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The statistical properties of ^{111,112,113}Sn studied with the Oslo method

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Abstract. The γ-ray strength function and level density of ^{111,112,113}Sn are being studied at the Oslo Cyclotron Laboratory (OCL) up to the neutron binding energy by applying the Oslo method to particle-γ coincidence data. The preliminary results for the γ-ray strength function are discussed in the context of the results for the more neutron-rich Sn-isotopes previously studied at OCL.

1 Introduction

The level density (LD) as a function of excitation energy is a fruitful concept for describing the nuclear structure of atomic nuclei in the quasi-continuum and above while the average electromagnetic decay properties of the nucleus are described by the γ-strength function (GSF). Additional strength for the γ-ray energies lying in the region 5-8 MeV has been observed for several nuclei [1]. This strength is called pygmy dipole resonance (PDR) and the dependence of the properties of the pygmy resonance on the neutron number has been investigated at the Oslo cyclotron laboratory (OCL) previously for $^{116-119,121,122}$Sn [2]. The physical origin of the PDR is not fully understood yet. Possible theoretical explanations are described in Refs. [3-4]. In this work we aim to extract experimental GSF and LD of the ^{111,112,113}Sn nuclei. Such a study is expected to shed light on the question of the origin of the pygmy resonance in the Sn-isotopes. The level densities of the Sn-isotopes have revealed interesting features related to pairing of nucleons and entropy [5].

The Oslo method [6-9] is an experimental method that allows for the extraction of both the LD and γ-ray strength function from the same particle-γ coincidence data. In this work the preliminary results for the isotopes ^{111,112,113}Sn are presented.

2 Experimental details

The experiments were carried out at the Oslo Cyclotron Laboratory (OCL) with proton and deuteron induced reactions on a self-supporting 99.8% enriched ^{112}Sn-foil of 4 mg/cm^2 thickness. The energy and angle relative to the beam axis of the charged particles emitted from the reactions were detected with the particle telescope system SiRi [10]. SiRi consists of thin Si-strips in the front and thick pads at the back providing separation between protons, deuterons and tritons. The signals from the back detectors are used as triggers for the data-acquisition. In coincidence with the particles, γ rays are measured in the CACTUS [11] NaI-scintillator array. SiRi was mounted in the backwards angles with respect to the beam direction in the experiments reported upon here, covering the angles 126° ≤ θ ≤ 140°. The details of the reactions of interest in this work are given in Table 1.

Table 1. Reaction details.

Reaction of interest	Beam energy
^{112}Sn(p,p'γ)^{112}Sn	16 MeV
^{112}Sn(p,dγ)^{111}Sn	25 MeV
^{112}Sn(d,pγ)^{113}Sn	11.5 MeV

2.1 The Oslo method

The reaction channel of interest is selected by the ΔE-E technique. The excitation energy is calculated from the total deposited energy and plotted together with the prompt γ rays that correspond to the channel of interest to give a particle-γ matrix. The γ-ray spectra are then unfolded, for every excitation energy bin, with the response function of the NaI-detectors of CACTUS [6].

The starting point of the Oslo method is the unfolded γ-particle coincidence matrix. The unfolded matrix, for the case of ^{112}Sn is shown in Fig. 1.

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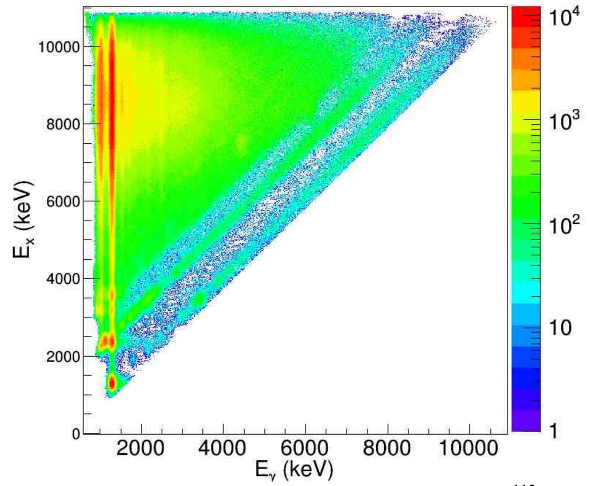

Figure 1: The unfolded particle-gamma matrix for ^{112}Sn.

It is the first γ rays emitted in the cascades that are of primary interest. The primary γ ray spectra are obtained by an iterative subtraction technique where the spectra for lower excitation energy bins are subtracted iteratively to obtain the first-generation spectra at each excitation energy bin [7].

The following step of the Oslo method is to assume that the probability of a γ decay from an initial excitation energy E_x to a final energy E_f by a γ ray with the energy $E_\gamma = E_x - E_f$ is proportional to the LD at the final excitation energy $\rho(E_x - E_\gamma)$ and a transmission coefficient $T(E_\gamma)$. This justifies the factorization of the normalized first-generation matrix, $P(E_\gamma,E_x)$, according to:

$$P(E_\gamma,E_x) \propto T(E_\gamma)\rho(E_x - E_\gamma) \quad . \qquad (1)$$

The separation of functions in Eq. (1) is based upon the assumption that the nucleus reaches a compound state after excitation, and that the manner of the subsequent γ decay is mainly statistical and independent of how the state was formed. Finally, the GSF, $f(E_\gamma)$, is calculated as $f(E_\gamma) = T(E_\gamma)/2\pi(E_\gamma)^3$ assuming that $L = 1$ is the dominant multipolarity for transitions in the quasicontinuum. $T(E_\gamma)$ being independent of E_x is in accordance with the Brink hypothesis [12].

The LD and $T(E_\gamma)$ are extracted by a χ^2-miNucl. Instr. Meth.izing the product $T(E_\gamma)\rho(E_x - E_\gamma)$ with respect to the normalized first-generation matrix as described in Ref. [8]. This procedure provides the functional form of the LD and $T(E_\gamma)$. It has been shown in [8] that one may construct an infinite number of functions that fit equally well with $P(E_\gamma,E_x)$ and hence one must normalize the functions to other measurements. We use the LD at low excitation energy where we can count the number of levels and the LD at the neutron binding energy, S_n, derived from the average resonance spacing, D_0, to normalize the LD and the slope of the GSF. Furthermore, the magnitude of the absolute strength of the GSF can be determined from the average radiative width, $<G_0>$, measured at S_n.

3 Results

The first-generation matrices are shown in Fig. 2. In the case of ^{111,113}Sn the data for Ex > 5000 keV are included in what follows, while for ^{112}Sn only data for E_x > 6300 keV could be included. For all three data sets E_γ > 1500 keV is set as the lower limit.

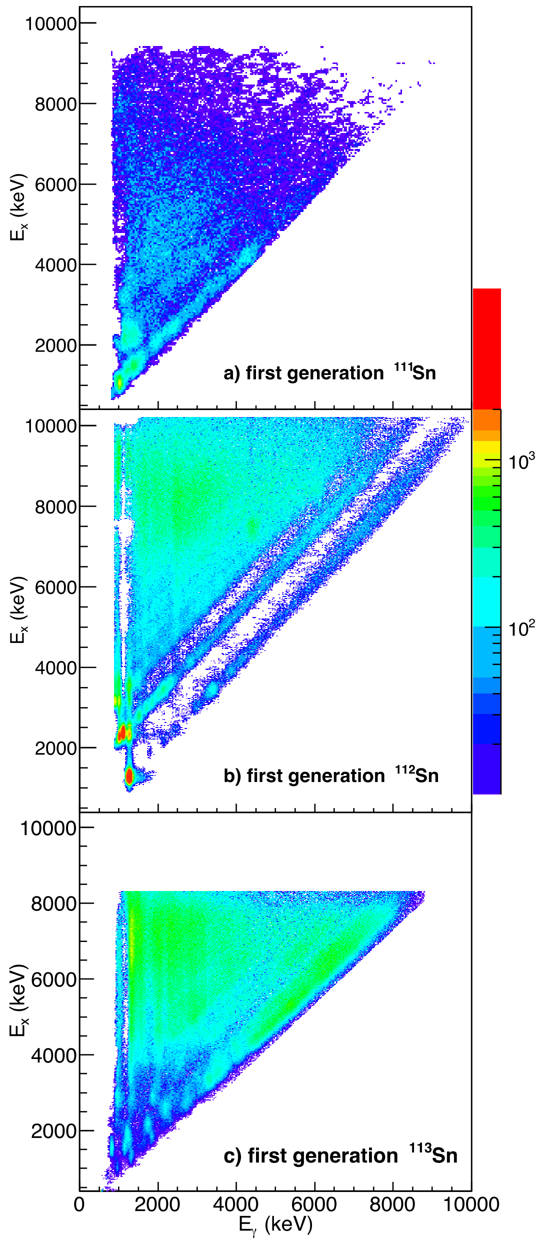

Figure 2: First-generation spectra for a) ^{111}Sn b) ^{112}Sn and c) ^{113}Sn.

In the case of ^{113}Sn, the experimental values for D_0 and G_0 that are needed for normalization are available in Ref. [13]. For ^{111,112}Sn these values have been estimated from systematics for the Sn-isotope chain. The preliminary LD results for ^{111,112,113}Sn are shown in Fig. 3. The preliminary results for the LDs indicate that a constant-temperature LD curve is well suited to describe the data above $E_x \approx 3$ MeV [14]. The spin cutoff parameter, σ, ranges from 3.84-6.2 depending on the choice of model for spin cutoff giving an uncertainty in the normalization.

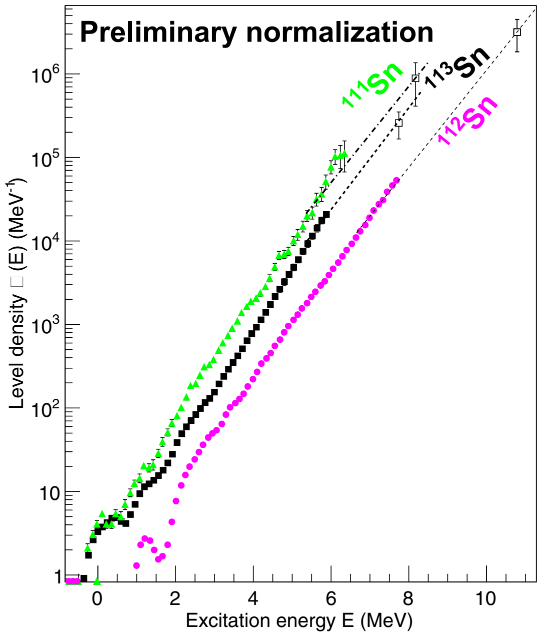

Figure 3: Level densities for $^{111, 112, 113}$Sn with preliminary normalization.

The preliminary GSFs for $^{111, 112, 113}$Sn are presented in Fig. 4. As expected, the GSFs of the three isotopes are rather similar in strength. Photo-neutron data for $E_x > S_n$ are available for several Sn-isotopes, where the lightest is ^{116}Sn.

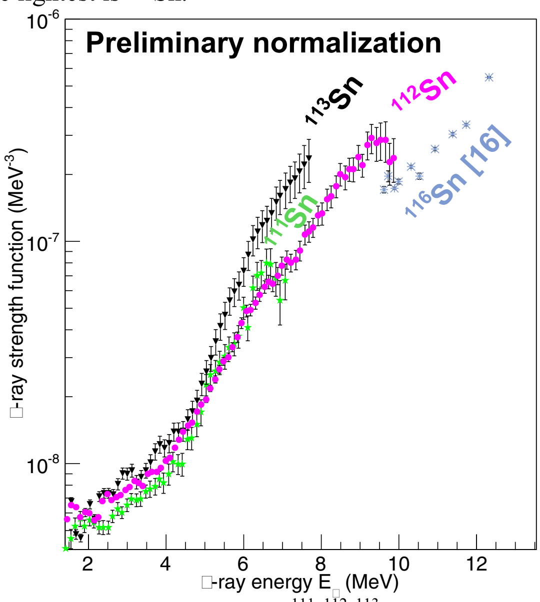

Figure 4: Preliminary GSFs for $^{111, 112, 113}$Sn plotted together with the GSF calculated from the ^{116}Sn(γ,n) data in Ref. [16].

4 Outlooks

The normalization of the data is in progress and will be improved upon. The properties of the PDRs in quasi-continuum of ^{111,112,113}Sn will be extracted.

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