Decay of 0^+ analogue state of ^{120}Sb

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The $(p, n\gamma)$ reaction studies on ^{119}Sn have been carried out at $E_p = 4.529$–5.553 MeV. Deexcited states of ^{119}Sb have been studied from γ-ray spectroscopy. Cross sections of the individual states of ^{119}Sb have been measured and compared with Hauser-Feshbach calculations. The 0^+ analogue state of ^{120}Sb has been observed from the (p,n) reaction of proton energies $E_p = 4.529$–4.758 MeV. A number of residual states in ^{119}Sb populated predominantly by the emission of neutrons from the 0^+ analogue state have been identified. The resonance parameters of the analogue state have been determined.

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I. INTRODUCTION

The states excited in ^{117,119}Sb were studied earlier from ^{117,119}Sn (p,n) reaction by Kernell and co-workers [1,2] from the direct measurement of neutrons from the 0^+ analogue states produced in ^{117,119}Sn (p,n) reaction. The present experiment in the study of the ^{119}Sb nucleus from $(p, n\gamma)$ reaction has been carried out with the motivation of looking into the deexcitation of the levels through high-resolution γ-ray spectroscopy and also to determine the level parameters from the study of the analogue resonance.

Spins of the excited state of ^{119}Sb were determined from the enhanced cross sections of the neutron groups from the 0^+ analogue state by Kim *et al.* [2]. The number of neutrons of energy E_n populating a particular residual state is proportional to the neutron transmission factor, $T_{lj}(E_n)$ where l is the neutron orbital angular momentum and spin $j = l \pm \frac{1}{2}$. Spins of the excited states were determined on the basis of the cross sections of the states in comparison with that of a state of known spin.

In the earlier work of Kernell *et al.* [1], enhancements of cross sections of residual states in ^{119}Sb were measured from on- and off-resonance data. A study of excitation function around the resonance has been carried out by us to locate the resonance. The present experiment has been done to measure the cross sections by taking excitation functions of the residual states rather than the study of enhancement from on- and off-resonance data. This has enabled us to determine the resonance parameters.

The formation of the 0^+ analogue state resulted from the absorption of s-wave protons by the $\frac{1}{2}^+$ ground state of ^{119}Sn. The ensuing decay by neutron emission populates the low-lying states of ^{119}Sb. The s-, p-, d-wave neutrons are expected to be predominantly emitted from the 0^+ analogue state. Emission of neutrons with high angular momenta are less probable due to the centrifugal barrier.

II. EXPERIMENTAL PROCEDURE

The experiment has been carried out using the proton beam of energies 4.529–5.553 MeV from the Pelletron machine of Institute of Physics, Bhubaneswar. A self-supporting isotopically enriched (86.7%) target of ^{119}Sn (1 mg/cm^2) has been used. γ-ray single measurements have been carried out with a HPGe detector of efficiency 10% (resolution 2.8 keV at 1332.5 keV), placed at a 90° angle with the beam direction. Absolute efficiency of the HPGe detector has been determined with an accuracy of 10% using the calibrating sources such as ^{133}Ba, ^{152}Eu, and ^{60}Co of known strength. Energy calibration of the HPGe detector has been done with the same sources. To ascertain background lines arising due to scattered beam hitting the target frame or beam pipe, a separate run was taken without the target allowing the beam to pass. Around the resonance, proton energies are varied from 4.529 to 4.758 MeV in seven energy steps. The analogue resonance has been observed at a proton energy of 4.641 MeV. Data at each of the energies near the resonance have been taken for 100 to 200 μC of charge.

III. RESULT AND DISCUSSION

Excitation cross section of the analogue state has been determined from the excitation cross sections of the residual states which showed resonance behavior.

The present investigation with γ-ray spectroscopy has the advantage of better energy resolution compared to the earlier work [1] of neutron time of flight. The relevant portions of the on-resonance and off-resonance γ-ray spectra are shown in Fig. 1. A number of states reported earlier from neutron time-of-flight measurements have not been observed by us. Many of them were not observed in the $(p, n\gamma)$ work of Duffait, Charvet, and

Chery [3] at proton energies up to 4.0 MeV. The ^{119}Sn target used in Ref. [1] was deposited onto platinum backing. Most of the Pt isotopes have (p,n) reaction channels open at proton energies $E_p = 4.4$ MeV. That might have led to emission of background neutrons from platinum. Although the enhancement in excitation of a few states at resonance has been reported [1], it may be noted that such enhancement also could come from compound nuclear resonances from the backing. The states at 1212.69, 1848.2, 1875.30, 1982.0, 2269.1, and 2415.5 keV reported by Duffait, Charvet, and Chery [3] have not been observed in the present work even at $E_p = 5.553$ MeV where the cross section is several times larger than that at 4.0 MeV. The low-lying states observed in the present work are at energies 270.5, 643.7, 699.4, 1047.2, 1326.9, 1337.8, 1411.7, 1487.3, 1643.7, 1746.4, and 1819.2 keV. The excitation cross sections of these states have been measured considering the transitions populating and depopulating them. Excitation functions of a few transitions from some of the above-mentioned states are shown in Fig. 2. This clearly shows their resonating behavior between the energies of 4.529 and 4.758 MeV.

Excitation cross sections of the individual states relative to the 270.5 keV $\frac{7}{2}^+$ state, as shown in Fig. 3, have been utilized for the determination of spins. Relative excitation functions were used earlier for the determination of spins in several nuclei by Glenn, Baer, and Kraushaar [4], Kajrys *et al.* [5], and Chatterjee [6]. From the slope of the relative excitation function, positive or negative with increasing proton energy, the spin of the state greater or less than $\frac{7}{2}$ can be determined. Such a study together with the known l transfer in the particle transfer reaction has been very useful in determining the most probable spin parities of the excited states of ^{119}Sb. The slopes of the relative excitation functions are in good agreement with predicted spins [7] except in the case of the 1411.7 keV state. The reported spin of $\frac{3}{2}^-$ for this state [7] will lead to a transition to the ground state with multipolarity $E1$, $M2$, or $E1 + M2$. The ground state transition from the 1411.7 keV state is stronger than a number of transitions to the ground state from other positive parity states. From this consideration the 1411.7 keV state is more likely to have a positive parity. A tentative spin-parity of $\frac{5}{2}^+$ or $\frac{7}{2}^+$ has been suggested for the 1411.7 keV state from the trend of relative excitation function. No attempt has been made in the present work to find out the trend of excitation function of the 1337.8 keV state as the experimental points are very scattered. The reason for such a behavior is not understood.

The nonresonant background cross sections for the individual states have been calculated on the basis of

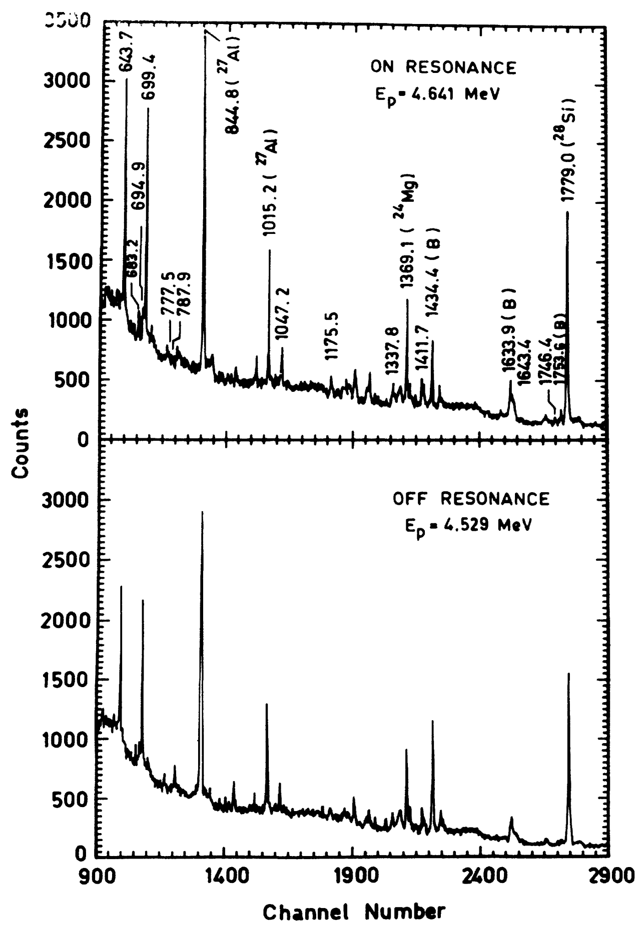

FIG. 1. Typical γ-ray spectra from the on- and off-resonance studies of 0^+ analogue state.

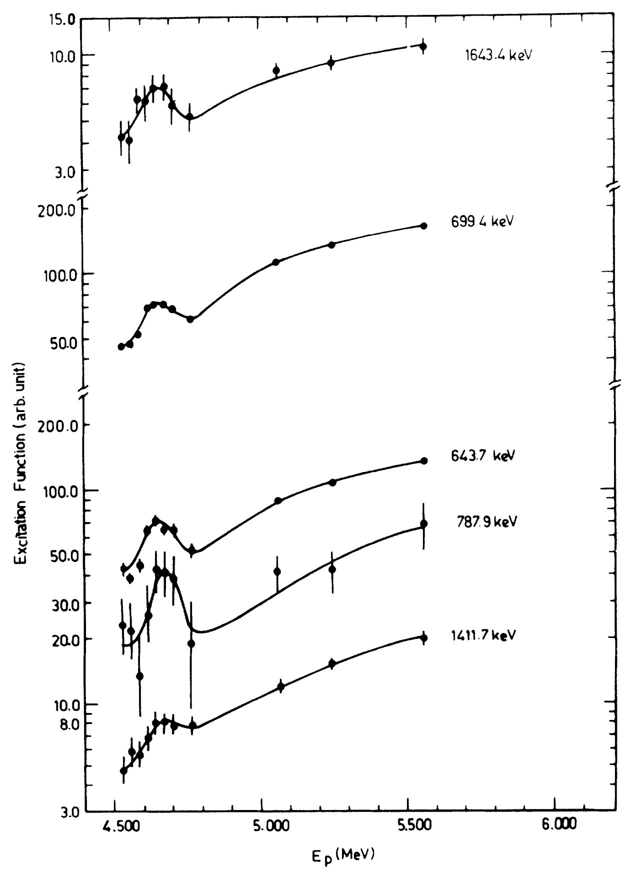

FIG. 2. Excitation functions of a few transitions from the ^{119}Sb states. The solid lines through the data points are given as visual guides.

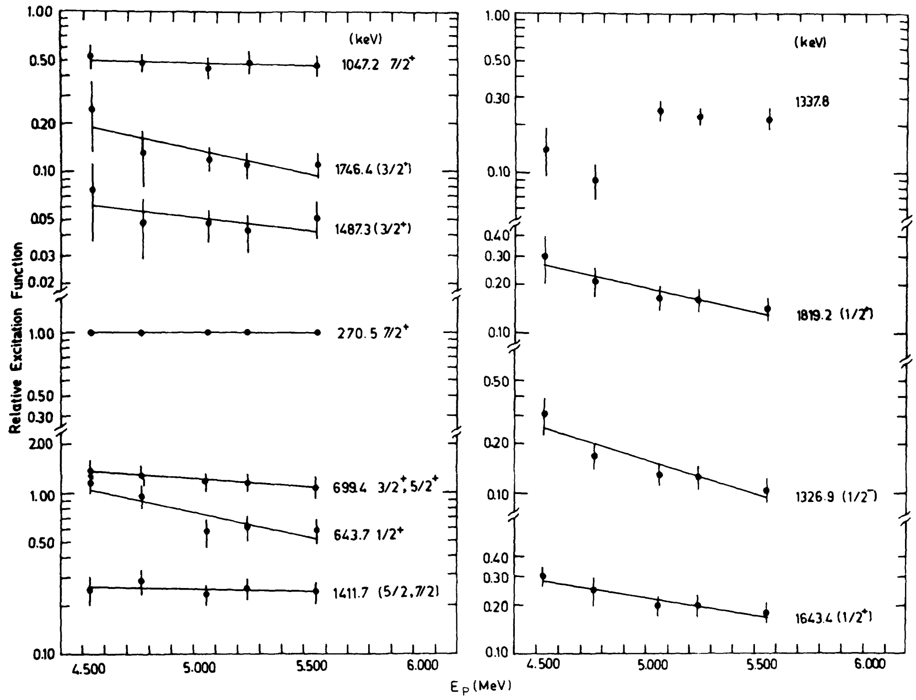

FIG. 3. Relative excitation functions of the states of ^{119}Sb with respect to 270.5 keV $\frac{7}{2}^+$ state. The solid lines through the data points are the least-squares fitted lines. Most probable spins from Ref. [7] are shown in the figure except for the 1411.7 keV state for which a tentative assignment of spin has been shown.

Hauser-Feshbach (HF) formalism used earlier by Chatterjee [6]. The theoretical cross sections have been calculated considering (p,n) and (p,p_0) channels. The (p,α), (p,γ), and other reaction channels have been neglected since they usually provide an insignificant contribution at these energies. The twelve states of ^{119}Sb, including the ground state, have been considered with their most probable spin parities in the theoretical calculation.

In order to calculate the nonresonant (p,n) cross section, the tabulated values [8,9] of the partial transmission coefficients of protons and neutrons have been used. The orbital angular momenta for both incoming protons and outgoing neutrons have been considered up to $5\hbar$. To determine the spin of the 1411.7 keV state, we have compared the experimental cross section for it with the theoretical ones for various spins. Figure 4 shows that $\frac{5}{2}^+$ is the most probable spin.

In the present work, it is assumed that the 0^+ analogue resonance at 4.641 MeV is located and incoherent with the background. Nonresonant HF background is subtracted to get the resonance contribution. Calculated nonresonant backgrounds of 699.4 and 1487.3 keV states have been adjusted slightly by normalizing their values to the experimental ones at 4.758 MeV. Absolute excitation cross sections of the individual states in ^{119}Sb have been measured and added to get the total cross sections of the excited states. The natural width of the Lorentzian resonance curve was determined, taking into account the measured total cross section using the Breit-Wigner formula [10]. Doppler broadening and beam resolution (< 2 keV) for the proton beam from a Pelletron machine has been neglected as they are small. Only the target thickness (35.4 keV at $E_p = 4.64$ MeV) and the natural width of the resonance is considered in the fit. The fit also took into account the 10% error of the absolute efficiency of the detector.

The resonance analysis yields a precise value of the total width and the resonance energy E_R. The fitted resonance energy E_R corresponds to a bombarding energy of 4.641±0.002 MeV which is in good agreement with the previously reported [1] value of 4.642 MeV. The natural width determined in the present experiment from the fitted resonance curve shown in Fig. 5 is Γ(lab)=114±4 keV.

The resonance strength has been determined from the measured yields using the expression given by Gove [10]

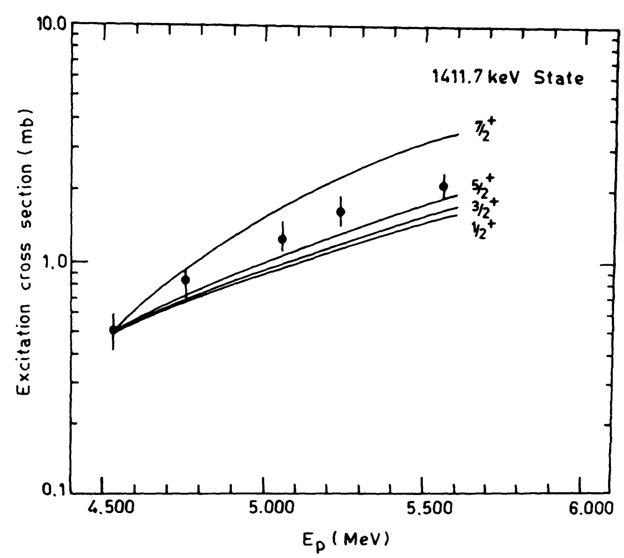

FIG. 4. Excitation cross sections of the 1411.7 keV state. The theoretical values calculated from Hauser-Feshbach formalism are shown with solid lines for various spins of this state. Theoretical cross sections are normalized with the experimental value at $E_p = 4.529$ MeV.

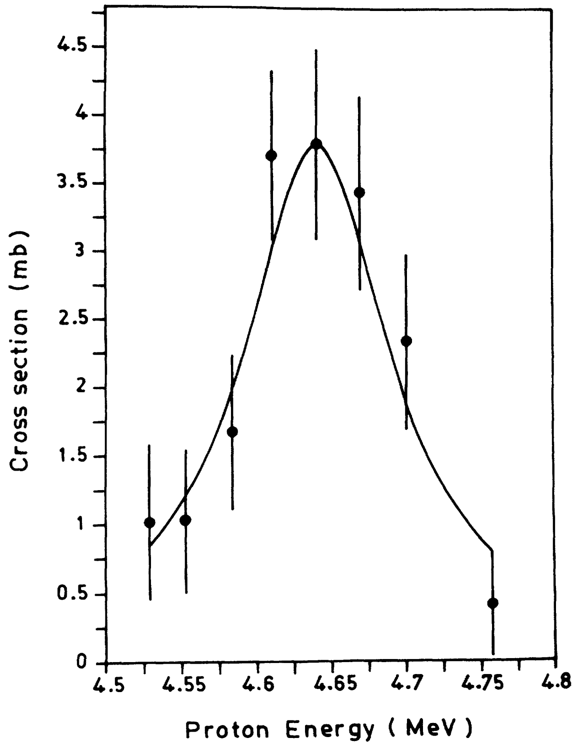

FIG. 5. Resonance curve for the 0^+ analogue resonance in ^{120}Sb determined from the measured total excitation cross sections of the states of ^{119}Sb. The solid line shows the Breit-Wigner fit to the data with natural width of $\Gamma_{lab} = 114$ keV.

$$
\begin{aligned}
&(2J_R+1)(\Gamma_p\Gamma_n/\Gamma) \\
&\quad = [A_T/(A_T+A_P)]^2(2J_P+1) \\
&\qquad \times(2J_T+1)\pi^{-2}\hbar^{-2}c^{-2}M_P E_R\int_{-\infty}^{+\infty}\sigma(E)dE\ ,
\end{aligned}
$$

where J_P, J_T, and J_R are, respectively, the spins of the projectile, the target nucleus, and the resonant level through which the reaction proceeds; Γ_p, Γ_n, and Γ are, respectively, the proton, neutron, and total widths of the resonance level; A_T and A_P are the mass numbers of the target nucleus and projectile, respectively; M_P is the proton mass; E_R is the resonance energy; and c is the velocity of light.

Neutron decay from an analogue state is isospin forbidden. Decay is possible only due to the mixing of the resonant state with densely populated compound nuclear states. Natural width can be expressed as $\Gamma = \Gamma_p + \Gamma_n$ where Γ_p is the proton decay width and Γ_n is the neutron decay width. γ decay width and other charge particle decay widths are neglected as they are usually small. Γ_{p_0} is the only contribution to the width by the protons in the formation channel since the analogue state can be formed only with s-wave protons from the $\frac{1}{2}^+$ ground state of ^{119}Sn. It was assumed that the proton decay from the analogue state is only through the formation channel, i.e., the elastic channel. Proton decay to inelastic channels has been neglected as the proton energies would be less, and l values would be higher, for those decay channels involving spins higher than the elastic channel. If there is no other significant decay channel, $\Gamma_n = \Gamma - \Gamma_{p_0}$. Summing $\Gamma_{p_0}\Gamma_n$ values as shown in column 5 of Table I, we obtain

$$\Gamma_{p_0}\Gamma_n = \sum \Gamma_{p_0}\Gamma_{n_i} = 451\ (\text{keV})^2$$

and

$$\Gamma_n = 114 - \Gamma_{p_0}\ (\text{keV})\ .$$

Solving the quadratic equation we obtain two roots of Γ_{p_0}: 109.9 and 4.1 keV. This implies that the values for Γ_n will be 4.1 or 109.9 keV. Neutron emission is generally favored over proton emission since neutron emission is not inhibited by the Coulomb barrier. The proton decay width $\Gamma_{\bar{p}}/\Gamma$ was determined by Bangert *et al.* [11] for the 0^+ analogue state by measuring the total cross section for the proton decay of the analogue state and the differential cross section for elastic scattering on this state at

TABLE I. Decay of 0^+ analogue state of ^{120}Sb to the levels of ^{119}Sb.

Excitation energy (keV)	Neutron groups (n_i)	$\int_{-\infty}^{+\infty}\sigma(E)dE$ (mb MeV)	$\frac{\Gamma_{p_0}\Gamma_n}{\Gamma}$ (keV)	$\Gamma_{p_0}\Gamma_n$ (keV)^2	Γ_n (keV)
0	n_0		1.70[a]	194	47.3
270.5	n_1	[b]			
643.7	n_2	0.17 ±0.06	0.73±0.27	83±31	20.3
699.4	n_3	0.12 ±0.06	0.51±0.27	58±31	14.2
1047.2	n_4	[b]			
1326.9	n_5	[b]			
1337.8	n_6	0.034±0.022	0.15±0.10	17±11	4.2
1411.7	n_7	0.057±0.018	0.25±0.08	28±9	7.0
1487.3	n_8	0.021±0.010	0.09±0.04	10±4	2.5
1643.7	n_9	0.058±0.028	0.26±0.12	30±14	7.2
1746.4	n_{10}	[b]			
1819.2	n_{11}	0.062±0.022	0.27±0.10	31±11	7.5

[a]Determined using the ratio of $\Gamma_{n_0}/\Gamma_{n_2}$ of Ref. [1].
[b]Not populated from the 0^+ resonance state of ^{120}Sb.

energies a few MeV above the threshold for excitation of the analogue state. The $\Gamma_{\bar{p}}/\Gamma$ value obtained by them is about 0.07 for the 0^+ analogue state. This shows that $\Gamma_{\bar{p}}$ is only for a small fraction of the total decay width. This rules out the other possibility of Γ_{p_0} being 109.9 keV out of a total width of 114 keV in the present case. Hence, the value of Γ_p would be 4.1 keV. However, it has been observed [11] that the ratio of $\Gamma_{\bar{p}}/\Gamma$ has a slight dependence on the parameters chosen for the distorted-wave Born approximation fit to the cross-section data. The minimum value of $\Gamma_{\bar{p}}/\Gamma \approx 0.07$ as determined earlier [11] is more than $\Gamma_{p_0}/\Gamma = 0.037$ determined by us. This discrepancy may be either due to the contribution of direct reaction in the measured proton elastic cross section at energies a few MeV above threshold or due to the underestimation of $\sigma(p,n)$ calculated theoretically by Bangert *et al.* [11].

The partial decay widths of neutrons to various residual states have been determined and are shown in Table I. The decay of 0^+ analogue state predominantly to a few low-lying states of ^{119}Sb has been observed. The neutron decay may be understood in terms of the structural configurations of the states in the target as well as in the residual nucleus. The ground state of ^{119}Sn is $\frac{1}{2}^+$. This state may be considered to be a possible neutron single particle state with the particle in the $3s_{1/2}$ orbital. However, the measured [12] spectroscopic factor $S = 0.29$ for this state suggests fragmentation of the spectroscopic strength. This occurs only when configuration mixing among several neutron states takes place. The formation of the 0^+ analogue state in ^{120}Sb will have configuration mixing along with the configuration of $(3s_{1/2})_\pi(3s_{1/2})_\nu$. The decay of 0^+ analogue state predominantly to ground state $(\frac{5}{2}^+)$, 643.7 $(\frac{1}{2}^+)$, and 699.4 keV $(\frac{3}{2}^+)$ states in ^{119}Sb shows that the 0^+ analogue state is not of pure $(3s_{1/2})_\pi(3s_{1/2})_\nu$ configuration as the states under consideration in ^{119}Sb could not be populated predominantly from the 0^+ state if it was of a pure $(3s_{1/2})_\pi(3s_{1/2})_\nu$ configuration. The spectroscopic factors [12] for the ground state ($S = 0.75$), and the 643.7 ($S = 0.45$) and 699.4 keV ($S = 0.45$) states in ^{119}Sb suggest the most likely configuration of these states as $2d_{5/2}$, $3s_{1/2}$, and $2d_{3/2}$. The population of $2d_{5/2}$ and $2d_{3/2}$ states is possible from the decay of 0^+ analogue state only if it contains some admixture from $2d_{5/2}$ and $2d_{3/2}$ states.

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