Structure of ^{116}Sb studied with the ^{115}Sn(^{3}He, d)^{116}Sb reaction

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The ^{115}Sn(^{3}He,d)^{116}Sb reaction was performed to obtain a more sensitive test of two quasiparticle calculations for ^{116}Sb. These calculations gave a good description of the excitation energies and partial half-lives of the low lying states of ^{116}Sb. Good agreement between measured and calculated spectroscopic factors is found. The calculated low lying $J^\pi = 0^+$ state ($E_x = 420$ keV) which has not been observed so far should be strongly excited in this reaction. However, no indication is found for such a state below $E_x = 1200$ keV.

[NUCLEAR REACTIONS ^{115,116}Sn(^{3}He, d), $E = 28.4$ MeV, measured $\sigma(\theta)$. ^{116,117}Sb deduced levels, J, π, S, DWBA analysis, magnetic spectrograph, enriched target.]

I. INTRODUCTION

Recently much information became available on the structure of the light odd-odd Sb isotopes. The low lying multiplet states were studied both from the β decay of the even Te isotopes[1] and with the (p,n) reaction on the even Sn isotopes.[2,3] Moreover, an exact number projected two quasiparticle calculation was performed for ^{112,114,116}Sb,[4] which gave a good description of the experimental data including partial half-lives. Another sensitive test of the calculated wave functions can be obtained by one particle transfer reactions. The lightest odd-odd Sb nucleus that can be studied in this way is ^{116}Sb, using the (^{3}He, d) reaction on ^{115}Sn (natural abundance only 0.35%). Since the ^{115}Sn ground state consists mainly of a $s_{1/2}$ neutron quasiparticle,[5] the spectroscopic factors for the transitions give directly the strength of the component consisting of a proton coupled to a $s_{1/2}$ neutron in the wave functions of ^{116}Sb. Another reason for this experiment is the discrepancy that exists between the level schemes of ^{116}Sb given in Refs. 2 and 3. Finally, the calculated low lying $J^\pi = 0^+$ state, resulting from the coupling of a $s_{1/2}$ proton to the ^{115}Sn ground state, which has not been observed so far, should be excited in this reaction.

II. EXPERIMENTAL METHODS AND RESULTS

The ^{115}Sn(^{3}He, d) ^{116}Sb experiment was performed with an energy analyzed ^{3}He beam from the AVF cyclotron of the Free University in Amsterdam at an incident energy of 28.4 MeV. Self-supporting foils of ^{115}Sn (39.8% enriched) with thicknesses of 150 μg/cm^2 were used. In order to correct for the contributions from other Sn isotopes in the ^{115}Sn target experiments were also performed on ^{116}Sn (88.9% enriched) and natural Sn. The isotopic composition of the different targets is given in Table I. The emerging deuterons were detected in an array of position sensitive solid state detectors placed along the focal plane of a split-pole spectrograph.[6] An energy resolution of 25 keV was obtained which was mainly due to the target thickness. Absolute cross sections were determined from an optical model analysis of elastically scattered ^{3}He particles in an angular range from 20° to 30°. The estimated uncertainty in the absolute cross sections is 10%. The relative normalization was obtained from the integrated current with an uncertainty of about 5%. The automatic spectrum analysis program SPAPAS[7] was used to determine the positions and number of counts of all peaks in the spectra.

Angular distributions of transitions leading to

TABLE I. Isotopic composition of the Sn targets in %.

Target	112	114	115	116	117	118	119	120	122	124
^{115}Sn	0.13	0.3	39.8	38.6	4.04	7.28	2.14	6.25	0.74	0.76
^{116}Sn	0.11	0.12	0.74	88.9	1.37	3.29	1.05	3.99	0.63	0.70
^{nat}Sn	1.0	0.66	0.35	14.4	7.6	24.1	8.6	32.8	4.7	5.8

states in ^{116}Sb are shown in Fig. 1. The curves are the results of distorted-wave Born-approximation (DWBA) calculations performed with the code DWUCK IV.[8] The optical model parameters are identical to those used in the description of the ^{124}Sn(^{3}He, d)^{125}Sb reaction at $E_{^3\mathrm{He}} = 25$ MeV.[9] The transferred proton was bound by its separation energy in a Woods-Saxon well. The optical model parameters are summarized in Table II. Corrections for the finite range of the (^{3}He, d) interaction were included. Absolute cross sections were calculated with a normalization constant of 4.42 as suggested by Bassel.[10] In this calculation the spectroscopic factors of states in ^{117}Sb, excited in the ^{116}Sn(^{3}He, d)^{117}Sb reaction, were reproduced. A comparison of these spectroscopic factors with the ones determined by Conjeaud[11] is given in Table III.

In Table IV the deduced spectroscopic factors for levels in ^{116}Sb are summarized and compared with the predictions of the two quasiparticle calculations. For the lowest five states the calculated levels are assigned to the experimental ones on the basis of spin and partial half-life.[4] Except for the $l = 0$ strength in the wave function of the state at 732 keV the agreement between the experiment and the calculation is good. The main part of the $(\nu s_{1/2}\, \pi d_{5/2})$ strength is located in the first two states. The 551 keV level reported in Ref. 3, which was not found by Ref. 2, is clearly observed. A state at 574 keV introduced by Ref. 3 was not excited in this reaction although the predicted spectroscopic factor is 0.10. Discrepancies with spin assignments based on the Hauser-Feshbach formalism are found for levels at 732 keV ($J^\pi = 4^2; l_p = 0+2$) and 821 keV ($J = 6, ^2J = 5, ^3l_p = 2$), indicating that spin assignments based on such a comparison of experimental excitation functions with predictions of statistical reaction model calculations should be considered with care. The $g_{7/2}$ strength is found to be more fragmented than predicted by the calculation, resulting in a somewhat weaker excitation of the level at 662 keV and a considerable excitation strength for the level at 882 keV. At about the calculated energy the main $d_{3/2}$ transfer strength is observed with a most probable $J^\pi = 2^+$ assignment for the 1163 keV state.

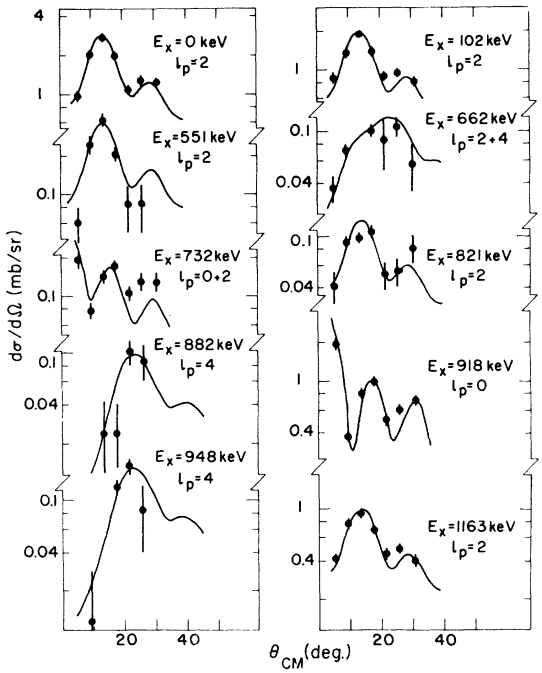

FIG. 1. Angular distributions of the ^{115}Sn(^{3}He, d)^{116}Sb reaction at $E_{^3\mathrm{He}} = 28.4$ MeV. The curves are the results of DWBA calculations.

The problem with the calculated low lying $J^\pi = 0^+$ state (420 keV) is still not solved. Below 1200 keV excitation energy only three $l = 0$ transfers have been observed leading to levels at 732, 918, and 1032 keV. The states at 732 and 918 keV are known $J^\pi = 1^+$ levels and the transition to the 1032 keV state, which is strongly contaminated by a transition from the ^{116}Sn(^{3}He, d)^{117}Sb reaction, has only a weak $l = 0$ component. If the excitation energy of the $J^\pi = 0^+$ state is above 1200 keV, where the level density is getting high, the discrepancy with the calculated energy would be unexpectedly large. If the spin of the state at

TABLE II. Optical model parameters used in the DWUCK calculation for the ^{115,116}Sn(^{3}He, d) ^{116,117}Sb reaction at $E_{^3\mathrm{He}} = 28.4$ MeV.

	V (MeV)	r_v (fm)	a_v (fm)	W [a] (MeV)	$4W_D$ [b] (MeV)	r_w (fm)	a_w (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)	r_c (fm)	λ_{so}
^{3}He	172	1.14	0.70	16		1.54	0.8				1.40	
d	101.4	1.085	0.857		68.0	1.293	0.788	14.4	1.085	0.857	1.30	
p		1.20	0.650								1.25	25

[a] Volume absorption. [b] Surface absorption.

TABLE III. Spectroscopic factors determined with the ^{116}Sn(^{3}He,d)^{117}Sb reaction at $E_{^3He}$ = 28.4 MeV.

E_x [a] (keV)	l_p	J^π	Shell model configuration	C^2S This work	C^2S Ref. 11
g.s.	2	$\frac{5}{2}^+$	$d_{5/2}$	0.70	0.70
530	4	$\frac{7}{2}^+$	$g_{7/2}$	0.76	0.81
719	0	$\frac{1}{2}^+$	$s_{1/2}$	0.49	0.59
924	2	$\frac{3}{2}^+$	$d_{3/2}$	0.42	0.42
1325	5	$\frac{11}{2}^-$	$h_{11/2}$	0.57	0.52

[a] Uncertainty 5 keV.

TABLE IV. Comparison of the experimental spectroscopic factors from the ^{115}Sn(^{3}He,d)^{116}Sb reaction with the results of the two quasiparticle calculations.

E_x [a] (keV)	l_p	J^π	Shell model configuration	C^2S_{exp}	C^2S_{calc}
g.s.	2	3^+	$\nu s_{1/2}\pi d_{5/2}$	0.60	0.97
102	2	2^+	$\nu s_{1/2}\pi d_{5/2}$	0.60	0.78
551	2	2^+	$\nu s_{1/2}\pi d_{5/2}$	0.15	0.15
662	4	3^+	$\nu s_{1/2}\pi g_{7/2}$	0.37	0.57
	2	3^+	$\nu s_{1/2}\pi d_{5/2}$	0.02	<0.02
732	2	1^+	$\nu s_{1/2}\pi d_{3/2}$	0.19	0.20
	0	1^+	$\nu s_{1/2}\pi s_{1/2}$	0.03	0.44
821	2	(3^+)	$\nu s_{1/2}\pi d_{5/2}$	0.03	
		(2^+)	$\nu s_{1/2}\pi d_{5/2}$	0.04	
882	4	3^+	$\nu s_{1/2}\pi g_{7/2}$	0.37	
918	0	1^+	$\nu s_{1/2}\pi s_{1/2}$	0.40	0.26
948	4	(4^+)	$\nu s_{1/2}\pi g_{7/2}$	0.62	0.87
1163	2	(2^+)	$\nu s_{1/2}\pi d_{3/2}$	0.53	0.41
		(1^+)	$\nu s_{1/2}\pi d_{3/2}$	0.87	0.32

[a] Uncertainty 5 keV.

732 keV was $J^\pi = 0^+$ the situation would be more satisfying. However, the observed mixed $l = 0 + 2$ transfer to this level and a measured $\log ft = 5.9$ [3] for the β decay of the ^{116}Te ground state exclude the $J^\pi = 0^+$ assignment.

From a comparison of Tables III and IV it is clear that about the same total $d_{5/2}$ and $g_{7/2}$ strength is excited in the ^{115}Sn(^{3}He, d)^{116}Sb reaction ($C^2S = 0.72$ and 0.68, respectively) as is found in the first excited $J^\pi = \frac{5}{2}^+$ and $J^\pi = \frac{7}{2}^+$ states of ^{117}Sb ($C^2S = 0.70$ and 0.76, respectively). Only half of the $s_{1/2}$ strength has been localized in the ^{115}Sn(^{3}He, d) ^{116}Sb reaction, whereas the $d_{3/2}$ strength cannot be well determined due to the ambiguity in the spin assignment for the level at 1163 keV. In this experiment Q values for the (^{3}He, d) reactions on ^{115,116,118}Sn were determined relative to the ^{120}Sn(^{3}He, d) ^{121}Sb reaction (Q = 0.291 MeV [12]) with an accuracy of 10 keV. The Q value for the ^{118}Sn(^{3}He, d) ^{119}Sb reaction (−0.382 MeV) and for the ^{116}Sn(^{3}He, d) ^{117}Sb reaction (−1.082 MeV) are in good agreement with the values given by Gove and Wapstra[12] (Q = −0.370 MeV and Q = −1.090 MeV, respectively). However, the Q value for the ^{115}Sn(^{3}He, d) ^{116}Sb reaction, which was measured as Q = −1.431 MeV, is in disagreement with the value given by Ref. 12 (Q = −1.210 MeV). This discrepancy of about 220 keV was also observed in the ^{116}Sn(p, n) ^{116}Sb reaction and is discussed in Ref. 2. Similar results have been reported recently by Johnson *et al.*[13]

III. CONCLUSIONS

The spectroscopic factors obtained from the one proton stripping reaction leading to states in ^{116}Sb have revealed detailed information on the structure of ^{116}Sb. Some discrepancies which exist in the literature on the level scheme of ^{116}Sb have been removed. The good agreement between the experimental ^{116}Sb data and the two quasiparticle calculation is consolidated by this comparison. However, the problem with the calculated low lying $J^\pi = 0^+$ state (420 keV) is still not solved. Below 1200 keV no additional $l_p = 0$ strength is observed apart from that leading to the known $J^\pi = 1^+$ states at 732 and 918 keV and to a weakly excited state at 1032 keV.

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