THE PYGMY DIPOLE RESONANCE IN ^{124}Sn*

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Dipole transitions in the semi-magic nucleus ^{124}Sn have been investigated by means of real photon scattering in order to complete a previous measurement. The experiment was performed at the superconducting Darmstadt electron linear accelerator S-DALINAC using an unpolarized, continuous spectrum of bremsstrahlung with an endpoint energy of approximately 7.8 MeV. A concentration of dipole transitions in the energy range between 5 and 7 MeV stemming from the pygmy dipole resonance (PDR) could be identified. Some of these states have been observed in an $(\alpha, \alpha'\gamma)$ experiment for the first time and could now be confirmed in our measurement.

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1. Introduction

Collective excitation are a common feature in strongly interacting many-body systems like the atomic nucleus. The isovector giant dipole resonance (IVGDR) is an important example of collective modes in nuclei and has been studied in great detail, see *e.g.* [1]. The IVGDR can be described in a macroscopic picture as an oscillation of the proton-fluid against the neutron-fluid [2]. Further dipole strength has been observed in neutron-rich nuclei energetically below the IVGDR [3, 4, 5, 6, 7, 8, 9, 10, 11]. This so-called pygmy dipole resonance (PDR) exhausts around 1% of the $E1$ isovector energy weighted sum rule (EWSR), while the IVGDR exhausts about 100% of the EWSR. The PDR is frequently explained in a macroscopic picture by an oscillation of a neutron skin against a proton–neutron core. The PDR has been investigated by using different methods. One method is the nuclear resonance fluorescence (NRF) method using real-photon scattering. The other method uses the $(\alpha, \alpha'\gamma)$-coincidence technique by means of α-scattering [12]. It has been shown that a combination of $(\alpha, \alpha'\gamma)$ and (γ, γ') experiments is a powerful tool to study the underlying structure of the PDR in great detail [13, 14]. In order to study the PDR in ^{124}Sn, an $(\alpha, \alpha'\gamma)$ experiment was performed by Endres *et al.* [15]. Dipole transitions have been observed for the first time, which had not been observed in a previous ^{124}Sn (γ, γ') experiment by Govaert *et al.* [16]. Therefore, the nucleus ^{124}Sn was reinvestigated using the NRF method to complete the previous measurement and to determine the missing $B(E1)\!\uparrow$ values for the newly observed states.

2. Experimental setup

The experiment was performed at the Superconducting DArmstadt LINear ACcellerator (S-DALINAC) [17]. The injector can provide electrons with energies up to 10 MeV, which were used to produce a continuous spectrum of bremsstrahlung by completely stopping the electrons in a thick copper target. In this experiment the endpoint energy was approximately 7.8 MeV. The Darmstadt high-intensity photon setup (DHIPS) is shown in figure 1 [18]. The setup provides two experimental sites, T1 and T2, which are available for NRF experiments. The second target position T2 reuses the transmitted photon beam for parity assignments using the NRF method with Compton polarimetry [19]. In this measurement the first target position T1 was used, but only two high-purity Germanium (HPGe) detectors (Det1 at $\theta = 90^\circ$ and Det2 at $\theta = 130^\circ$) were installed. Both detectors were shielded by an active bismuth germanate (BGO) anti-Compton shield and they were passively shielded against low-energy photons by lead and copper absorbers.

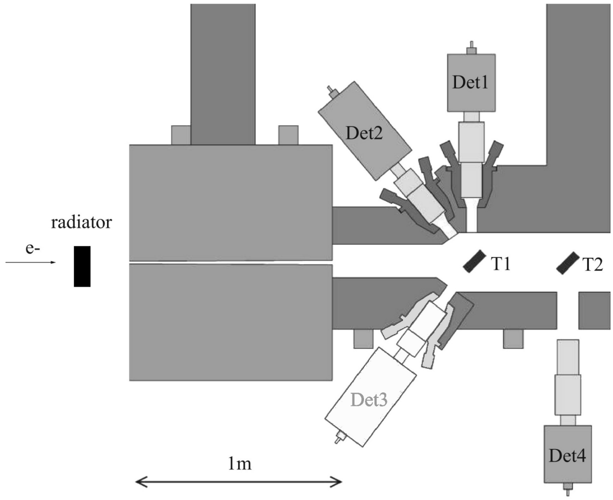

Fig. 1. The Darmstadt high-intensity photon setup [18]. The electrons are stopped in the copper radiator to produce a continuous, unpolarized spectrum of bremsstrahlung. The first target position was used for this experiment.

3. Data analysis

Just a short summary of the analysis of NRF experiments will be given, for more details see, *e.g.* Ref. [20]. In figure 2 the obtained spectrum for Det2 is shown. Few peaks are stemming from ^{11}B which was included in the target to be used for an energy dependent photon flux calibration. The integrated

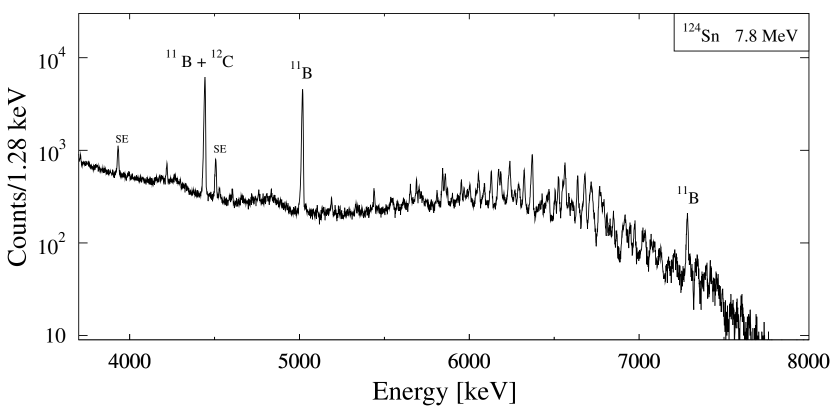

Fig. 2. The NRF spectrum from Det2 is shown for ^{124}Sn taken with bremsstrahlung with an endpoint energy of 7.8 MeV. The peaks marked with ^{11}B are stemming from the sandwich target and were used for the photon flux calibration.

cross section I_0 of a transition to the ground state could be calculated from the observed peak area $A_{i\to 0}$ using

$$I_0 = \frac{A_{i\to 0}}{N_{\mathrm{T}}\, N_\gamma(E_i)\, \epsilon(E_i)\, \Delta\Omega\, W_{\mathrm{eff}}^{0\to i\to 0}(\theta, \Delta\Omega)}\,, \tag{1}$$

where N_{T} is the number of target nuclei, N_γ is the total number of the photons and $W_{\mathrm{eff}}^{0\to i\to 0}(\theta, \Delta\Omega)$ denotes the angular distribution, where θ represents the angle between the incoming and the scattered photon and the solid angle is represented by $\Delta\Omega$. The absolute detector efficiency $\epsilon(E_i)$ was determined with calibration sources up to 3.5 MeV and extrapolated to high energies using a GEANT4 simulation [21]. The photon flux was also simulated with GEANT4 and, in addition, the product $N_\gamma\, \epsilon$ was determined using the well-known transitions in ^{11}B. The elastic transition strength Γ_0^2/Γ can be determined from the integrated cross section I_0 using the equation

$$I_0 = g\,\pi^2 \left(\frac{\hbar c}{E_x}\right)^2 \frac{\Gamma_0^2}{\Gamma}\,, \tag{2}$$

where g represents the spin factor $g = \frac{2J+1}{2J_0+1}$. In this work, only the results for the $J = 1$ states are presented, *i.e.* $g = 3$. In the case of known branching ratios Γ_0/Γ and the parity of the states, the reduced transition probability $B(E1)\!\uparrow$ can be determined by

$$B(E1)\!\uparrow = 2.866 \times 10^{-3}\, \frac{\Gamma_0}{E_\gamma^3}\, \left[e^2\mathrm{fm}^2\right]. \tag{3}$$

The observed values for the elastic transition strength Γ_0^2/Γ have not been corrected for feeding from higher-lying states. However, for the majority of the states above 5–6 MeV the influence on the transition strengths due to feeding is negligible since only states up to 7.8 MeV are excited. In general, energetically low-lying states can be investigated by decreasing the endpoint energy E_0. Thereby, feeding transitions are strongly suppressed, see *e.g.* Ref. [22]. The results for the transition strengths Γ_0^2/Γ of our experiment are shown in figure 3 and compared to the results of Govaert *et al.* [16]. Due to the highly increased sensitivity of the new NRF setup using active BGO anti-Compton shields, we have observed many more states, especially in the energy region below 6 MeV compared to the previous experiment and, in particular, the states which were observed for the first time in [15] could also be determined in this experiment.

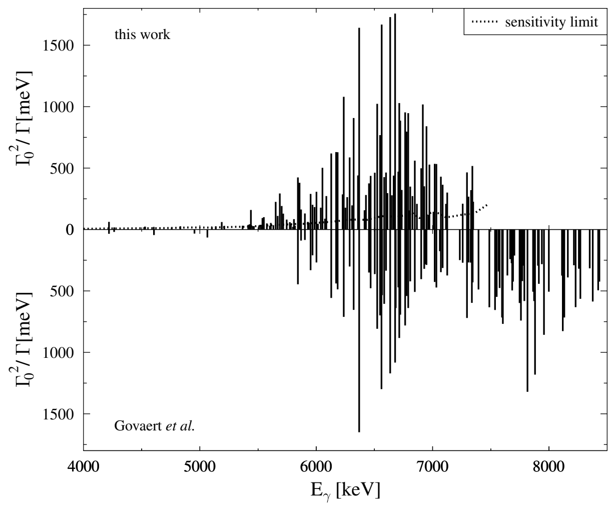

Fig. 3. Comparison of the results of this experiment for the transition widths with the results of the experiment by Govaert *et al.* [16]. The dotted line in the upper panel indicates the sensitivity limit of the new data.

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