Measurement of 2_1^+ level lifetime in ^{120}Sn by DSAM

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Introduction

There has been a considerable interest focused on the study of enhancement or suppression in collectivity of the excited 2_1^+ states in the stable even-mass $^{112-124}$Sn isotopes. The transition probabilities, $B(E2; 0^+_{\rm g.s.} \rightarrow 2_1^+)$, have been consolidated from several measurements into the adopted values by Raman *et al.* [1]. Independent measurements of Coulomb excitation cross sections and 2_1^+ level-lifetimes report discrepant values; estimates for 2_1^+ lifetime [2] indicate reduced collectivity. It may be mentioned that the lifetime analysis for ^{118,120,124}Sn in Ref. [2] employed a natural Sn target covered by a front layer of natural Pd, with γ-rays detected in coincidence with projectiles backscattered from both Sn and Pd foils. Since the 2_1^+ excitation energies in the neighbouring Sn isotopes are closely spaced, a demerit of this choice of target is an apparent overlap between the Doppler broadened high-energy tail of the lineshapes, particularly as seen for ^{120,122,124}Sn in Ref. [2]. Additionally, there could be contaminant γ energies from the Pd layer buried under the lineshapes from the Sn nuclei, e.g., the decay of long-lived levels in ^{106,108,110}Pd. In order to address this discrepancy, particularly for the most abundant ^{120}Sn isotope, a re-examination of the 2_1^+ lifetime, using updated techniques, is warranted. The exercise is also expected to facilitate concluding on the $B(E2, 0^+_{\rm g.s.} \rightarrow 2_1^+)$ value determined therefrom.

Experimental details

Low-lying 2_1^+ level ($E_{\rm x}$ = 1171 keV) in the vibrational ^{120}Sn nucleus have been excited by inelastic scattering with ^{32}S beam at $E_{\rm lab}$=120 MeV, at BARC-TIFR Pelletron facility, Mumbai. The target comprised an enriched ^{120}Sn foil of thickness $\approx$ 6.4 mg/cm^2, with a ^{197}Au backing of thickness $\approx$ 6.2 mg/cm^2. The excitation is predominantly mediated by the Coulomb interaction between the colliding nuclei. Emitted γ-rays from the recoiling ^{120}Sn nuclei are detected using a segment of the Indian National Gamma Array (INGA), with 11 Compton-suppressed segmented clover HPGe detectors, mounted at a distance of 25 cm from the target center. The clovers are distributed w.r.t. the beam direction at $\theta = 90^{\rm o}$ (three at $\phi = 60^{\rm o}$,$120^{\rm o}$,$300^{\rm o}$), $\theta = 115^{\rm o}$ (two at $\phi = 90^{\rm o}$, $330^{\rm o}$), $\theta = 140^{\rm o}$ (three at $\phi = 0^{\rm o}$, $120^{\rm o}$, $240^{\rm o}$) and $\theta = 157^{\rm o}$ (three at $\phi = 60^{\rm o}$, $180^{\rm o}$, $300^{\rm o}$).

Analysis

Level-lifetime measurements are carried out using the Doppler Shift Attenuation Method (DSAM). The recoiling ^{120}Sn nuclei, in relative motion w.r.t. the detectors, emit γ-rays in-flight, which exhibit Doppler effect. Owing to inelastic scattering of ^{120}Sn recoils with a wide angular coverage as permitted by two body kinematics (see Fig. 1), each HPGe detector recorded an inclusive decay spectrum for scattering at all possible recoil directions. The heavy ^{32}S beam facilitated large excitation probability of the target, with substantial recoil velocity ($\beta \approx 2\%$) of the scattered nuclei, which manifests into larger Doppler broadening of the emitted gamma rays as shown in Fig. 2.

Lifetime analysis of the 2_1^+ state has been carried out using the developments by Das *et al.* [3] in conjunction with the LINESHAPE [4] package. Additional considerations consequent to the use of thick target are imbibed. The cross

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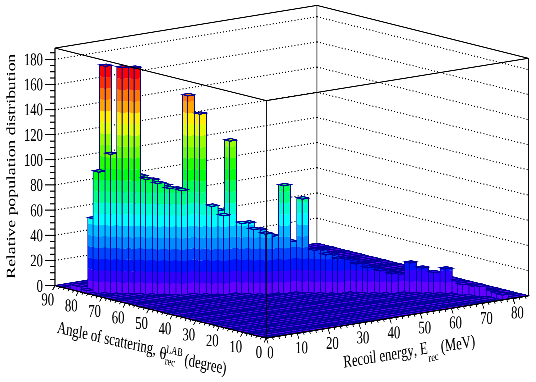

FIG. 1: CRC calculation of relative population distribution of the scattered ^{120}Sn recoils in their 2_1^+ state as a function of laboratory scattering angle $\theta_{\rm rec}^{\rm LAB}$ and kinetic energy $E_{\rm rec}$, at $E_{\rm lab}$ = 120 MeV.

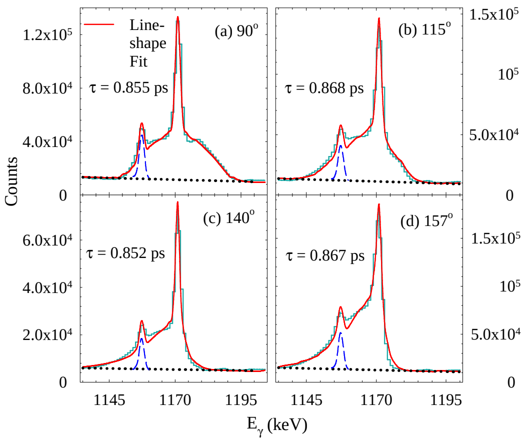

FIG. 2: Experimental Doppler broadened γ spectra and the results of the LINESHAPE calculations (solid lines) for the $2_1^+ \to 0_{\rm g.s.}^+$ decay in ^{120}Sn, at E_x = 1171 keV. The dashed lines represent deconvoluted fit of the additional stopped peak from the decay of a long lived ($\tau \approx 8.1$ ps) state in ^{43}Sc, and is not expected to affect the lineshape of the 1171-keV peak.

sections for inelastic excitation of the ^{120}Sn nuclei at different beam energies along the target thickness have been estimated in the framework of a coupled reaction channels (CRC) model using FRESCO. The analysis principally incorporates the simulation of trajectories of the scattered ^{120}Sn nuclei traversing in the target and the backing media, in time steps of 0.002 ps, using the TRIM program, with stopping powers calculated by the SRIM code. The origin of the trajectories were distributed across the production thickness of the target binned into six divisions as per the evolving excitation cross section of the ^{120}Sn in the 2_1^+ state.

The simulated trajectories are used to calculate the velocity profiles of the recoils, as viewed by the different detectors, using the HISTAVER program of the LINESHAPE package [4]. The LINESHAPE code uses these velocity profiles to calculate Doppler shapes of the γ-ray of interest at different angles. Single detector (clover) spectra at the 11 different (θ, ϕ) positions have been least-squares fitted simultaneously, which facilitates to constrain the multiple parameters associated with the minimization exercise. The calculated shapes, shown by continuous curves in Fig. 2, are sensitive to the lifetime, $\tau_{2_1^+}$, one of the fitting parameters.

Results and Discussion

A value of the lifetime, $\tau_{2_1^+} = 0.863^{+0.029}_{-0.036}$ ps, is obtained from this analysis. Given the accuracy of the methodology adopted in the present work, with lower uncertainty on the stopping power, the present result is an improved estimate of the 2_1^+ level lifetime in ^{120}Sn by the DSAM method. The corresponding transition probability for the $0_{\rm g.s.}^+ \to 2_1^+$ excitation, $B(E2)$ = $0.215^{-0.007}_{+0.009}$, is found to be in good agreement with the adopted value, and is considerably enhanced compared to the estimate given in Ref. [2].

TABLE I: $\tau_{2_1^+}$ and $B(E2)$ for the 1171 keV excitation in ^{120}Sn, compared with a recent estimate.

$\tau_{2_1^+}$ (ps)	$B(E2; 0_{\rm g.s.}^+ \to 2_1^+)$ (e^2b^2)	Ref.
0.97(5)	0.191(10)	[2]
$0.863^{+0.029}_{-0.036}$	$0.215^{-0.007}_{+0.009}$	This work

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