Nuclear Level Density of ^{115}Sn from neutron evaporation

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Introduction

The nuclear level density (NLD) defined as the number of accessible states in a given nucleus at a given excitation energy is the most critical input of the statistical model (SM) calculations of compound nuclear reactions. The SMs play an important role in the cross-section calculations in different areas of nuclear science such as nuclear astrophysics, reactor technology, *etc*. Apart from being the most critical input of the SM calculations, the NLD is of fundamental interest as it provides crucial information on the structure and statistical properties of atomic nuclei. The behavior of the nuclear level density as a function of neutron and proton number (iso-spin dependence) is an open question [1]. It has been suggested that the level density should depend on both the proton (Z) and neutron (N) numbers rather than simply on the mass number (A) [1].

In recent times, the NLDs of the different Sn isotopes (^{116,117,118,119}Sn) have been measured below the particle separation energy using the so-called Oslo Method [2,3]. The measured NLD in most of the cases (^{116,117,119}Sn) showed interesting step-like structures that could be a signature of the subsequent breaking of nucleonic pairs. It would be interesting to extend the investigation to other neutron-deficient Sn isotopes for which experimental data in a wide energy range are unavailable. In the present paper, we report the measurement of the NLD of ^{115}Sn in an excitation energy range of 5 – 13 MeV from the measurement of the neutron evaporation spectra using the ^{115}In(p,n)^{115}Sn reaction. The particle evaporation technique has been extensively used at VECC in recent time to understand the shell, collective and angular momentum effects on NLD [4-6]. The new NLD results of the neutron-deficient ^{115}Sn will be useful to understand the isospin dependence of NLD in a systematic manner.

Experimental details

The experiment has been performed using the 12 MeV proton beam from the K130 cyclotron at VECC, Kolkata. A self-supporting foil of ^{115}In (thickness ~1 mg/cm^2) was used as the target. The compound nucleus ^{116}Sn* (p + ^{115}In) was populated at the excitation energy of E^*~21.2 MeV. The neutrons emitted during the compound nuclear evaporation process were detected using seven liquid scintillator (EJ-301) based neutron detectors (size: 5″×5″) placed at the laboratory angles of 35°, 55°, 85°, 105°, 120°, 140°, 155° at a distance of 1.5 m from the target. The neutron kinetic energies were measured using the time-of-flight (TOF) technique. The start trigger for the TOF measurement was generated using the low energy γ-rays detected by a 50-element BaF$_2$ detector array placed near the target position. The prompt γ-γ peak in the TOF spectrum was taken as the time reference. The efficiencies of the neutron detectors were measured in the in-beam condition using a ~35μCi ^{252}Cf source. Neutron-γ discrimination was achieved by both the TOF and pulse shape measurements (PSD). The scattered neutron contributions in the measured neutron spectra were estimated and subtracted using the “shadow bar” technique.

Results and discussions

The experimental neutron kinetic energy spectra measured at various laboratory angles have been converted to the centre-of-mass (c.m.) frame. The neutron angular distribution in the c.m. frame for the p + ^{115}In reaction at the proton energy of 12 MeV is shown in the inset of Fig. 1. The angular distribution was fitted with the phenomenological Kalbach formula [7],

$$\sigma(\theta) = C\{\exp(a_d \cos\theta) + R[\exp(a_c \cos\theta) + \exp(-a_c \cos\theta)]\} \qquad (1)$$

The first term in Eq. (1) describes the forward peaked (direct) component and the second one with the relative contribution R is related to the symmetric part (compound) of the angular distribution. Parameters a_d and a_c describe the steepness of the slope for both direct and compound components, respectively. From the phenomenological fit of the neutron angular distribution, it was found that the non-compound fraction for the ^{115}In(p,n)^{115}Sn reaction is about 25% in the whole angular range. However, the spectra at the backward angles are mostly contributed from the compound nuclear process. The neutron energy spectrum measured at θ_{lab}=155° is shown in Fig. 1 by closed circles. The experimental data were compared with the statistical Hauser-Feshbach (HF) calculation (shown by the continuous line in Fig. 1). In the HF calculation, the NLD (ρ) is evaluated using the back-shifted Fermi gas (BSFG) expression [8]. The shell effect in NLD was incorporated using an excitation energy and shell correction dependent parameterization of the level density parameter (*a*) as suggested by Ignatyuk *et al.* [9]. The asymptotic value of the shell corrected level density parameter ($\tilde{a}$) was tuned to match the high energy (slope) part of the experimental spectrum. The detailed computational method of the HF calculation has been described in Ref. [10].

The “experimental” level densities $\rho_{exp}(E)$ were extracted using the following relation [11]

$$\rho_{\exp}(E) = \rho_{\mathrm{model}}(E)\frac{(d\sigma/dE)_{\exp}}{(d\sigma/dE)_{\mathrm{model}}} \qquad (2)$$

Here $(d\sigma/dE)_{exp}$ is the experimental differential cross section and $(d\sigma/dE)_{model}$ is the differential cross section calculated by the HF calculation using $\rho(E)_{model}$ as its input level density. The $\rho(E)_{exp}$ cannot be obtained in absolute units from Eq. (2) alone because the ratio of $(d\sigma/dE)_{exp}/(d\sigma/dE)_{model}$ depends not only on the ratio $\rho(E)_{exp}/\rho(E)_{model}$, but also on the competition with other decay channels.

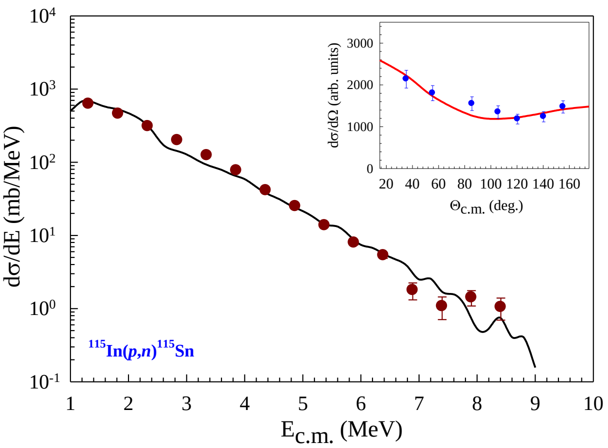

Fig. 1 Measured neutron spectrum (closed circles) alongwith statistical HF calculation (solid line). (Inset) The measured neutron angular distribution (closed circles) and the phenomenological fit (see text).

However, in the present case the compound nucleus ^{116}Sn decays predominately (>95%) through 1*n* emission channel populating ^{115}Sn as the residual nucleus. The contributions of the other decay channels are insignificant. In any case, to get the absolute experimental level densities from Eq. (2), the data were renormalized to $\rho(S_n)$. Here, $\rho(S_n)$ is the level density at the neutron separation energy, which is determined from the measured s-wave neutron resonance spacing (D_0) [12]. The measured level densities for ^{115}Sn in the excitation energy range of ~5 – 13 MeV is shown in Fig. 2. The density of discrete levels obtained from the experimental energy levels [12] of ^{115}Sn is also plotted in Fig 2. The experimental level densities measured in this work were compared with the results of the microscopic Hartree-Fock-Bogoliubov (HFB) plus combinatorial model calculation of S. Goriely *et al.* [13]. The experimental result was found to be in reasonable agreement with the HFB calculations (shown by the dashed line in Fig 2).

The experimental details and the physical implications of the results will be presented during the symposium.

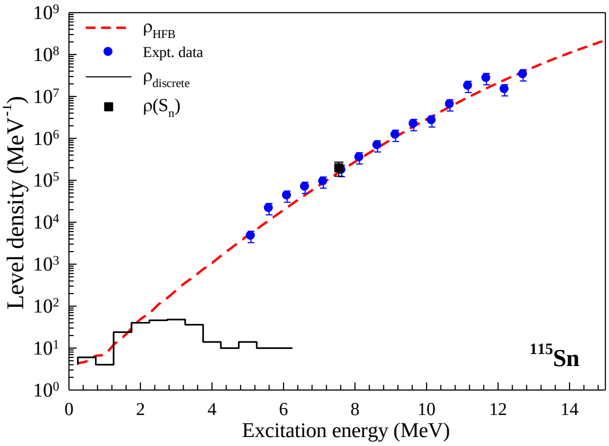

Fig. 2 The experimental level density (closed circles) at different excitation energies for ^{115}Sn. The density of the discrete levels (Ref. 12) is shown by the continues (black) line. The level density from neutron resonance data $\rho(S_n)$ is shown by the filled square. The result of the HFB calculation (Ref. 13) is shown by the dashed (red) line.

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