Determination of hexadecapole (β_4) deformation of the light-mass nucleus ^{24}Mg using quasi-elastic measurement

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Introduction

Knowing precise information about nuclear structure is of fundamental importance, not only for its roles in heavy-ion reaction dynamics, but also to understand the microscopic interaction responsible for the structure. In this context, static ground state deformations of atomic nuclei such as quadrupole (β_2), octopole (β_3), and hexadecapole (β_4) are of vital significance. Previously, electron-scattering [1], proton-scattering [2], α-scattering [3], Coulomb excitation, and muonic X-rays have been used to determine the deformed nuclear shapes experimentally. In comparison to lower order multipoles such as the quadrupole and octopole, the hexadecapole deformation is difficult to determine experimentally, primarily because of weak sensitivity of the aforementioned probes to β_4.

Systematic study of heavy-ion reaction dynamics reveals that there is a strong interplay between nuclear structure effects and relative motion of the two colliding nuclei. In particular, during heavy-ion fusion, the coupling of internal degrees of freedom of the fusing nuclei, such as vibrational (spherical), rotational (deformed), and particle transfer, gives rise to a distribution of fusion barriers instead of a single barrier [4]. These barrier distributions provide fingerprint of nuclear structure effects of the colliding nuclei. Later, it has also been established that a representation of barrier distribution can be extracted from quasi-elastic (QEL) scattering, measured at backward angles. If colliding partners are chosen appropriately such that the transfer channel coupling is weak, QEL scattering can be used as a probe to determine quantitatively the strengths of collective degrees of freedom. Simplistic approach of QEL scattering comes very handy when dealing with poor intensity radioactive ion beams. However, its applicability to determine the ground state deformation has been demonstrated only in few cases so far, that too in the heavy-mass region of rare-earths [5]. In the present paper, it is shown that using QEL scattering, not only the β_2, but also the much more difficult β_4 of a light-mass nucleus, ^{24}Mg, can be determined.

Experimental Details and Data Analysis

Quasi-elastic scattering measurements were carried out using ^{16}O and ^{24}Mg beams from the FN accelerator facility at Nuclear Science Laboratory, University of Notre Dame, USA. A 150 μg/cm^2 foil of highly enriched (>95%) ^{90}Zr was used as the target. Beam energies were used in the range of 36 to 62 MeV (for ^{16}O) and 61 to 91 MeV (for ^{24}Mg) in steps of 1-MeV (for ^{16}O) and 2-MeV (for ^{24}Mg). Quasi-elastic events were extracted using three silicon-telescopes placed at 158°, 148°, and 138° with respect to the beam direction [6].

Two SSB detectors placed at ±20° were used to measure Rutherford scattering events for normalization. Differential cross section for quasi-elastic events normalized with Rutherford scattering cross section was obtained as a function of centrifugal-corrected center-of-mass energy for each telescope, $E_{\rm eff} = 2E_{\rm c.m.}/(1+{\rm cosec}(\theta_{\rm c.m.}/2))$, where $\theta_{\rm c.m.}$ is the center-of-mass angle of the telescope. It is seen that the quasi-elastic excitation functions determined from three different back angles are overlapping [6]. Quasi-elastic barrier distribution $D_{\rm qel}$ ($E_{\rm eff}$) from quasi-elastic excitation function was determined using the re-

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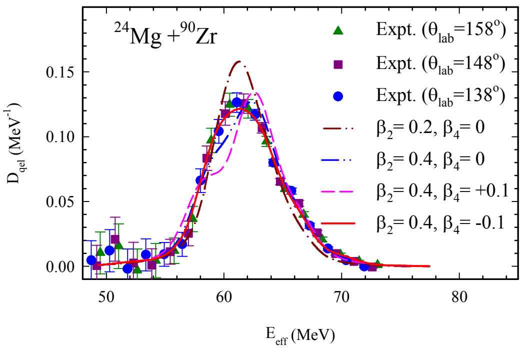

FIG. 1: Quasi-elastic barrier distribution determined from QEL excitation functions measured at three backward angles. Different lines correspond to CCQEL calculations for different values

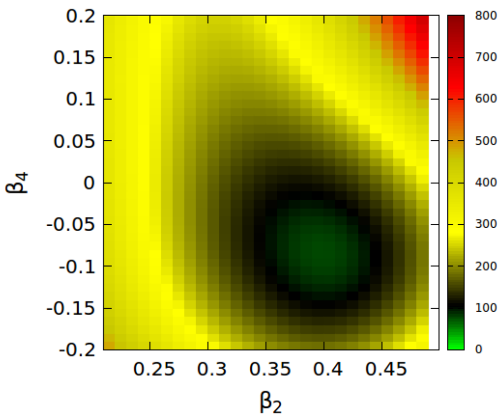

FIG. 2: χ^2 in the two-dimensional space of deformation parameters β_2 and β_4.

lation [4]:

$$D_{qel}(E_{\rm eff}) = -\frac{d}{dE_{\rm eff}}\left[\frac{d\sigma_{\rm qel}(E_{\rm eff})}{d\sigma_{\rm R}(E_{\rm eff})}\right], \qquad (1)$$

where $\sigma_{\rm qel}$ and $\sigma_{\rm R}$ are the differential cross sections for the quasi-elastic and Rutherford scatterings, respectively. The barrier distribution for the ^{24}Mg+^{90}Zr system is shown in Fig. 1. Coupled-channel calculations for quasi-elastic excitation function have been carried out using the code CCQEL [7] from which the barrier distributions for ^{16}O+^{90}Zr and ^{24}Mg+^{90}Zr reaction partners have been derived.

Results and Discussion

Considering ^{16}O as an inert partner, the strength of vibrational degrees of freedom for ^{90}Zr (λ=2 and 3) were determined by comparing experimental quasi-elastic barrier distribution of ^{16}O+^{90}Zr with that of corresponding theoretical calculations. The deformation lengths (vibrational) so obtained are well consistent with previously reported values. CC-QEL calculations have been carried out for ^{24}Mg+^{90}Zr system with varying quadrupole (β_2) and hexadecapole (β_4) deformation parameters of ^{24}Mg while fixing the vibrational couplings of ^{90}Zr at the values determined from the ^{16}O+^{90}Zr system. The minimum of χ^2 was explored in the two dimensional space of β_2 and β_4, in the range of 0.2 to 0.5 and -0.2 and 0.2, respectively with a step size of 0.01 for both parameters, as shown in Fig.2. It is observed that the minimum χ^2 corresponds to β_2 ~0.4 and β_4 ~-0.1. Experimental barrier distributions along with CCQEL predictions at few combinations of β_2 and β_4 are shown in the Fig. 1. Detailed results including uncertainties on the β_2 and β_4 will be presented.

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