^{116}Sn from ^{116}Cd(α, 4$n\gamma$) reaction

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The ^{116}Sn nucleus was studied with the (α,4n) reaction on ^{116}Cd. Investigation of the interband and intraband transitions from the excited states of the ^{116}Sn nucleus was carried out by measuring gamma-ray singles, gamma-gamma coincidence, and gamma-ray angular distribution. The excitation functions of several transitions have also been studied and the absolute cross sections of (α,xn) reactions have been measured.

The even Sn nuclei with $Z=50$ have drawn considerable attention in the recent past.[1–4] The low-lying structures of such nuclei are found to be dominated by a variety of complicated excitations, contrary to expectations from simple shell model, and different band structures have been observed.[2,3] From neutron pickup reactions,[1,4] it is known that the neutron shell occupations in ^{116}Sn are not restricted to $2d_{5/2}$ and $1g_{7/2}$ orbitals only, but that the other active orbitals in the $N=50-82$ shell, i.e., $1h_{11/2}$, $2d_{3/2}$, and $3s_{1/2}$ orbitals , have sizable strengths. Two distinct bands were observed using ^{114}Cd (α,2n) ^{116}Sn reaction at 28 MeV.[2,3] Of these, the positive

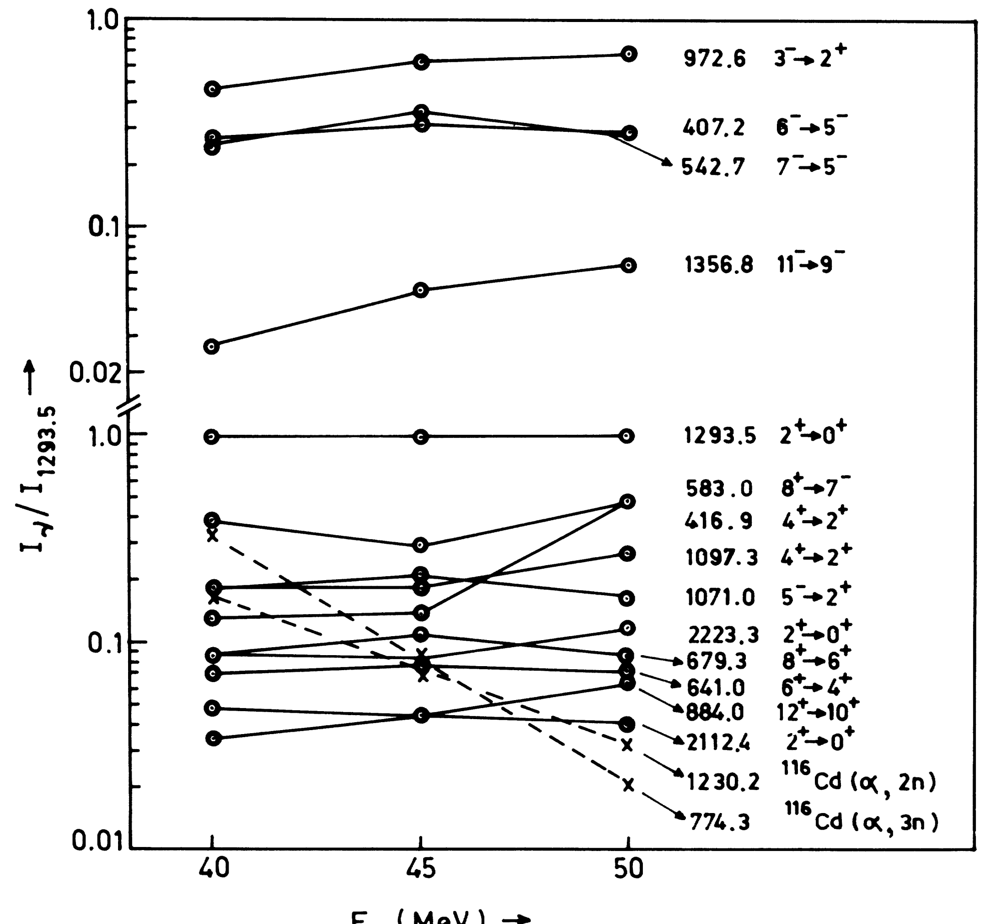

FIG. 1. Relative excitation functions for some prominent γ transitions from the (α,4n) reaction (shown as solid lines) and the (α,3n) and (α,5n) reactions (shown as dashed lines) on a ^{116}Cd target.

TABLE I. Energies, relative intensities, and angular distribution coefficients of γ rays from ^{116}Sn observed in ^{116}Cd(α,4n)^{116}Sn reaction at E_α=50 MeV.

		Angular distribution coefficients		
		Present work	Previous work (Refs. 2 and 3)	
E_γ (keV)	I_γ	A_2	A_2	A_4
99.07(3)	26.30±1.12			
134.80(3)	23.70±0.94			
138.85(3)	21.99±1.54			
294.03(3)	11.30±0.42			
318.51(3)	43.50±1.74	0.112±0.014	−0.06(2)[a]	−0.01(3)
334.84(11)	1.04±0.08			
386.50(6)	5.0±1.0			
407.17(10)	27.10±1.27	0.157±0.028	−0.293(12)[a]	−0.01(2)
416.86(10)	9.61±0.44			
505.30(20)	5.0±1.0			
542.73(13)	30.50±1.22	0.212±0.033	0.36(3)[a]	−0.10(5)
583.04(12)	27.60±1.04			
641.03(10)	5.82±0.22			
679.35(8)	8.04±0.34	0.327±0.043	0.370(10)	−0.12(2)
746.43(8)	1.78±0.21			
793.19(5)	7.54±0.28	0.499±0.062	0.32(2)	−0.11(3)
818.53(8)	3.56±0.13			
882.1(5)	6.50±0.52			
972.62(6)	54.90±2.19	0.141±0.060	−0.08(1)	−0.13(13)
1072.26(17)	16.3±0.68	0.198±0.047	0.075(8)	−0.013(13)
1097.28(11)	16.1±0.62	0.165±0.04	0.297(10)	−0.06(2)
1293.52(6)	100	0.116±0.022	0.113(8)	−0.027(12)
1356.76(50)	5.02±0.24	0.284±0.095	0.40(3)	−0.09(6)
1508.55(52)	1.09±0.13			
2112.41(70)	4.35±0.25	0.192±0.131	0.27(2)	−0.08(3)

[a]Coefficients estimated from intensities pertaining to prompt transition.

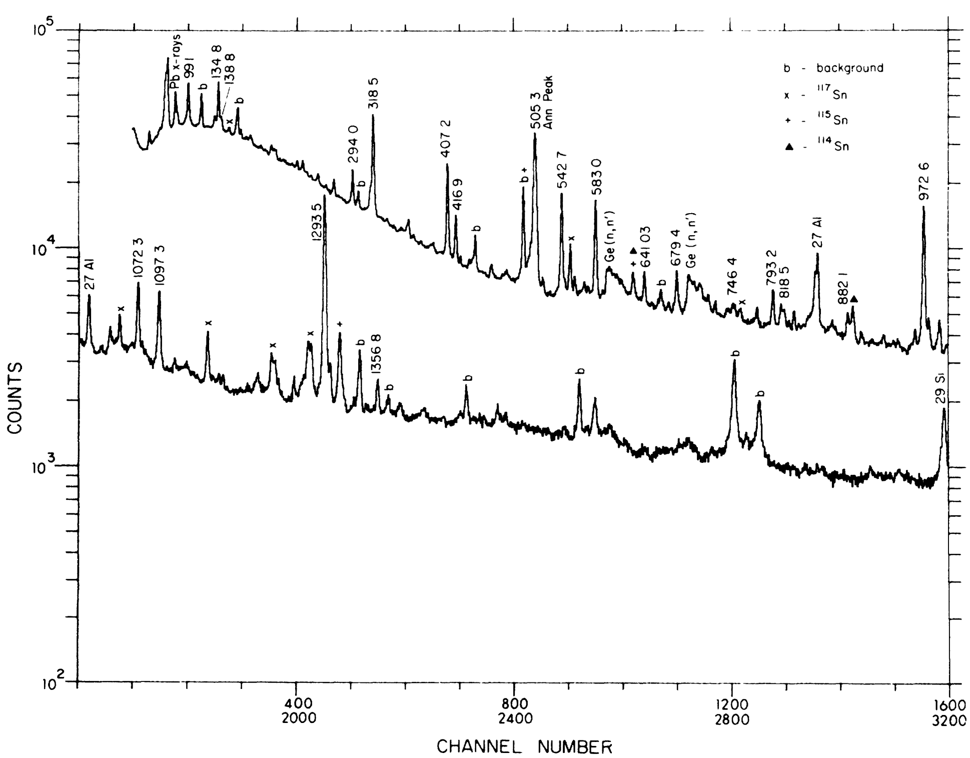

FIG. 2. Typical γ-ray singles spectrum obtained from bombardment of enriched ^{116}Sn with 50 MeV alpha particles, taken with a 25% HPGe detector placed at 90° to the incident beam direction.

TABLE II. Experimentally measured cross sections of ^{116}Cd(α,xn) reactions.

Reaction	Transitions considered	$\sigma(\alpha,xn)$ (mb) 40 MeV	45 MeV	50 MeV
^{116}Cd(α,3n)^{117}Sn	553, 1278, and 1310 keV	1204±88	767±54	475±38
^{116}Cd(α,3n)^{117m}Sn	1278 and 1310 keV	1099±86	638±50	354±30
^{116}Cd(α,4n)^{116}Sn	1293 and 2112 keV	982±118	1178±136	1360±160
^{116}Cd(α,5n)^{115}Sn	497 keV	155±17	160±18	586±65

parity band extending upto 12$\hbar$ is interpreted by Bron *et al.*[2] as members of a quasirotational band built upon the 0^+ state that originates from a nonclosed $Z=50$ shell. The negative parity states form a band with a two-quasiparticle neutron character, based on $(g_{7/2}^{-1}h_{11/2})$ and $(d_{5/2}^{-1}h_{11/2})$ neutron configurations. Recently, van der Werf *et al.*[5] extended the level scheme further in excitation energy using (α,t), (p,p'), and (e,e') reactions and identified clusters of states at 4.8, 5.8, and 6.3 MeV as candidates for the proton stretched spin states. Very recently, Schippers *et al.*[6] reported an extensive investigation on ^{116}Sn via neutron pickup and proton stripping reactions and compared the experimental spectroscopic factors and their fragmentation below $E_x=3.8$ MeV with those derived from model calculations. The aim of the present work was mainly to look for high spin states at still higher excitation using (α,4n) reactions, which has not been exploited so far, and to estimate the cross section for (α,xn) channels at several incident energies.

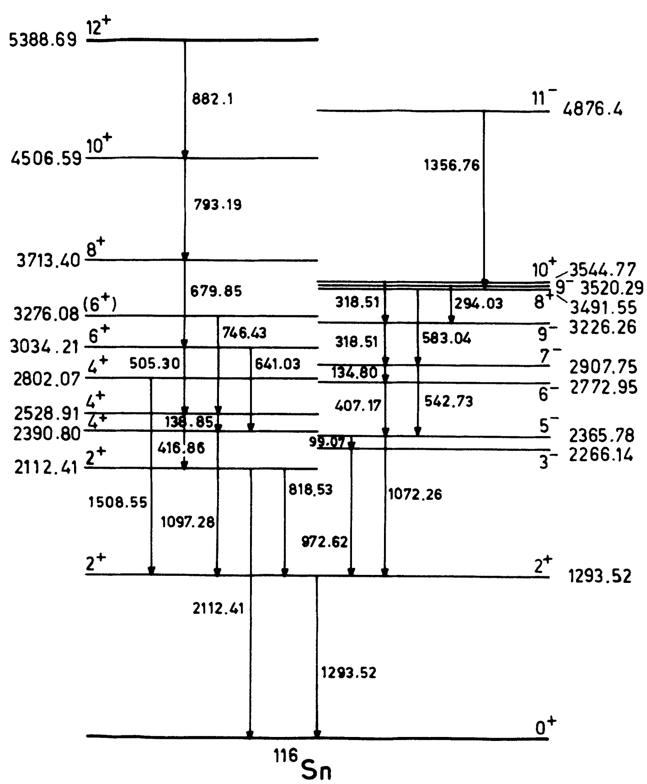

FIG. 3. Level scheme of ^{116}Sn constructed from the transitions observed in the ^{116}Cd(α,4$n\gamma$) reaction.

The experiment was carried out at the Variable Energy Cyclotron (VEC) of Bhabha Atomic Research Centre, Calcutta. The α beam of 1–2 nA from VEC was used to bombard an enriched (87.2%) target 1.7 mg/cm^2 thick of metallic ^{116}Cd deposited onto a 10 μg/cm^2 C backing. The total charge on the Faraday cup was monitored with a current integrator. Absolute-efficiency calibrated, high-resolution (FWHM ~2.3 keV at 1.33 MeV) HPGe detectors, having efficiencies of 10% and 25%, were employed for the measurement of γ-ray angular distributions, γ-γ coincidences, and excitation functions for total charge of 6 mC or more on the target. The γ-ray spectra were recorded with a CANBERRA series 88 MCA and on-line NORSK-DATA computer facility.[7] The data were analyzed with the computer code[8] SAMPO adopted on IRIS-80 computer and also using the interactive program[9] VECSORT available with the NORSK-DATA computer. In the measurement of angular distributions, spectra were taken with the detector having 25% efficiency placed at 90°, 105°, 120°, and 140°, respectively, with $E_\alpha=50$ MeV, keeping the detector at a distance of 22 cm from the target center. The second detector placed at 55° was used as a monitor. The data for angular distributions of individual γ rays were normalized with respect o the 774.3 keV transition from the isomeric state of ^{117}Sn (Ref. 10) to minimize the effect of anisotropy and off-centering of the beam spot on target. The γ-γ coincidence studies were done in a close geometry using the same detectors. Coincidence resolving time was about 50 ns using standard ORTEC electronics. The coincidence data were collected in "listmode" on NORSK-DATA computer and were sorted off-line using the program VECSORT.

The energy and efficiency calibration of the detectors were done using standard calibration sources, such as ^{152}Eu, ^{60}Co, etc. γ intensities were deduced from the spectra taken with the 25% detector placed at 125°. The measured angular distributions of reasonably strong γ rays were fitted with an approximate function, viz., $W(\theta)=A_0[1+A_2P_2(\cos\theta)]$ as the angular range was small because of experimental constraints and inclusion of A_4 term in some cases leads to unphysical A_2 coefficients.

The excitation function of a number of γ rays was studied using the larger (25% efficiency) HPGe detector placed at 125° for beam energies of 40, 45, and 50 MeV. Such a study enabled us to distinguish the γ rays from the (α,4n) reaction from those due to (α,3n) and (α,5n) reaction. In Fig. 1, relative excitation functions for some prominent γ transitions due to the above reaction channels are shown, which exhibit distinctly different trends in their respective excitation functions. A total of 25 γ rays have been assigned to ^{116}Sn. A typical γ-ray spectrum observed in our experiment is shown in Fig. 2, in which γ rays are labeled by the appropriate nuclei. The energies, relative intensities, and the angular distribution coefficients for the γ rays assigned to ^{116}Sn are listed in Table I. These agree reasonably well in most cases with those reported earlier.[2,3] On the basis of observed energies, their relative intensities, and γ-γ coincidence relationship together with other known information,[2-6] a level scheme of ^{116}Sn has been proposed and is shown in Fig. 3. In the present work, most of the transitions observed have been depicted in the level scheme, excepting the transitions at 334.8, 386.5 and 2223.3 keV. These transitions could not be placed in the level scheme because of lack of supporting evidence. We failed to corroborate the assignment of 355.3, 436.6, and 463.3 keV transitions in ^{116}Sn as reported earlier.[2,3] The 844.2 and 1267.9 keV transitions seen by earlier workers[2,3] were contaminated in our case by background lines due to ^{27}Al(α,α') and Ge(n,n') reactions. It is observed that there is hardly any population of states having spins greater than 12^+, contrary to expectations, whereas states up to 22^+ have been observed in heavy-ion induced reactions.[11] Such a saturation in angular momentum has been reported recently[12] in (α,xn) reactions.

The results of absolute cross-section measurements are shown in Table II for three energies, viz., 40, 45, and 50 MeV. The measured cross section at 40 MeV for the (α,3n) reaction leading to the isomeric state of ^{117}Sn compares reasonably well with the only reported result[13] of 994 mb at $E=39.6$ MeV. It would be interesting to repeat the (α,4n) reaction on the neighboring Cd nuclei to see whether similar features are exhibited as observed in the present work.

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