

STUDY OF DIPOLE EXCITATIONS IN ^{124}Sn VIA $(p, p'\gamma)$ AT 15 MeV*

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An inelastic proton scattering experiment was performed with the combined setup SONIC@HORUS at a beam energy of 15 MeV in Cologne. First results for the deduced branching ratios as well as the E1 strength distribution obtained with the $^{124}\text{Sn}(p, p'\gamma)$ reaction are presented. Additionally, a qualitative comparison to excitations in experiments with different probes like $(\alpha, \alpha'\gamma)$ and (γ, γ') will be discussed.

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1. Introduction

During the last century, various experimental techniques, using stable and radioactive ion beams, have been developed to investigate nuclei over the whole chart of nuclides. While radioactive ion beam facilities enable the study of exotic nuclides, stable ion beams are still indispensable to provide the possibility for detailed studies of nuclear structure.

The electric dipole response of a nucleus exhibits different excitation modes [1–4]: The quadrupole–octupole phonon coupled 1^- states at low energies, the pygmy dipole resonance (PDR) around the neutron separation energy S_n , and the giant dipole resonance (GDR) at higher energies. Theoretical calculations, involving, *e.g.* the relativistic quasi-particle random-phase approximation (RQTBA), revealed the dominant isoscalar character of the PDR in contrast to the isovector (IV) character of the GDR [1, 4]. In a macroscopic interpretation, these can be pictured as an oscillation of

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the neutron skin, emerging from the neutron excess, against the isospin saturated core (PDR) and as an oscillation of all neutrons against all protons (IVGDR) [1], respectively.

The Nuclear Resonance Fluorescence (NRF) method [2] is an ideal tool to explore these excitations due to its high selectivity for dipole excitations. A (γ, γ') measurement on ^{124}Sn was already performed by Govaert *et al.* [5] using bremsstrahlung and reduced transition widths were extracted although branching ratios could not be studied. Therefore, branching ratios are needed to correct $B(E1)$ values from NRF experiments [1]. Additionally, the decay behaviour is an important observable for probing the overlap of the two involved wave functions.

In order to study the response of the PDR to different excitation mechanisms, measurements with different probes are performed [1]. Apart from the already mentioned (γ, γ') experiment, inelastic scattering with α -particles [6] and ^{17}O -ions [7] was already performed at beam energies of 136 MeV and 340 MeV, respectively. A comparison of the different excitation patterns revealed a difference in the excitation behaviour. In agreement with theory, this so-called isospin splitting is assumed to be correspondent to the isoscalar PDR and the low-energy tail of the isovector GDR [8]. Similar observations were made in the $N = 82$ isotones ^{138}Ba [9, 10] and ^{140}Ce [9–11]. To extend this systematic study concerning the structure of Sn isotopes and the mentioned isospin splitting, an inelastic proton scattering experiment was performed at $E_p = 15$ MeV detecting the scattered proton and the emitted γ rays in coincidence.

2. Experiment

The $^{124}\text{Sn}(p, p'\gamma)$ experiment was performed at the combined Cologne setup SONIC@HORUS [12], consisting of 12 silicon detectors and up to 14 High-Purity Germanium (HPGe) detectors. The 15 MeV proton beam was provided by the 10 MV FN-Tandem accelerator in Cologne and impinged on a 0.37 mg/cm^2 thick ^{124}Sn target. For this measurement, the coincidence technique was used yielding energy information of both the scattered protons and the subsequent de-exciting γ rays. The scattered protons were detected by the silicon detectors which are installed in the target chamber SONIC [12] at angles of 107° , 123° and 145° . The γ rays were detected with the γ -ray spectrometer HORUS [13]. For the analysis, 11 silicon detectors and 13 HPGe detectors were used. Detailed information about this combined setup can be found in [12].

3. First results

Up to 168 Si-HPGe detector combinations can be analysed with the combined setup SONIC@HORUS. The resulting proton- γ coincidence matrix for

the $^{124}\text{Sn}(p, p'\gamma)$ reaction is shown in Fig. 1. The excitation energy E_X is correlated with the energy of the ejectile $E_{p'}$ by the relation $E_p - E_{p'} \approx E_X$, where E_p is the beam energy. Since the silicon detectors under 145° are not able to stop high energetic protons completely, a broad pattern appears between 2 MeV and 4 MeV. The excitation band at approximately $E_X = 7$ MeV stems from carbon contaminations. The diagonal band structure of the ground state as well as the first and second excited state are also visible. By applying the corresponding diagonal gate, transitions to a particular final state can be selected.

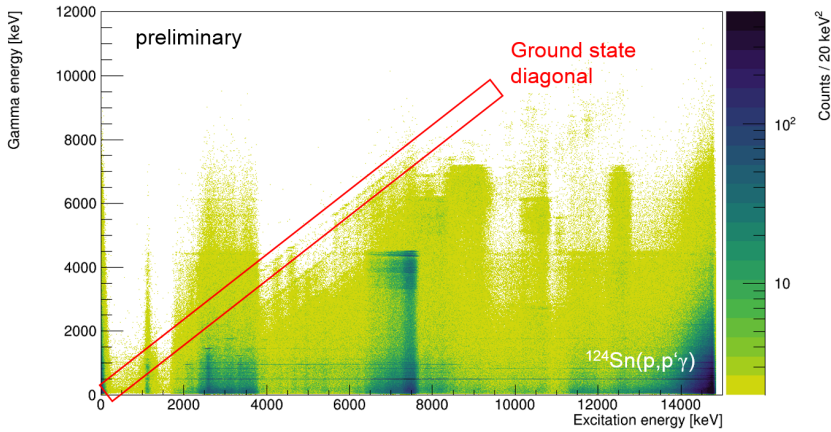


Fig. 1. The p - γ coincidence matrix for ^{124}Sn HPGe detector combinations in bins of $10 \times 2 \text{ keV}^2$. A correction for the time-background was not applied for the presented matrix. See the text for details.

3.1. Branching ratios

The branching $\Gamma_i/\Gamma_{0_1^+}$ of a state can be studied by analysing its decays to the first excited states i relative to its ground-state decay. In the left panel of Fig. 2, the branching of several states to the 2_1^+ state in ^{124}Sn is illustrated. Branching ratios from $J_i^\pi = 2_i^+$ states are compared to previous measurements on ^{124}Sn , namely an $(n, n'\gamma)$ experiment from Demidov and Mikhailov [14] and an $(\alpha, \alpha'\gamma)$ experiment from Spieker *et al.* [15]. The new values are in a very good agreement with the $(n, n'\gamma)$ data. For the 2^+ state at 3762 keV, the obtained branching ratio deviates from the $(n, n'\gamma)$ – $(\alpha, \alpha'\gamma)$ agreement, however, two higher-lying states exist whose $(p, p'\gamma)$ data are consistent with the literature values. The right panel in Fig. 2 shows the results for the $J = 1$ states that were observed by Govaert *et al.* [5] and Demidov and Mikhailov [14]. For the state at 3697 keV, the branching ratio of the $(n, n'\gamma)$ and the $(p, p'\gamma)$ measurement is not consistent.

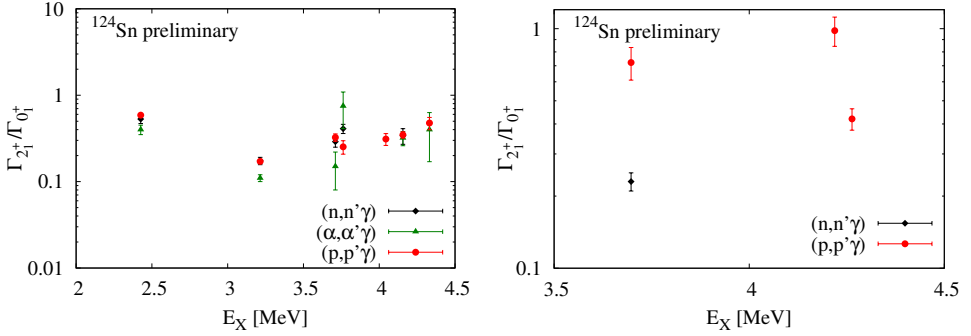


Fig. 2. Branching to the first excited 2^+ state at 1132 keV in ^{124}Sn relative to the ground state transition. The left diagram shows the comparison between the results from the $^{124}\text{Sn}(p,p'\gamma)$ analysis and previous measurements on ^{124}Sn for quadrupole excitations. The right figure illustrates the branching ratios for dipole transitions. The $(n,n'\gamma)$ data are taken from Demidov and Mikhailov [14] and the $(\alpha,\alpha'\gamma)$ data are obtained by Spieker *et al.* [15]. See the text for details.

In total, eight branching ratios are observed for the first time. Apart from transitions to the 2^+_1 state, transitions to higher-lying excited states were observed, too. Their branching ratios relative to the ground state are depicted in Fig. 3. All five branchings were observed for the first time.

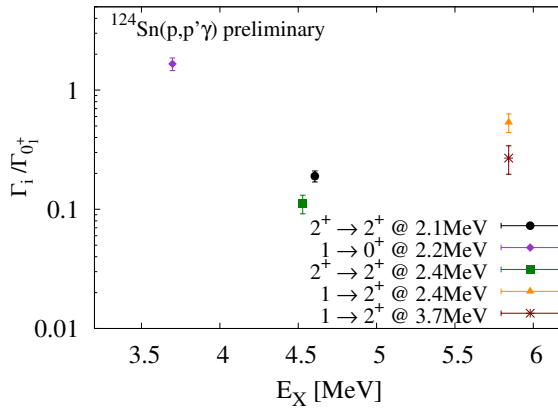


Fig. 3. Branching ratios for the decay to low-lying 2^+ states and the second 0^+ state in ^{124}Sn . No literature values are presently available.

3.2. Excitation response

In the $(p,p'\gamma)$ experiment presented here, the focus is set on low-lying $J = 1$ states. A projection of the ground state diagonal in the PDR region is depicted in Fig. 4 (upper panel). In the energy regions below 5 MeV and

between 6 MeV and 7 MeV, many $J = 1$ states can be identified. Additionally, Fig. 4 shows the E1 response measured with the inelastic α -particle scattering at $E_\alpha = 136$ MeV [7] (middle panel) and with the NRF experiment using bremsstrahlung [5] (lower panel). Due to the similar excitation pattern of the inelastic α -particle and ^{17}O scattering, the results of only one of the mentioned reactions are depicted here. The results of the $^{124}\text{Sn}(^{17}\text{O}, ^{17}\text{O}'\gamma)$ experiment can be found in [7]. As for the $(\alpha, \alpha'\gamma)$ and (γ, γ') experiment, an accumulation of states below 7 MeV is visible in the ground state diagonal spectrum of the presented $(p, p'\gamma)$ measurement. However, above 7 MeV, the excitation probability seems to be low. This excitation pattern is rather in resemblance with the inelastic α -particle scattering than with the (γ, γ') experiment, hence indicating an isospin splitting.

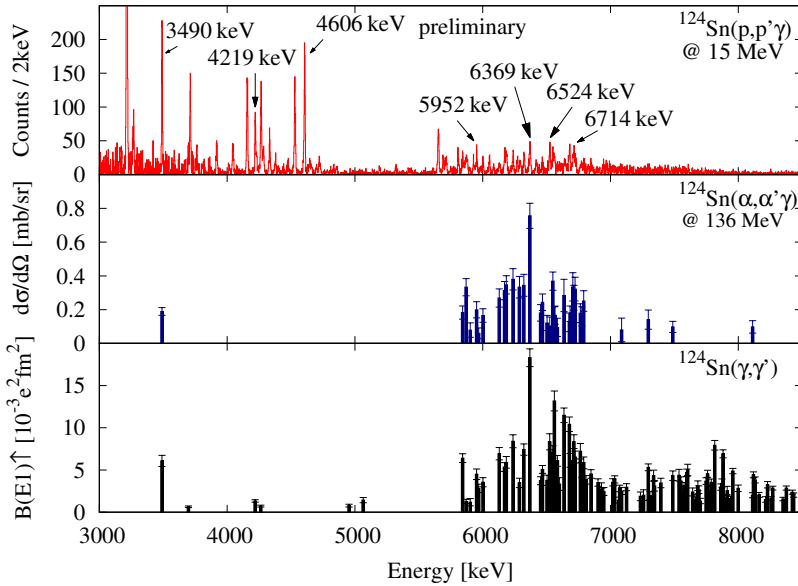


Fig. 4. The projected ground state diagonal of $^{124}\text{Sn}(p, p'\gamma)$, corrected for the time-background, is depicted in the upper panel. Some strong transitions are marked and belong to dipole excitations in ^{124}Sn . In comparison, the E1 response observed in the $^{124}\text{Sn}(\alpha, \alpha'\gamma)$ [6] (middle panel) and $^{124}\text{Sn}(\gamma, \gamma')$ [5] (lower panel) reactions are shown. See the text for details.

4. Conclusions and outlook

In this proceeding, the preliminary results of the $^{124}\text{Sn}(p, p'\gamma)$ reaction, performed at an energy of 15 MeV, are presented. Branching ratios as well as the ground state diagonal spectrum are shown. In total, 15 branching ratios were determined, eight of them for the first time. Except for the $J = 1$ state

at 3697 keV, the branching ratios of the low-energy states analysed here agree with the literature values obtained from the $^{124}\text{Sn}(n, n'\gamma)$ experiment by Demidov and Mikhailov [14] and from the $(\alpha, \alpha'\gamma)$ measurement performed by Spieker *et al.* [15].

The qualitative comparison of the excitation response of the inelastic proton scattering to the (γ, γ') experiments suggests an isospin splitting. This pattern supports the isoscalar excitation mechanism of the proton which seems, at first appearance, to be similar to the excitation mechanism of α -particles and ^{17}O -ions at significantly higher beam energies.

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