Deformed nuclei in the black-sphere approximation

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The size of an atomic nucleus is one of the most fundamental quantities that characterize the bulk properties of the nucleus. It is well known for β stable nuclei in the ground state thanks to systematic measurements of electron and proton elastic differential cross sections. This helps clarify the equation of state of nuclear matter near the saturation point.[1)] When studying the density derivative L of the symmetry energy of nearly symmetric nuclear matter, the total reaction cross section, σ_R, of neutron-rich nuclei is one of the most important observables.

In this work, in order to obtain the value of L, we focus on the empirical data of the interaction cross section, σ_I, measured at ~900 MeV per nucleon,[2,3)] as a first step. Since the data of Ne and Mg isotopes at ~240 MeV per nucleon have already been obtained at the RI Beam Factory of RIKEN,[4)] systematic analyses are necessary. For the analyses, we adopt the black-sphere (BS) model of nuclei.

We have so far systematically analyzed the proton elastic scattering and σ_R data for stable nuclei at a proton incident energy of $T_p \sim$ 800–1000 MeV on the basis of a "black-sphere picture" of nuclei.[5)] We showed that for proton beams incident on stable nuclei, the cross section of a black sphere of radius a, which is determined by fitting the angle of the first elastic diffraction peak calculated for proton diffraction by a circular black disk of radius a to the measured value, is consistent with the measured σ_R.[5)] This finding is also observed for σ_R of nucleus-nucleus reactions down to approximately 100 MeV per nucleon.[6)]

In the model, the absorption cross section is written by $\sigma_{BS} = \pi\left(a_0(\text{proj.}) + a_0(\text{C})\right)^2$, where $a_0(\text{proj.})$ is the BS radius of a projectile. $a_0(\text{C})$ is the BS radius of the target C nucleus obtained using the method mentioned above.[5,6)] For proton incident energies higher than ~ 800 MeV, $a_0(\text{C}) = 2.69 \pm 0.07$ fm.

According to the systematic analysis based on a macroscopic nuclear model, at large neutron excess, the calculated nuclear matter radius increases with L via the L dependence of the nuclear matter saturation density. It is indispensable to duly incorporate such dependence into the BS model for application to the reactions involving neutron-rich nuclei.

The relatively large neutron excess of the isotopes of Ne and Mg is advantageous for studying the value of L. However, nuclear deformation occurs in this region of nuclei. We change the black sphere into a spheroid of the same volume to take nuclear deformation into account before discussing the L dependence. The values of the deformation parameter, β, are taken from microscopic nuclear structure models.[7)] Under the adiabatic approximation, the values of σ_R for deformed nuclei should be evaluated by angle averaging of the cross section values over the deformation direction of nuclei.[8)]

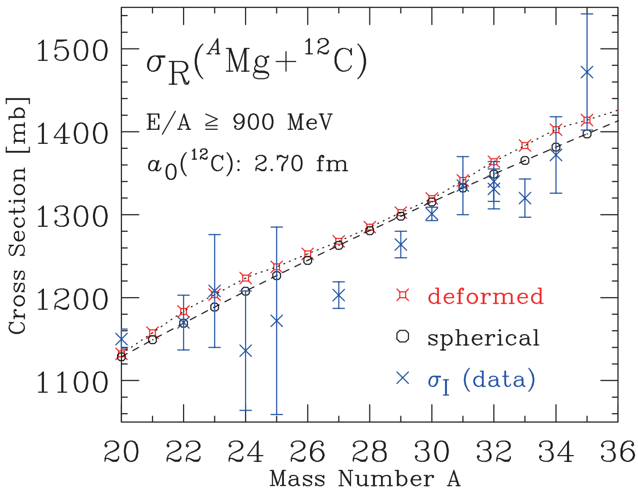

Fig. 1. Effect of nuclear deformation on σ_R as a function of projectile mass number, A, indicated by squares with crosses. The values of β are from SkM*. The spherical cases (○) are obtained by "BS scaling", $a_0(\text{proj.}) \simeq 1.2135A^{1/3}$ fm, in σ_{BS}.[5)] For comparison, we plot the empirical values of σ_I of ^{A}Mg on a carbon target.[2,3)]

The results are shown in Fig. 1. Although we adopt the values of β given by a mean field calculation with the effective interaction SkM*, which tends to offer large deformation, the effect on σ_R is rather small. This is consistent with the work of Christley and Tostevin,[8)] but inconsistent with the work of Horiuchi *et al.*[9)] Before drawing conclusions, we have to examine the interaction dependence by adopting SLy4, KTUY,[7,10)] etc. The study is now in progress.

References
1) K. Oyamatsu *et al.*: Prog. Theor. Phys. **109**, 631 (2003).
2) A. Ozawa *et al.*: Nucl. Phys. A **693**, 32 (2001).
3) R. Kanungo *et al.*: Phys. Rev. C **83**, 021302(R) (2011).
4) M. Takechi *et al.*: Phys. Lett. B **707**, 357 (2012).
5) A. Kohama *et al.*: Phys. Rev. C **72**, 024602 (2005).
6) A. Kohama *et al.*: Phys. Rev. C **78**, 0061601(R) (2008).
7) T. Inakura *et al.*: Nucl. Phys. **A710**, 261 (2002).
8) J. A. Christley *et al.*: Phys. Rev. C **59**, 2309 (1999).
9) W. Horiuchi *et al.*: Phys. Rev. C **86**, 024614 (2012).
10) H. Koura *et al.*: Prog. Theo. Phys. **113**, 305 (2005).

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