Structural effects in ^{34}Na

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Introduction

The continuous efforts towards refinement of experimental technology over the last few decades has paved way to study in detail the exotic nuclei near the drip lines. Coulomb dissociation (CD) has emerged as an elegant method to explain the data emanating from these experiments. Theoretically, CD, or Coulomb breakup as it is often called, is the rupturing of a projectile into a core and valence nucleon(s) as it moves in the changing Coulomb field of a target. As the name suggests, nuclear contribution is often ignored in CD as it usually involves scattering at large impact parameters.

Due to their low dissociation energies, CD has been successfully used to study drip line nuclei like ^{11}Be, ^{19}C, ^{31}Ne, ^{37}Mg and ^{34}Na among many others [1–4]. Of these, ^{34}Na, is the least understood as its ground state spin-parity and one neutron separation energy are not very well known. Also, since it forms a part of the N = 20 −30 (medium mass) region where the concept of magic numbers becomes hazy due to the structural changes, it would be interesting to observe if it undergoes configuration reversal due to the $\nu(sd)^{-2}(fp)^2$ intruder configurations, like its peers (e.g., ^{31}Ne, ^{37}Mg). This could lead to ^{34}Na being deformed, which would eventually result in an enhanced total reaction cross-section [3]. Indeed, strongly deformed nuclei have been found in this 'island of inversion'.

A recent experimental result lists one neutron separation energy (S_n) for ^{34}Na to be (0.17 ± 0.50) MeV [5] while the NNDC database shows it to be ≃ (0.75 ± 0.008) MeV [6]. The uncertainty is very large. Moreover, it is highly probable that the ground state (g.s.) of ^{34}Na has a dominant p-wave contribution [2–5]. A better knowledge of these uncertain quantities is essential in determining the rates of reactions ^{34}Na might be a part of in the stellar plasma, where it can serve as a seed nucleus in r-process paths [7]. In this text, we have used the method of CD to calculate the relative energy spectra for ^{34}Na(γ,n)^{33}Na reaction as a part of the investigation of the possible allowed ground state configurations for ^{34}Na and its binding energy.

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Formalism

Consider a projectile a (^{34}Na) impinging on a target t (^{208}Pb) at 100 MeV/u. Due to the strong Coulomb repulsion from the target nucleus, the projectile breaks up elastically into a core b (^{33}Na) and a valence neutron c, i.e., ^{34}Na + ^{208}Pb ⟶ ^{33}Na + n + ^{208}Pb.

We use the finite range distorted wave Born approximation (FRDWBA) theory extended to incorporate deformation effects, and calculate the triple differential cross section which is then integrated to find the relative energy spectrum $\left(\frac{d\sigma}{dE_{rel}}\right)$ for the above mentioned breakup reaction. The triple differential cross-section is given by,

$$\frac{d^3\sigma}{dE_{rel}d\Omega_{at}d\Omega_{bc}} = \frac{2\pi}{\hbar v_{at}}\rho_{(phase)}\sum_{l,m}|\beta_{lm}|^2 \tag{1}$$

where E_{rel} is the b-c relative energy in the final channel, v_{at} is the a-t relative velocity in the initial channel, Ω's are the solid angles of the a-t and b-c systems, respectively, and $\rho_{(phase)}$ is the phase factor. The reduced amplitude β_{lm} is defined as:

$$\beta_{lm} = \left\langle \chi_b^{(-)}(\mathbf{q}_b, \mathbf{r}_i) e^{i\delta \mathbf{q}_c \cdot \mathbf{r}_c} | \chi_a^{(+)}(\mathbf{q}_a, \mathbf{r}_i) \right\rangle \times \left\langle e^{i(\gamma \mathbf{q}_c - \alpha \mathbf{K}) \cdot \mathbf{r}_1} | V_{bc}(\mathbf{r}_1) | \phi_a^{lm}(\mathbf{r}_1) \right\rangle \quad (2)$$

In Eq. 2, the $\mathbf{r}$'s are the position vectors of the particles according to the Jacobi coordinate system with α, γ, and δ being the mass factors (see Fig. 1 of Ref. [2]), χ's are the pure Coulomb distorted waves and $\phi_a^{lm}(\mathbf{r}_1)$ is the ground state wavefunction of a with angular momentum l and projection m. The $\mathbf{q}$'s are the Jacobi wave vectors and $\mathbf{K}$ is the effective local momentum for the core-target relative system. The deformation enters our theory through Eq. 2 via the deformed potential, V_{bc}. We can semi-analytically factorize the breakup amplitude in two parts: one, the structure part (which essentially contains the effects of deformation), and two, the dynamics part (which can be evaluated analytically).

For further details on the formalism, one may refer to Refs. [2, 3].

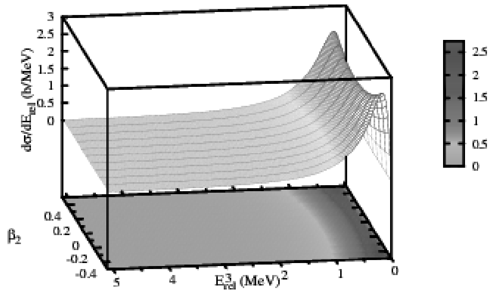

FIG. 1: The relative energy spectra with quadrupole deformation, β_2, as a parameter for ^{34}Na breaking on ^{208}Pb at 100 MeV/u beam energy to form a ^{33}Na core and a neutron.

Results and discussion

In Fig. 1, we present the relative energy spectra for the breakup of ^{34}Na on a ^{208}Pb target at 100 MeV/u beam energy as a function of quadrupole deformation parameter (β_2) for a possible ground state configuration of ^{34}Na being ^{33}Na$(3/2^+) \otimes 2p_{3/2}\nu$, fixing S_n at a mean value of 0.17 MeV. It is evident that deformation affects the peak position of the spectrum for this g.s. configuration of ^{34}Na. Relative energy spectrum is important because it can be used with scaling laws to put stricter limits on the S_n value of the nucleus under consideration, since it is a known fact that peak positions of the relative energy spectra are directly proportional to the binding energies of a nucleus [1].

Using our fully quantum mechanical theory we will also present calculations for the total cross-section for different possible g.s. configurations as well as the results for momentum and angular distributions and average momentum. In the process, we will try and argue that at an S_n value of 0.17 MeV, the g.s. of ^{34}Na is expected to dominated by ^{33}Na$(3/2^+) \otimes 2p_{3/2}\nu$ configuration [4]. This will be useful for radiative capture reactions involving ^{34}Na and in predicting seed nuclei for r-process paths.

Acknowledgments

This text results from research supported by DST, Govt. of India (SR/S2/HEP-040/2012). [GS] and [MD] acknowledge MHRD for the research fellowships. [S] is supported by U.S. NSF Grant No. PHY-1415656 and U.S. DOE Grant No. DE-FG02-08ER41533.

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