sudden formalism the core-target and valence nucleon-target Coulomb scattering amplitudes also known as $g^{Recoil}(b_c)$ and $g^{Direct}(b_v)$ are respectively [11,17,18].

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

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

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

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

Finally, the single-nucleon knockout cross-section in Coulomb and diffraction dissociation mechanism is calculated using

$$\sigma = \frac{1}{8\pi^3} \int d\vec{k} \int d\vec{b_c}\, |S_{ct}(\vec{b_c})|^2 |g^{Recoil} + g^{Direct} + g^{Diff}|^2$$

here, $S_{ct}(b_c)$ and $S_{vt}(b_v)$ are the core-target and valence nucleon-target *s*-matrices, calculated with MOMDIS code using Hartree-Fock nuclear density forms of core and target nucleus [19, 20]. b_c *and* b_v are the core and valence nucleon impact parameters respectively. The bound state wave function of projectile nucleus, $\phi_i(\vec{r})$ is also calculated using MOMDIS code [19] by numerically solving the Schrodinger wave equation for WS nuclear potential form, the depth of nuclear potential is varied to fit the binding energy of the valence nucleon i.e. S_p=1.51 MeV.

3. Results and discussion

The single proton or neutron knockout cross sections are calculated exclusively for each breakup mechanism i.e. nuclear diffraction, pure Coulomb mechanisms (containing direct and recoil Coulomb interactions), and also together for both the mechanisms using the above discussed formalism.

It is quite interesting to investigate the presence of Coulomb diffraction interference in ^{13}O nucleus breakup reactions, in case of neutron knockout and proton knockout at 28.5. MeV/n incident beam energy on ^9Be target. All the calculations are done in the light of work carried out in ref. [10-14]. The obtained results are shown in Table 1.

Table 1: Calculated single proton knockout cross-sections exclusively for nuclear diffraction, Coulomb and Coulomb plus diffraction mechanisms together

Breakup Mechanism	Single proton knockout cross section
σ^{Diff} (in mb)	24.12
$\sigma^{Coul.}$ (in mb)	2.54
$\sigma^{Coul.} + \sigma^{Diff}$ (Simple sum) (in mb) [A]	26.66
$\sigma^{Coul.+Diff}$ Calculated together (in mb)[B]	32.03
% variation in cross section manitude ([B]- [A]) / [A]X100%	+20%

It is clear from the table that magnitude of single proton breakup cross section jointly calculated for Coulomb and diffractions mechanism is more than that of their simple sum of separately calculated Coulomb and diffraction cross sections. The variation in magnitude of single proton breakup cross section is around 20%, which reflects the presence of constructive interference between Coulomb and nuclear diffraction mechanisms. The observed results are consistent with the reported results [11-13].

The obtained results reflect that Coulomb and nuclear diffraction interferences are quite important for revealing clear structural informative for ^{13}O nucleus and also helpful for interpretation of experimental results.

Conclusion

In this investigation I found that interference between Coulomb and nuclear diffraction mechanisms is quite significant in ^{13}O nucleus breakup reaction even in case of light target, which could enhance the magnitude of single proton breakup cross section upto 20%. This enhancement in cross section magnitude reflects the constructive interference between Coulomb and nuclear diffraction breakup mechanism. This observation indicates that in ^{13}O breakup reaction, Coulomb nuclear interference is very important and ignorance of which may lead to misinterpretation of experimental data. Also, I believe that this work is helpful for better understanding of reaction mechanisms in other reactions and reveal their better interpretation of experimental data.

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