Neutron radii of Mg-isotopes and halo structure of ^{37}Mg

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Introduction

The study of density distributions of protons and neutrons in atomic nuclei play an essential role to understand the exotic phenomena such as neutron halos and neutron skin in neutron-rich nuclei. A proper understanding of the development of nuclear halo structure and nuclear skin in neutron-rich nuclei is crucial not only to determine the equation of state (EOS) of the astrophysical objects, but also important to test, validate and perfecting the nuclear models. In the past and recent, the electron scattering experiments and isotope-shift measurements are extensively used for probing the proton (charge) radii in stable nuclei, but this very approach has been utilized so far for limited short-lived unstable nuclei, thus one needs to involve other sources of measurements to extract charge radii of such nuclei.

Charge-changing cross sections and reaction (interaction) cross sections have been extensively used to probe nuclear matter radii especially for unstable nuclei. Unfortunately, no experimental data are available on CCCSs for Mg-isotopes. Therefore, one needs to involve the model-dependent proton radii in the analysis of the available reaction cross sections for Mg-isotopes.

In this study, taking the proton radii from deformed relativistic Hartree -Bogoliubov theory in continuum (DRHBc) calculations [1], we predict the neutron radii by analyzing the reaction cross sections of $^{24\text{-}38}$Mg on ^{12}C at ~ 240 MeV/nucleon in the framework of the Glauber model. The calculations involve descriptions of nuclei in terms of the Slater determinant using harmonic oscillator single particle wave functions. Moreover, we have also investigated the halo structure of ^{37}Mg.

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Formulation

According to the Glauber multiple scattering theory (GMST), the S-matrix element S_{00} describing the elastic scattering of the projectile nucleus with ground state wave function ψ_B on a target nucleus with ground state wave function ψ_A is written as

$$S_{00}(\vec{b}) = \left\langle \psi_A\psi_B \,\middle|\, \prod_{i=1}^{A}\prod_{j=1}^{B}\left[1-\Gamma_{NN}(\vec{b}-\vec{s_i}+\vec{s_j})\right] \,\middle|\, \psi_B\psi_A \right\rangle, \quad (1)$$

where, A(B) corresponds to mass number of the target(projectile) nucleus. The $\vec{s_i}$ ($\vec{s_j}$) is the projection of the target(projectile) i^{th}(j^{th}) nucleon coordinate on a plane perpendicular to the incident direction. The NN profile function Γ_{NN}related to the NN scattering amplitude f_{NN} as

$$\Gamma_{NN}(\vec{b}) = \frac{1}{2\pi ik}\int d^2q \exp(-i\vec{q}.\vec{b})\, f_{NN}(\vec{q}), \quad (2)$$

where, k is the incident nucleon momentum of projectile kinetic energy per nucleon.

Further, as outlined in Ahmad [2], the S-matrix element S_{00} with two-body density term is given by

$$S_{00}(\vec{b}) \approx S_0(\vec{b}) + S_2(\vec{b}) \quad (3)$$

The reaction (interaction) cross section is given by

$$\sigma_{I(R)} = \int d^2b[1 - |S_{00}(\vec{b})|^2] \quad (4)$$

Results and Discussion

The inputs required in the calculation are (i) the NN scattering amplitude at ~ 240 MeV/A [3], and (ii) the proton and neutron density distributions of colliding nuclei, which are constructed using the Slater determinant harmonic oscillator (SDHO) framework [4].

Table1: R_p and R_n are, respectively, the DRHBc proton and neutron radii that provide the SDHO densities by adjusting the oscillator parameters. The last column gives our predicted neutron radii.

Proj.	***R_p(fm)* [1]**	***R_n(fm)* [1]**	***R_n(fm)* Present**
^{24}Mg	2.968	2.945	3.182
^{25}Mg	2.937	2.969	3.133
^{26}Mg	2.927	3.014	3.122
^{27}Mg	3.016	3.156	3.047
^{28}Mg	3.058	3.243	
^{29}Mg	3.072	3.315	
^{30}Mg	3.090	3.375	3.208
^{31}Mg	3.089	3.419	
^{32}Mg	3.114	3.471	
^{33}Mg	3.138	3.558	
^{34}Mg	3.187	3.642	
^{35}Mg	3.208	3.701	
^{36}Mg	3.230	3.759	3.688
^{37}Mg	3.245	3.857	
^{38}Mg	3.259	3.885	

We first predict the reaction cross sections of $^{24-38}$Mg on ^{12}C at ~ 240 MeV/nucleon corresponding to proton and neutron radii as obtained using DRHBc calculations (Table 1). The results, given in Fig. 1, show that, in general, the agreement with the data [5] is quite satisfactory, providing confidence in using the DRHBc proton and neutron radii in such calculations. However, the observed discrepancy in $^{24-27,30,36}$Mg isotopes needs to reexamine their neutron radii that can reproduce the corresponding reaction cross sections. The neutron radii of $^{24-27,30,36}$Mg isotopes, obtained in this way, are also reported in Table 1.

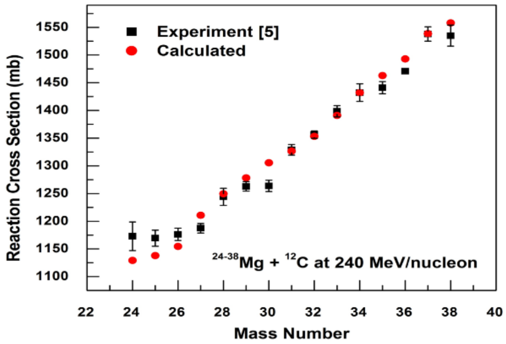

FIG. 1: The reaction cross sections of $^{24-38}$Mg isotopes on ^{12}C using DRHBc matter radii.

Finally, we have obtained the neutron distribution of ^{37}Mg involving the (core+n) model [6] and SDHO density (Fig 2). The extended neutron distribution corresponding to (core+n) model, along with its one-neutron separation energy (S_n = 0.22 MeV) and the enhanced value of σ_R, shows that ^{37}Mg is a halo nucleus.

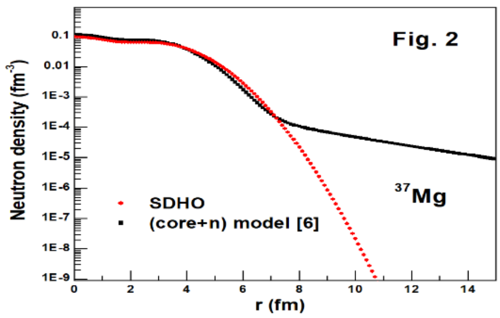

FIG. 2: Neutron distributions for ^{37}Mg using (core+n) model with SDHO density.

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