

A NEW METHOD FOR MEASURING NEUTRON-SKIN THICKNESS IN RARE ISOTOPE BEAMS*

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A new method, based on the excitation of the anti-analog giant dipole resonance (AGDR) in (p, n) reaction, for measuring the neutron-skin thickness has been tested. The γ -decay of the AGDR to the isobaric analog state (IAS) has been measured. The difference in excitation energy of the AGDR and IAS was calculated. By comparing the theoretical results with the measured one, the ΔR_{pn} value for ^{124}Sn was deduced to be 0.209 ± 0.066 fm. The present method provides a new possibility for measuring neutron-skin thickness of very exotic nuclei.

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1. Introduction

New interest in nucleon density distributions of nuclei is being prompted by the production of rare isotopes in radioactive beam facilities. To measure the neutron-skin thickness of exotic nuclei using radioactive ion beams (RIBs), it is imperative to find a feasible method that makes use of reactions with low-intensity RIBs in inverse kinematics. In this paper, we propose a new method for determining the neutron-skin thickness of a nucleus based on the measurement of the excitation energy of the anti-analog of the giant dipole resonance (AGDR), *i.e.* the $T_0 - 1$ component of the charge-exchange GDR; with T_0 denoting the ground-state isospin of the target nucleus [1].

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2. The experiment

The experiments, aimed at studying the neutron-skin thickness of ^{124}Sn , were performed at GSI using 600 MeV/nucleon ^{124}Sn relativistic heavy-ion beams on CH_2 and C targets. This allowed us to subtract the contribution of the C to the yield measured from the CH_2 target during the analysis.

The ejected neutrons were detected by a low-energy neutron-array (LENA) ToF spectrometer [2], developed in Debrecen and it was placed at 1 m from the target and covered a laboratory scattering-angle region of $65^\circ \leq \Theta_{\text{LAB}} \leq 75^\circ$.

The energy of the de-exciting γ transitions was measured in coincidence with the neutrons by six large cylindrical ($3.5'' \times 8''$) state-of-the-art LaBr_3 γ detectors. The Doppler shift was taken into account in the analysis. Precise energy and efficiency calibrations of the detectors were performed after the experiments by using different radioactive sources and (p, γ) reactions on different targets [3]. The response function of the detectors was also checked up to 17.6 MeV and could be reproduced well with GEANT Monte-Carlo simulations. The γ ray-energy spectrum measured in coincidence with the low-energy neutrons is shown in Fig. 1.

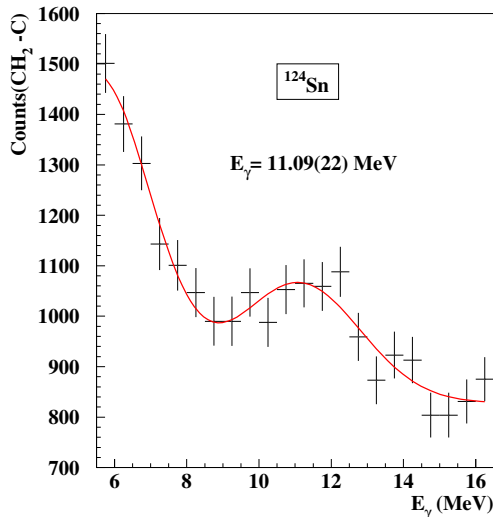


Fig.1. The γ -ray energy spectrum measured in coincidence with the low-energy neutrons that fulfilled the conditions of $1.0 \leq E_n \leq 3.5$ MeV and $67^\circ \leq \Theta_{\text{LAB}} \leq 70^\circ$, which corresponds to the excitation of the AGDR in inverse kinematics. The calibrated energy scale was corrected already for the Doppler effect. The solid line shows the result of the fit described in the text.

The width of the peak can be explained by the Doppler broadening caused by the large solid angle of the detectors. The energy distribution of the γ rays was fitted by a Lorentzian curve and a second order polynomial background. The contribution of the statistical error in the uncertainty of the position of the peak is 0.2 MeV, while the systematical error coming from the uncertainty of the energy calibration is about 0.25 MeV (2.5%), which can be improved in the future. If we take into account the E_γ^3 dependence of the γ -transition probability ($\Delta E = 0.2$ MeV), then the $E_{\text{AGDR}} - E_{\text{IAS}} = 10.89 \pm 0.32$ MeV.

The direct γ -branching ratio of the AGDR to the IAS is expected to be similar to that of the GDR to the g.s. in the parent nucleus, which can be calculated from the parameters of the GDR [4]. In contrast, the γ -decay branching ratio was in the range of 10^{-4} in the investigation of the electromagnetic decay properties of the SDR by Rodin and Dieperink [5]. Therefore, the coincidence measurements deliver a precise energy for the AGDR.

To demonstrate the accuracy of this method, we considered the available data for the AGDR for ^{124}Sn from Sterrenburg *et al.* [1] ($E(\text{AGDR}) - E(\text{IAS}) = 10.60 \pm 0.20$ MeV), but slightly increased to $E(\text{AGDR}) - E(\text{IAS}) = 10.93 \pm 0.20$ MeV in order to approximately compensate the effect of the energy shift caused by the mixing with the IVSGDR.

As the corrected energy difference taken from the literature ($E(\text{AGDR}) - E(\text{IAS}) = 10.93 \pm 0.20$ MeV) agrees very nicely with our experimental data ($E_{\text{AGDR}} - E_{\text{IAS}} = 10.89 \pm 0.32$ MeV), we can be sure that our method for determining such energy difference is correct.

3. Theoretical analysis

The theoretical analysis is performed using the fully self-consistent relativistic proton–neutron quasiparticle random-phase approximation based on the relativistic Hartree–Bogoliubov model (RHB) [6] as described previously in Ref. [7].

In Fig. 2, the resulting energy differences $E(\text{AGDR}) - E(\text{IAS})$ are plotted as a function of the corresponding neutron-skin thickness ΔR_{pn} predicted by these effective interactions.

The two parallel solid lines in Fig. 2 delineate the region of theoretical uncertainty for the used set of effective interactions. By comparing the experimental result for $E(\text{AGDR}) - E(\text{IAS})$ to the theoretical energy differences (see Fig. 2), we deduce the value of the neutron-skin thickness in ^{124}Sn : $\Delta R_{np} = 0.209 \pm 0.066$ fm (including theoretical uncertainties). The very good agreement with previously determined values [8] reinforces the expected reliability of the proposed method.

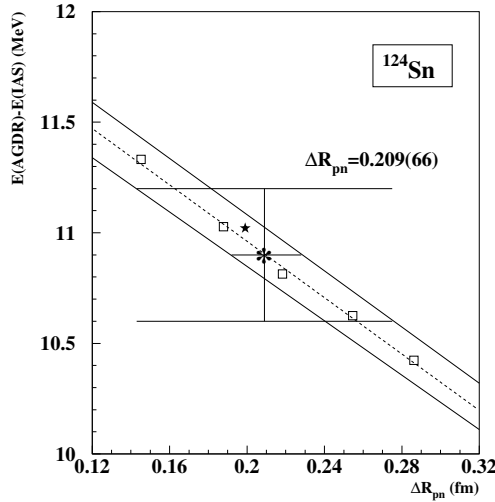


Fig. 2. The difference in the excitation energy of the AGDR and the IAS for the target nucleus ^{124}Sn , calculated with the pn -RQRPA using five relativistic effective interactions characterized by the symmetry energy at saturation $a_4 = 30, 32, 34, 36$ and 38 MeV (squares), and the interaction DD-ME2 ($a_4 = 32.3$ MeV) (star). The theoretical values $E(\text{AGDR}) - E(\text{IAS})$ are plotted as a function of the corresponding ground-state neutron-skin thickness ΔR_{pn} , and compared to the experimental value.

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