Effect of projectile deformation in the breakup of ^{37}Mg

Shubhchintak[1],* R. Chatterjee[1], and R. Shyam[1,2]
[1] Department of Physics, Indian Institute of Technology, Roorkee - 247667, India and
[2] Theory Group, Saha Institute of Nuclear Physics,
1/AF Bidhannagar, Kolkata 700064, India

Introduction

In the past few decades the studies of the exotic few body systems have been focused on the neutron rich isotopes of light nuclei like Li, Be and C. With increasing experimental sophistication, it is now possible to extend this study to the medium mass region where the Coulomb breakup has been one of the most successful probes to unravel their structure. Recently, studies have been performed of the medium mass exotic systems, ^{23}O [1] and ^{31}Ne [2]. In fact, in the region around the neutron number $(N) = 20$, strongly deformed nuclei have been found. This region, called the "island of inversion", consists of unstable nuclei from ^{30}Ne to ^{34}Mg with $N = 20$. This is a very new and exciting development which has expanded the field of light exotic nuclei to the deformed medium mass region.

In this contribution we apply the recently developed extended theory of the Coulomb breakup within the post-form finite range distorted wave Born approximation that includes deformation of the projectile [2], to study the breakup of ^{37}Mg on Pb. The electromagnetic interaction between the fragments and the target nucleus is included to all orders and the breakup contributions from the entire non-resonant continuum corresponding to all the multipoles and the relative orbital angular momenta between the fragments are taken into account. Only the full ground state wave function of the deformed projectile, of any orbital angular momentum configuration, enters in this theory as input. Thus this theory is free from the uncertainties associated with the multipole strength distributions that may exist in many of the other models.

In particular, we study the Coulomb breakup of ^{37}Mg on Pb target at 240 MeV/u using this novel approach. Comparing our calculated cross section with the available Coulomb breakup data [4], we determine the possible ground state configuration of ^{37}Mg. Furthermore, by using this theory, we investigate the effect of projectile ground state deformation on various reaction observables, like the relative energy spectra, parallel momentum distributions and energy-angular distributions.

Formalism

We consider the elastic breakup of a two body composite 'deformed' projectile a in the Coulomb field of a target t, $a + t \rightarrow b + c + t$, where projectile a breaks up into fragments b (charged) and c (uncharged). The reduced transition amplitude, $\beta_{\ell m}$, for this reaction is given by

$$\beta_{\ell m} = \left\langle e^{i(\gamma \mathbf{q_c} - \alpha \mathbf{K}).\mathbf{r_1}} \left| V_{bc}(\mathbf{r}_1) \right| \phi_a^{\ell m}(\mathbf{r}_1) \right\rangle \times \left\langle \chi_b^{(-)}(\mathbf{q_b}, \mathbf{r_i}) e^{i\delta \mathbf{q_c}.\mathbf{r_i}} \middle| \chi_a^{(+)}(\mathbf{q}_a, \mathbf{r_i}) \right\rangle \quad (1)$$

The ground state wave function of the projectile $\phi_a^{lm}(\mathbf{r}_1)$ appears in the first term (vertex function), while the second term that describes the dynamics of the reaction, contains the Coulomb distorted waves $\chi^{(\pm)}$. This can be expressed in terms of the bremsstrahlung integral. α, γ and δ are the mass factors pertaining to the three-body Jacobi coordinate system (see Fig. 1 of Ref. [2]). In Eq. 1, $\mathbf{K}$ is an effective local momentum appropriate to the core-target relative system and $\mathbf{q}_i$'s $(i = a, b, c)$ are the Jacobi wave vectors of the respective particles.

$V_{bc}(\mathbf{r}_1)$ [in Eq. (1)] is the interaction between b and c, in the initial channel. We

*Electronic address: shub1dph@iitr.ac.in

introduce an axially symmetric quadrupole-deformed potential, as

$$V_{bc}(\mathbf{r}_1) = \frac{V_{ws}}{1+exp(\frac{r_1-R}{a})} - \beta_2 R V_{ws}\frac{df(r_1)}{dr_1}Y_2^0(\hat{\mathbf{r}}_1), \quad (2)$$

where V_{ws} is the depth of spherical Woods-Saxon potential, β_2 is the quadrupole deformation parameter. The first part of the Eq. (2) is the spherical Woods-Saxon potential $V_s(r_1)$ with radius $R = r_0 A^{1/3}$. r_0 and a being the radius and diffuseness parameters, respectively. To preserve the analyticity of our method, we calculate the radial part of the ground state wave function of the projectile using the undeformed Woods-Saxon potential (radius and diffuseness parameters taken as 1.2 fm and 0.6 fm respectively, which reproduce the ground state binding energy). We emphasize that the deformation parameter (β_2) has already entered into the theory via V_{bc} in Eq. (1). For more details on the formalism we refer to Ref. [2].

Results and discussions

The nucleus ^{37}Mg has a large uncertainty in its one-neutron separation energy (0.162 ± 0.686 MeV [3]) and has controversies regarding its ground state spin-parity. Recently measured large breakup cross section [4] and reaction cross section [5] seems to suggest a halo structure in ^{37}Mg.

In Fig.1, we present the one-neutron removal cross section as a function of the separation energy (S_n), in the Coulomb breakup of ^{37}Mg on Pb at 240 MeV/u beam energy for different possible ground state configurations ($J^\pi = 5/2^-, 7/2^-, 3/2^-$ and $1/2^+$). The shaded region corresponds to the experimental data taken from Ref. [4]. With the present data our calculations suggest that possible J^π in this case is either $3/2^-$ or $1/2^+$.

To get further confirmation of the J^π and the ground state separation energy we will present results on the variation of the total cross section as a function of the quadrupole deformation, with the separation energy as a parameter. This will put constraints on the quadrupole deformation itself. Further calculations of the relative energy spectra, momentum and angular distributions, in the breakup of ^{37}Mg on Pb, will be presented and comparison with newly available data (eg. [6]) will be made. This will help us to reduce the uncertainties in the ground state spin-parity of this nucleus, as was done in the case of ^{31}Ne [2].

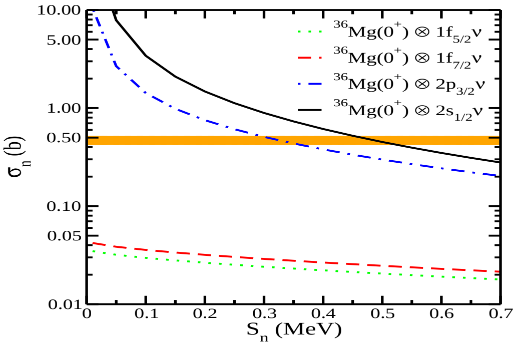

FIG. 1: Total cross section in the Coulomb breakup of ^{37}Mg (for $J^\pi = 5/2^-, 7/2^-, 3/2^-$ and $1/2^+$) on Pb target at 240 MeV/u beam energy calculated for different values of S_n. The experimental data (preliminary) shown by the shaded region are from Ref. [4].

Acknowledgments

This work is supported by the Council of Scientific and Industrial Research (CSIR) and the Department of Science and Technology, Govt. Of India.

References

[1] R. Chatterjee, R. Shyam, K. Tsushima, A. W. Thomas, Nucl. Phys. A **913**, 116 (2013).
[2] Shubhchintak and R. Chatterjee, Nucl. Phys. A **922**, 99 (2014).
[3] J. Cameron, J. Chen, B. Singh and N. Nica, Nucl. Data. Sheets **113**, 365 (2012).
[4] N. Kobayashi *et al.*, J. Phys: Conf. Series **436**, 012047 (2013).
[5] M. Takechi *et al.*, EPJ Web of Conferences. **66**, 02101 (2014).
[6] N. Kobayashi *et al.*, Phys. Rev. Lett. **112**, 242501 (2014).