Uncovering the sign of nuclear deformations: Determination of prolate or oblate shape via low-energy α inelastic scattering†

S. Watanabe,[*1,*2] Y. Suzuki,[*3] M. Kimura,[*2] and K. Ogata[*4,*3]

Understanding nuclear shape is a crucial problem in nuclear physics, and it significantly influences our knowledge of nucleon single-particle dynamics and collective nuclear behavior. The most essential part of nuclear deformation is quantified by the quadrupole deformation parameter β_2, if we assume axial symmetry. Although β_2 has been extensively examined in terms of its magnitude $|\beta_2|$, determining its sign—prolate or oblate—remains a challenging problem because many observables are sensitive only to β_2^2. Conventional approaches, such as measurements of electric quadrupole moments and Coulomb excitation experiments, provide crucial insights into nuclear deformation, including its sign. However, these methods are often impractical for neutron-rich unstable nuclei. These unstable nuclei are essential for studying shell evolution, emphasizing the necessity of alternative methods to determine magnitude and sign of deformation.

In this study, we propose a method for determining the sign of nuclear deformation via low-energy α inelastic scattering. Our approach utilizes nuclear reorientation effect (RE), which is known as a self-coupling of excited states.[1)] Using a standard coupled-channel method within the macroscopic model, we demonstrate how RE affects cross sections differently for prolate and oblate shapes. To validate this approach, we analyzed α scattering on the stable nucleus ^{154}Sm at 50 MeV, for which the experimental data are available.[2)]

First, we determined the Woods-Saxon optical potential parameters by fitting them to the elastic scattering data.[2)] Next, we analyzed the inelastic scattering data[2)] using the deformation parameter β_2 as a free parameter in the macroscopic model. We varied β_2 from negative to positive values to determine the optimal deformation parameters for the inelastic scattering data ($\beta_-^{(\mathrm{opt})}$ and $\beta_+^{(\mathrm{opt})}$). Note that ^{154}Sm has a prolate shape ($\beta_2 > 0$).[3)] Figure 1 illustrates the angular distribution of the inelastic scattering cross section for α+^{154}Sm scattering to the 2_1^+ state. The solid line represents the best fitted result with $\beta_+^{(\mathrm{opt})} = +0.25$, while the dotted line corresponds to $\beta_-^{(\mathrm{opt})} = -0.16$, which was the best fit among the negative sign results of β_2. The result with $\beta_+^{(\mathrm{opt})}$ was in good agreement with the experimental data from the forward to backward angles. Conversely, the result with $\beta_-^{(\mathrm{opt})}$ deviated from the data even at the forward angle. This difference could be attributed to RE for $\beta_\pm^{(\mathrm{opt})}$. The cross section became larger for oblate deformation than the prolate one when $|\beta_2|$ was the same. Therefore, the smaller magnitude of $|\beta_-^{(\mathrm{opt})}| = 0.16$ is necessary to reproduce the experimental data. However, it failed to reproduce the rise of the cross section at forward angle $\theta \approx 25°$ and the position of the diffraction minimum (the effective reaction radius). Thus, the sign of deformation can be determined by analyzing the RE in low-energy α inelastic scattering.

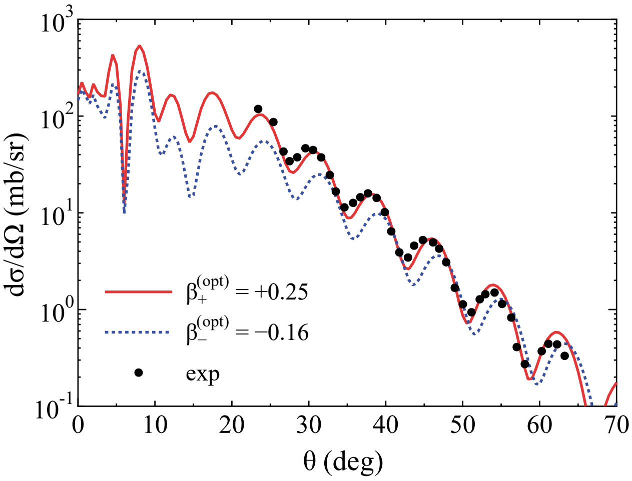

Fig. 1. Inelastic scattering cross section for the scattering of α+^{154}Sm at 50 MeV. The solid and dotted lines represent the optimized results for $\beta_+^{(\mathrm{opt})} = +0.25$ and $\beta_-^{(\mathrm{opt})} = -0.16$, respectively. The experimental data are taken from Ref. 2).

This analysis highlights the utility of low-energy α inelastic scattering to distinguish the signs of nuclear deformations. Systematic application of this technique enables determination of the sign for stable and unstable nuclei, offering valuable insights into nuclear structure and shell evolution.

References

1) G. R. Satchler, *Direct Nuclear Reactions* (Clarendon Press, Oxford, 1983).
2) D. L. Hendrie *et al.*, Phys. Lett. B **26**, 127 (1968).
3) N. J. Stone, At. Data Nucl. Data Tables **90**, 75 (2005).

† Condensed from the article in Phys. Rev. C **110**, 034618 (2024)

*1 National Institute of Technology (KOSEN), Gifu College
*2 RIKEN Nishina Center
*3 Research Center for Nuclear Physics (RCNP), Osaka University
*4 Department of Physics, Kyushu University

DOI:10.34448/RIKEN.APR.58-012