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Resonance (n,γ) measurements and weak-coupling model calculations of levels in ^{119}Sn, ^{117}Sn, and ^{115}Sn

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Neutron capture γ-ray measurements have been performed upon enriched samples of ^{118}Sn, ^{116}Sn, and ^{114}Sn following resonance capture. The γ rays, measured with a Ge(Li) detector, have been incorporated in level schemes for ^{119}Sn, ^{117}Sn, and ^{115}Sn. Spin and parity assignments have been made for many of the levels. Neutron separation energies for ^{119}Sn, ^{117}Sn, and ^{115}Sn were determined to be 6484.6 ± 1.5, 6942.9 ± 2.0, and 7545.3 ± 2.0 keV, respectively. The level schemes have been compared with those of heavier Sn isotopes to investigate systematic behavior. Various spectroscopic properties (level energies, electromagnetic moments, and transition rates) of ^{119}Sn, ^{117}Sn, and ^{115}Sn were calculated on the basis of a model which pictures these nuclei as being formed by coupling the motion of the odd neutron quasiparticle to the states of the neighboring even-mass core. The experimentally determined level properties of these Sn isotopes have been qualitatively reproduced by these calculations.

NUCLEAR REACTIONS ^{118}Sn(n,γ), $E = 0.3$-5.1 keV, ^{116}Sn(n,γ), $E = 0.09$-1.6 keV, ^{114}Sn(n,γ), $E = 0.09$-2.4 keV; measured E_γ, I_γ. ^{119}Sn deduced resonances, J. ^{117,115}Sn, deduced resonances. ^{119,117,115}Sn deduced levels, J, π, neutron separation energies. ^{115,117,119,121,123,125}Sn systematics. Enriched targets.
NUCLEAR STRUCTURE Weak-coupling model. ^{119,117,115}Sn calculated E(level), μ, Q, $B(E2)$ and $B(M1)$. Comparison with experiment.

I. INTRODUCTION

The large number of stable isotopes of tin facilitates any study aimed at the elucidation of systematic trends in experimental or shell-model features of these nuclei. This situation, for some investigations, results at the same time in interference from unwanted isotopes. The power of resonance neutron capture, when used in combination with enriched targets, comes from the suppression of resonances known to be due to nuclei other than those under investigation. We have reported results of such level structure investigations for ^{121}Sn, ^{123}Sn and ^{125}Sn in previous papers.[1,2] The present paper concludes a systematic investigation of the six odd tin isotopes between $A = 115$ and $A = 125$ utilizing resonance neutron capture γ-ray measurements upon highly enriched isotopes with a discussion of systematic trends in this region, and with a comparison between experimental results and calculations based on the weak-coupling model.

In the case of ^{119}Sn, we have constructed a level scheme consisting of 27 levels, including several new ones, by piecing together 70 γ rays (23 primary and 47 secondary) from 26 neutron resonances up to 5.1 keV neutron energy. Gamma rays from seven resonances in ^{116}Sn and from fourteen resonances in ^{114}Sn have been analyzed in constructing the level schemes for ^{117}Sn and ^{115}Sn. Spin and parity assignments have been made to many of the levels on the basis of results from the present work and results from previous reaction and decay studies.

The odd tin isotopes exhibit interesting systematic trends in the location of one and three quasiparticle states. The simplicity introduced by the single-closed-shell characteristic of Sn isotopes and the experimental regularities that have been observed prior to 1971 have been summarized by Baranger.[3] Several recent studies of the tin isotopes (see below) have focussed attention on particle-phonon states [also called three quasiparticle ($3qp$) states] built upon low lying $2d_{3/2}$ and $1h_{11/2}$ quasiparticle states. In the present paper, we present calculations for such states in ^{115}Sn, ^{117}Sn and ^{119}Sn. Comparisons are made with experimental energy levels identified in the present and previous studies and also with transition rates and electromagnetic moments.

TABLE I. References to previous works on levels in ^{119}Sn, ^{117}Sn and ^{115}Sn

Measurement	Ref.	Measurement	Ref.	Measurement	Ref.
(i) ^{119}Sn levels		(ii) ^{117}Sn levels		(iii) ^{115}Sn levels	
18-min ^{119}In decay	4,5	40-min ^{117}In decay	13	32-min ^{115}Sb decay	19
2-min ^{119}In decay	4,5	117-min ^{117}In decay	13	Coulomb excitation	20
Coulomb excitation	6	2.8-h ^{117}Sb decay	14	^{114}Sn (d,p) reaction	7
^{118}Sn (d,p) reaction	7,8	Coulomb excitation	6	^{112}Cd $(\alpha,n\gamma)$ reaction	21
^{116}Cd $(\alpha,n\gamma)$ reaction	9	^{116}Sn (d,p) reaction	7,15	^{113}Cd $(\alpha,2n\gamma)$ reaction	21
^{118}Sn $(d,p\gamma)$ reaction	9	^{114}Cd $(\alpha,n\gamma)$ reaction	9	^{115}In $(p,n\gamma)$ reaction	21,22
^{120}Sn (p,d) reaction	10	^{116}Sn $(d,p\gamma)$ reaction	9	^{115}In $(d,2n\gamma)$ reaction	21
^{120}Sn (d,t) reaction	7	^{118}Sn (p,d) reaction	10	^{116}Sn (p,d) reaction	10
^{118}Sn (n,γ) reaction^a	11,12	^{118}Sn (d,t) reaction	7	^{116}Sn (d,t) reaction	7,23
		^{118}Sn $(\vec{d},t)$ reaction^b	16	^{117}Sn (p,t) reaction	17
		^{119}Sn (p,t) reaction	17,18		

^{a}Limited to the 45 eV resonance.
^{b}With polarized deuterons.

The existing nuclear structure information on ^{119}Sn arises mainly from decay studies,[4,5] Coulomb excitation,[6] a variety of nuclear reactions,[7-10] and the ^{118}Sn(n,γ) reaction[11,12] limited to the 45 eV resonance. Approximately 40 states in ^{119}Sn below 4 MeV have been identified in these measurements. In the case of ^{117}Sn, decay studies,[13,14] Coulomb excitation,[6] and nuclear reaction measurements[7,9,10,15-18] have provided information concerning approximately 50 states below 4 MeV. Finally, decay studies,[19] Coulomb excitation,[20] and reaction studies[7,10,17,21-23] have contributed information regarding approximately 30 states in ^{115}Sn below 4 MeV. These measurements have been explicitly identified in Table I.

II. EXPERIMENTAL PROCEDURE

The Oak Ridge Electron Linear Accelerator (ORELA) facility was used to provide a pulsed beam (20-nsec burst at a repetition rate of 800 Hz) of neutrons for capture studies of 53 g, 97% enriched ^{118}Sn; 50 g, 95% enriched ^{116}Sn; and 18 g, 64% enriched ^{114}Sn. The neutrons were produced by a beam of 140 MeV electrons which were stopped in a water-cooled Ta target. The resulting bremsstrahlung produced neutrons via the (γ,xn) reaction. The neutrons were moderated by a 3.2 cm thick water moderator of 15 cm diameter which surrounded the Ta target. The (n,γ) measurements were carried out at a station 10.45 m from the target. The quoted neutron energies in this paper are accurate to ±0.5%. Each sample was placed in the beam for a running time of approximately 2 weeks with a shielded 37 cm^3 Ge(Li) detector located 20 cm below. The γ-ray intensity values given in this paper are based on data obtained at 90° only. Overlap neutrons were suppressed by a ^{10}B filter in the beam. Two stainless steel shadow bars totalling 1.5 m and a lead filter 5 cm thick were inserted in the beam in order to shield the target from fast neutrons and from the γ flash. Additional experimental details follow closely those outlined in Ref. 1.

III. RESULTS

A. Levels in ^{119}Sn

Fig. 1 shows a spectrum of neutron capture γ rays *versus* neutron flight time. From such data, appropriate time gates were selected corresponding to different neutron energies, some on resonance and some off resonance. Twenty-six neutron resonances were analyzed up to 5.1 keV neutron energy. Fig. 2 shows the high-energy portions of the γ-ray spectra from 5 resonances and Fig. 3 shows the low-energy portion from the 355 eV resonance. The γ-ray energies (and relative intensities) are listed in Tables II and III. The decay scheme based on the present data is shown in Fig. 4. All levels in this scheme except those at 90, 787, 1062 and 1304 keV were populated by primary γ transitions. The energies of the excited states determined in the present (n,γ) reaction agree well (see Table IV) with those for states excited in previous reaction and decay studies. The neutron separation energy, S_n, was determined to be 6484.6 ± 1.5 keV.

A close-lying doublet of collective levels at 921 keV with a separation of less than 1 keV was proposed from Coulomb excitation measurements carried out earlier at Oak Ridge.[6] Convincing evidence for

TABLE II. Relative photon intensities of the primary γ rays from the ^{118}Sn(n,γ)^{119}Sn reaction

	Neutron resonance energy (eV)									
	45.2	304.2	340.3	355.2	761.9	783.5	1254	1347	1384	1567[c]
E_γ[a] (keV)	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]
6483.4 *15*	62 *3*				4.8 *7*	5.7 *2*	22.8 *15*		8.9 *20*	
6460.2 *15*	57 *3*	103 *6*	101 *5*	24 *1*	3.1 *7*		57 *2*			
5563.2 *15*	6.7 *5*					50 *3*	29 *2*	95 *5*		
5395.4 *15*	21 *1*			5.7 *5*						
5297.8 *20*	2.7 *6*									
5235.0 *15*	11.4 *6*					8.0 *20*				
5129.0 *20*	1.7 *6*					11.3 *16*				
4931.4 *20*			18.0 *13*							
4913.0 *20*	9.4 *6*			3.7 *6*						
4867.3 *15*		20 *3*		2.1 *5*			12 *2*	40 *4*		
4766.9 *20*						9.3 *20*				
4710.2 *20*	5.9 *5*					18 *2*				
4695.3 *20*					8 *1*					8.3 *15*
4555.3 *20*				2.9 *9*	9.1 *15*					
4541.8 *20*				6.4 *6*				18 *4*		
4500.6 *20*		15 *3*								
4480.6 *20*	1.9 *7*						7.4 *30*			
4444.7 *20*										12.0 *15*
4354.3 *20*	2.9 *10*									
4246.8[d] *20*							5.6 *20*			
3639.4 *20*					9.2 *14*					
3604.1 *20*			11.7 *20*							
3473.8 *20*				5.4 *8*						
3434.0 *20*										11 *2*

[a] In our notation 6483.4 *15* ≡ 6483.4 ± 1.5, etc. The γ-ray energies correspond to zero energy.

[b] Relative photon intensity based on a value of 100 for the sum of Ge(Li) detector counts between 2.5 and 3.5 MeV for each resonance. In our notation 62 *3* ≡ 62 ± 3, etc.

[c] Useful data were obtained up to 5.1 keV neutron energy but no new γ transitions were found.

[d] Not placed on level scheme.

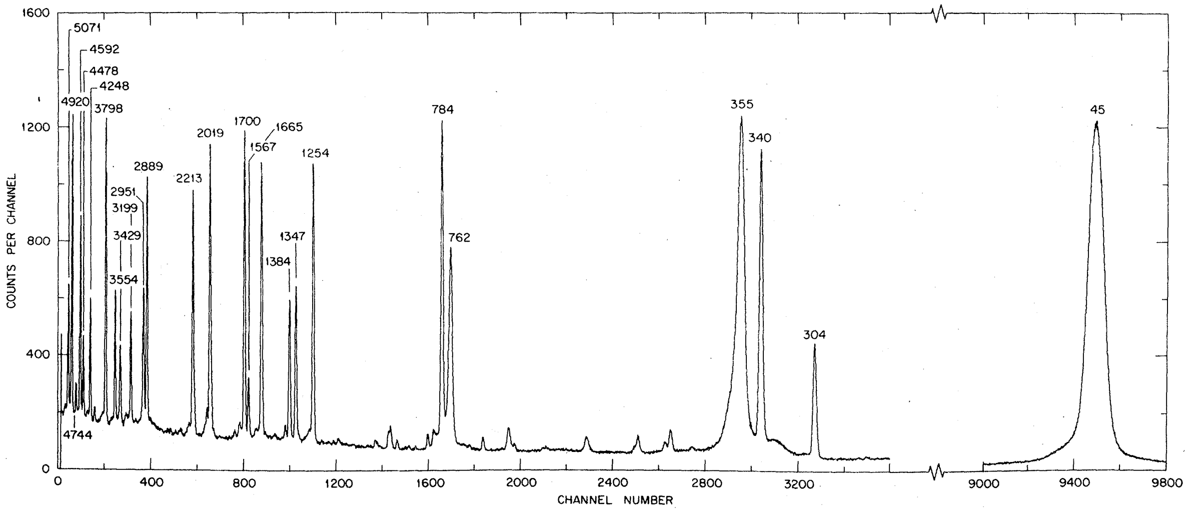

FIG. 1. Time-of-flight plot of events in the Ge(Li) detector. The peaks are labelled with neutron energies in eV (uncertainty ± 0.5%) and correspond to resonances in ^{118}Sn.

the existence of such a doublet was obtained subsequently *via* the ^{118}Sn(n,γ) reaction at various resonances as discussed in detail elsewhere.[5]

In Table IV, we have collected all well-established energy levels in ^{119}Sn below 1.8 MeV. We have also indicated in the table J^π assignments for most of the levels based on the reasonings given therein. The 45 eV resonance is known to be p-wave and the 355 and 762 eV resonances to be s-wave ($J^\pi = 1/2^+$) based on a lack of (p-wave) or the presence of (s-wave) interference between resonance and potential scattering in the curve of neutron transmission *versus* neutron energy.[24] The 45 eV resonance has been shown to be $3/2^-$ from γ-ray angular distribution measurements.[11]

The levels at 24, 1090, 1572, 1618, 1929, 1939 and 3012 keV are populated by primary γ rays from the 355 eV, $1/2^+$ resonance (see Table II). Normally we would make the assumption that the observed primary γ rays are of dipole character, resulting in a 1/2 or 3/2 spin assignment for these levels. In the case of the 1090 keV level the above assignment, together with the known $\ell_n = 2$ assignments from single nucleon stripping and pick-up reactions, would lead to a $3/2^+$ assignment for this level. The 1090 keV level is known to result principally from coupling of the odd $2d_{3/2}$ neutron to the 2^+ state of the even-mass core.[6] A $3/2^+$ assignment for this level would contradict the systematics of $B(E2)$ values for core-coupled states as discussed below.

Most vibrational nuclei with ground state spin of 1/2 exhibit strong Coulomb excitation to a pair of states with spins 3/2 and 5/2 which result from core-coupling.[25] There might also be excitation to additional 3/2 and 5/2 (predominantly) shell-model states. For such nuclei, it can be shown that the $\Sigma B(E2)\downarrow$ values for the $3/2 \rightarrow 1/2$ and $5/2 \rightarrow 1/2$ transitions are nearly equal (see Table V) and are similar to the $B(E2;\ 2_1 \rightarrow 0)$ values of the even-mass core. In the case of ^{119}Sn, the above near equality is obtained with a 5/2 assignment for the 1090 keV level but not with a 3/2 assignment. Our adoption of a $5/2^+$ assignment for the 1090 keV level would imply that the 5395 keV transition from the 355 eV, $1/2^+$ resonance to this level is an $E2$ transition. High-energy, primary γ transitions in the (n,γ) reaction are predominantly $E1$ or $M1$;

TABLE III. Secondary γ rays from the ^{118}Sn(n,γ) ^{119}Sn reaction

E_γ[a] (keV)	E_γ[a] (keV)	E_γ[a] (keV)
323.0 *20*	920.8 *5*	1572.4 *10*
420.9 *20*	972.9 *10*	1593.4 *10*
430.6 *20*	987.7 *3*	1694.5 *15*
434.2 *20*	1065.6 *3*	1750.4 *20*
465.2 *15*	1082.6 *10*	1765.8 *20*
632.9 *15*	1089.9 *15*	1915.7 *20*
650.6 *10*	1164.0 *3*	1929.6 *20*
695.6 *15*	1188.1[c] *10*	1939.4 *20*
713.8[b] *15*	1214.8 *10*	1959.1 *20*
716.9[b] *15*	1225.7 *10*	2041.0 *25*
763.0 *5*	1249.7 *5*	2130.2 *20*
767.4 *5*	1331.0 *5*	2344.6[b] *20*
834.3[b] *10*	1354.9 *10*	2845.8 *20*
849.4 *5*	1429.8 *20*	2881.2 *20*
855.6 *15*	1547.7 *10*	2988.9 *20*
897.3 *3*	1554.5 *15*	3010.9 *20*

[a] In our notation 323.0 *20* ≡ 323.0 ± 2.0.
[b] Not placed on the level scheme.
[c] This γ-ray is incorrectly listed as 1181.1 keV in column 3, Table 1 of Ref. 5.

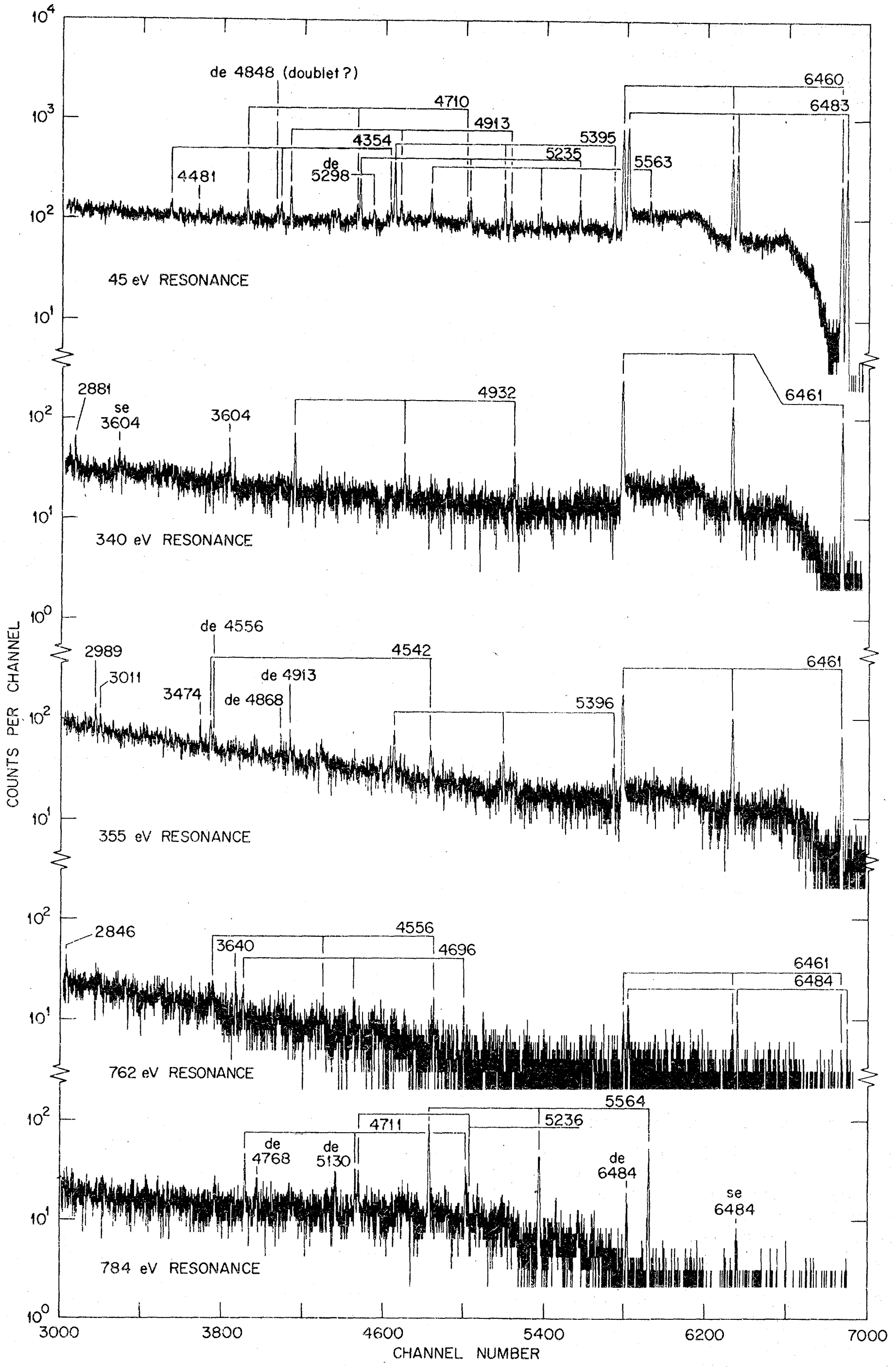

FIG. 2. High-energy portions of γ-ray spectra from 5 neutron resonances in ^{118}Sn. All γ-ray energies are in keV.

primary *E2* transitions are extremely rare. A survey of the literature yielded only fifteen additional *E2* transitions in an equal number of nuclei [we considered only those primary *E2* transitions following thermal or (isolated) resonance neutron capture].

Using a simple statistical model, Huizenga and Vandenbosch[26] have shown that the γ ray population

TABLE IV. Energy levels in ^{119}Sn

Other works[a] Energy (keV)	Present work Energy (keV)	J^π [b]	Reasons for J^π assignments[c]
0	0	$1/2^+$	Atomic beam; $\ell_n = 0$ in (d,p) and (p,d)
23.87 *1*	(23.87 *1*)	$3/2^+$	Gamma ray to ground state is *M1*; $\ell_n = 2$ in (d,p)
89.54 *2*	(89.54 *2*)	$11/2^-$	Gamma ray to 24 keV level is *M4*; $\ell_n = 5$ in (d,p) and (p,d)
787.01 *4*	787.0 *4*	$7/2^+$	$\ell_n = 4$ in (d,p) and (p,d); Strong γ ray to 24 keV level
920.5 *3*	(920.5 *3*)	$3/2^+$	Angular distribution in Coulomb excitation; comparison between *B(E2)* and $T_{\frac{1}{2}}$
921.4 *3*	(921.4 *3*)	$5/2^+$	
1062 *10*	1062.4 *10*	$(7/2)^-$	$\ell_n = 3$ in (d,p); Shell-model
1089.5 *1*	1089.5 *3*	$(5/2^d)^+$	Coulomb excitation; $\ell_n = 2$ in (d,p) and (p,d)
1187.8 *1*	1187.8 *3*	$(3/2)^+$	$\ell_n = 2$ in (d,p) and (p,d); Log *ft* value favors $3/2^+$
1249.7 *1*	1249.6 *5*	$1/2^+$	$\ell_n = 0$ in (d,p)
1304.4 *2*	1304.3 *10*	$>7/2^e$	Gamma ray to $11/2^-$ level seen in both $^{118}\mathrm{Sn}(n,\gamma)$ reaction and ^{119}In decay
1354 *1*	1354.9 *5*	$5/2^+$	Angular distribution in Coulomb excitation
1553 *10*	1554.4 *6*	$3/2^+$, $5/2^+$	$\ell_n = 2$ in (d,p) and (p,d)
1574 *5*	1572.0 *6*	$(3/2)^+$	$\ell_n = 2$ in (d,p); Fed by primary γ ray from 355 eV, $1/2^+$ resonance
	1617.5 *7*	(1/2, 3/2)	Fed by primary γ ray from 355 eV, $1/2^+$ resonance
1631 *10*			
1715 *10*	1718.1 *13*		
1778 *7*	1774.8 *5*		
...			
...			
	1789.4 *15*	(1/2, 3/2)	Fed by primary γ ray from 762 eV, $1/2^+$ resonance
	...		
	...		
	6484.6[f] *15*		

[a] Mainly from ^{119}In decay - Ref. 5; Coulomb excitation - Ref. 6; $^{118}\mathrm{Sn}(d,p)$ - Ref. 8; and $^{118}\mathrm{Sn}(n,\gamma)$ - Ref. 11. In our notation for level energy 23.87 *1* ≡ 23.87 ± 0.01 keV, etc.

[b] Parentheses around a J^π value imply that the assignment is most probable but not certain beyond reasonable doubt.

[c] The atomic beam measurements are by W. J. Childs and L. S. Goodman, Phys. Rev. 137, A35 (1965). The other data referred to in this column are from the following references: (d,p) - Refs. 7 and 8; (p,d) - Ref. 10; γ-ray multipolarities - J. P. Bocquet, Y. Y. Chu, G. T. Emery and M. L. Perlman; Phys. Rev. 167, 1117 (1968); Coulomb excitation - Ref. 6; Log *ft* value - Ref. 5; and (n,γ) - present paper.

[d] See also discussion in the text concerning this assignment.

[e] Excluding $7/2^+$ assignment.

[f] Neutron separation energy.

of a low-lying state is sensitive to the spin of the capturing resonance. By considering two suitable low-energy γ rays and forming intensity ratios for the various resonances, we find (see Fig. 5) that these ratios separate into two distinct groups. As mentioned earlier, the 45 eV resonance is known to be $J = 3/2$ and the 355 eV and 762 eV resonances to be $J = 1/2$ from previous studies.[11,24] Fig. 5 shows our preferred J assignments for the remaining six resonances by this technique.

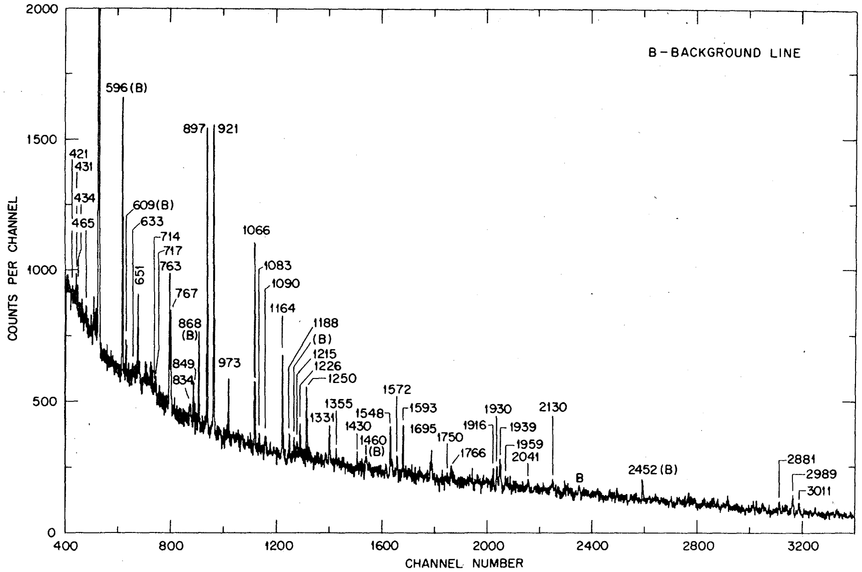

FIG. 3. Low-energy portion of γ-ray spectrum from the 355 eV resonance in ^{118}Sn. All γ-ray energies are in keV.

TABLE V. Summary of $B(E2)\downarrow$ values for $J = 3/2$ and $J = 5/2$ states of selected odd-A nuclei with $J = 1/2$ ground states and for $J^{\pi} = 2_1^+$ states of the corresponding even-mass core nuclei.

Odd-A nucleus	$\Sigma B(E2)\downarrow$[a] for 3/2 states (e^2b^2)	$\Sigma B(E2)\downarrow$[a] for 5/2 states (e^2b^2)	$B(E2)\downarrow$[a,b] for 2_1^+ state (e^2b^2)	Core nucleus
^{103}Rh[c]	0.114 *8*	0.126 *9*	0.132 *12*	^{102}Ru
^{107}Ag[d]	0.106 *10*	0.102 *8*	0.131 *7*	^{106}Pd
^{109}Ag[d]	0.118 *10*	0.112 *9*	0.152 *8*	^{108}Pd
^{115}Sn[e]	0.0292 *19*	0.0275 *12*	0.046 *10*	^{114}Sn
^{117}Sn[f]	0.037 *2*	0.035 *2*	0.042 *2*	^{116}Sn
^{119}Sn[f]	0.036[g] *4* 0.052[h] *4*	0.038[g] *3* 0.027[h] *4*	0.042 *2*	^{118}Sn
^{125}Te[i]	0.093 *3*	0.098 *3*	0.114 *2*	^{124}Te

[a] In our notation, 0.114 *8* ≡ 0.114 ± 0.008, etc.

[b] S. Raman, W. T. Milner, C. W. Nestor, Jr., and P. H. Stelson, contributed paper in *Proceedings of the International Conference on Nuclear Structure (Tokyo, 1977)*, p. 79, and to be published.

[c] R. O. Sayer, J. K. Temperly and D. Eccleshall, Nucl. Phys. A179, 122 (1972).

[d] R. L. Robinson, F. K. McGowan, P. H. Stelson and W. T. Milner, Nucl. Phys. A150, 225 (1970).

[e] Reference 20.

[f] Reference 6.

[g] With a $5/2^+$ assignment for the 1090 keV level. $B(E2)\downarrow$ values from Ref. 6.

[h] With a $3/2^+$ assignment for the 1090 keV level. $B(E2)\downarrow$ values from Ref. 6.

[i] J. Barrette, M. Barrette, R. Haroutunian, G. Lamoureux, S. Monaro and S. Markiza, Phys. Rev. C 11, 282 (1975).

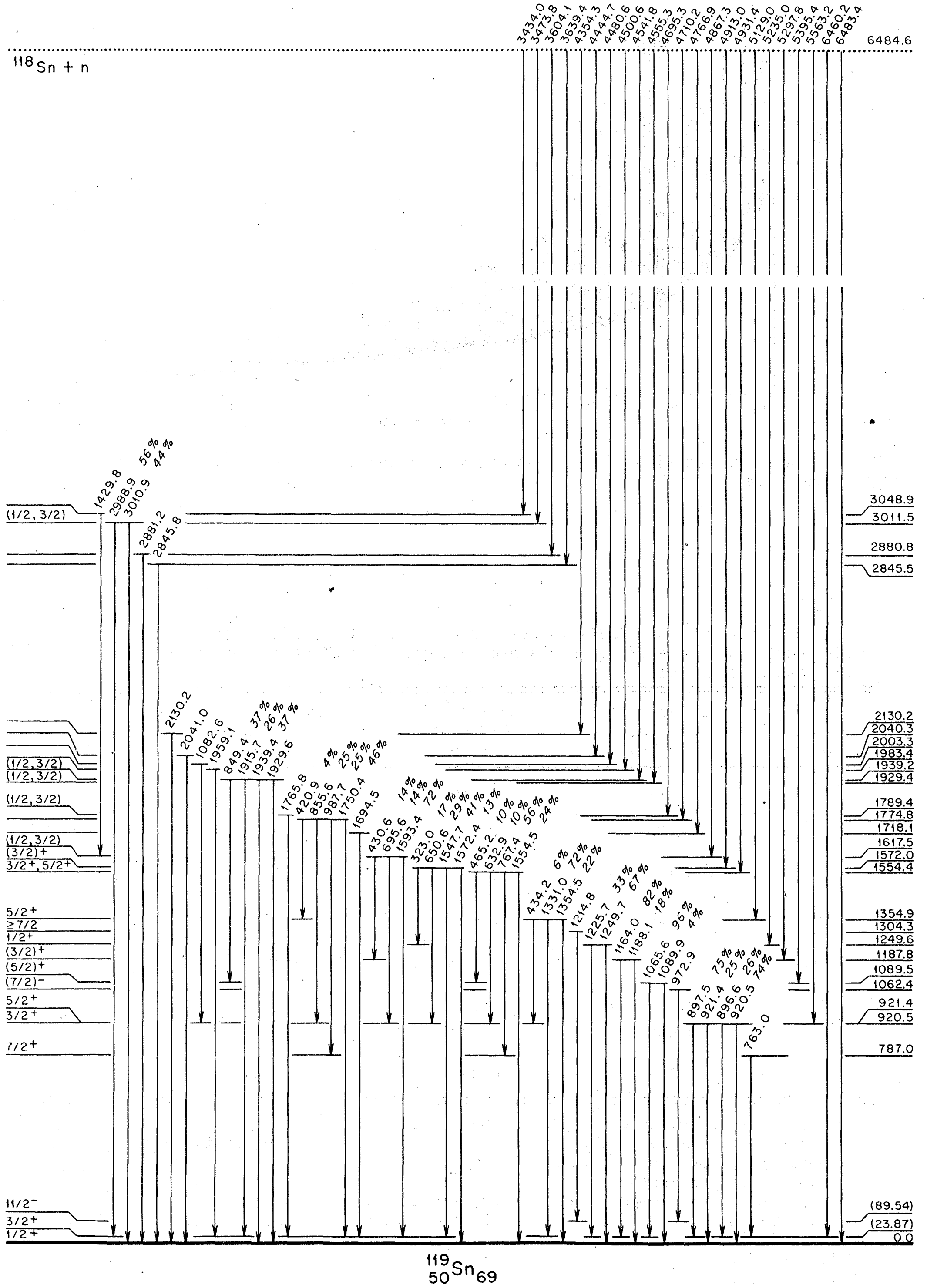

FIG. 4. Level scheme for ^{119}Sn from present experiment. All energies are in keV. The γ branching ratios are based on data obtained at only 90°.

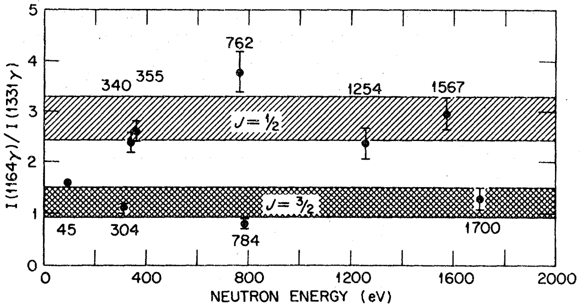

FIG. 5. Ratio of the intensities of the 1164 (1188 → 24 keV level) and the 1331 (1355 → 24 keV level) keV transitions for various neutron resonances in ^{118}Sn.

B. Levels in ^{117}Sn

Fig. 6 shows the neutron time-of-flight spectrum from which appropriate time gates were selected. Pulse height spectra from seven resonances below 1.6 keV were analyzed to obtain γ-ray energies and relative intensities. High-energy portions of the γ-ray spectra from two resonances are shown in Fig. 7 and the low energy portion from the 0.111 keV resonance is shown in Fig. 8. The γ-ray energies (and relative intensities) are listed in Tables VI and VII. The decay scheme based on the observed γ rays is shown in Fig. 9. All levels except those at 315, 712, 1021, 1304 and 1496 keV are populated by probable primary γ transitions. The energies of 8 excited states determined in the present (n,γ) reaction agree well (see Table VIII) with those for states excited in previous reaction and decay studies. The neutron separation energy, S_n, was determined to be 6942.9 ± 2.0 keV.

In Table VIII we have shown all well-established energy levels in ^{117}Sn below 3.3 MeV. We have also indicated in the table J^π assignments for most of the low-lying levels based on the reasonings given therein. The 0.148 and 0.663 keV resonances are known to be $3/2^-$ from transmission measurements[24] and angular distribution measurements (90° and 135°) involving the 6785 and 6943 keV γ transitions.[27] The 0.111 keV resonance is known to be $1/2^+$ due to s-wave interference in transmission studies.[24] The presence from the 0.111 keV, $1/2^+$ resonance (see Fig. 7) of the 6785 and 5938-keV

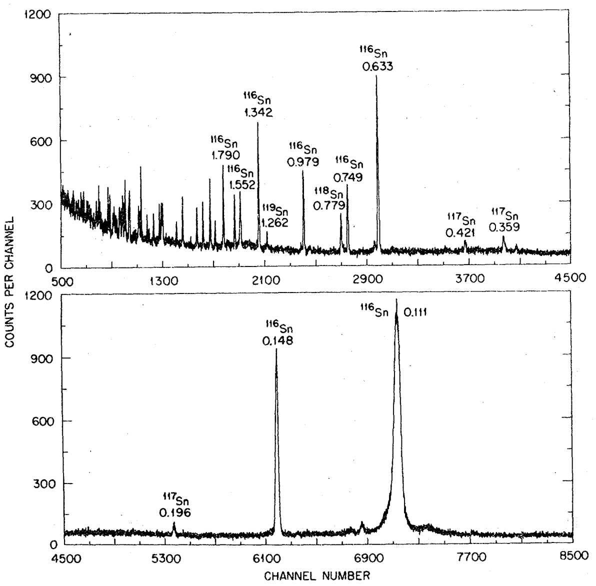

FIG. 6. Time-of-flight plot of events in the Ge(Li) detector. The peaks are labelled with neutron energies in keV (uncertainty ± 0.5%).

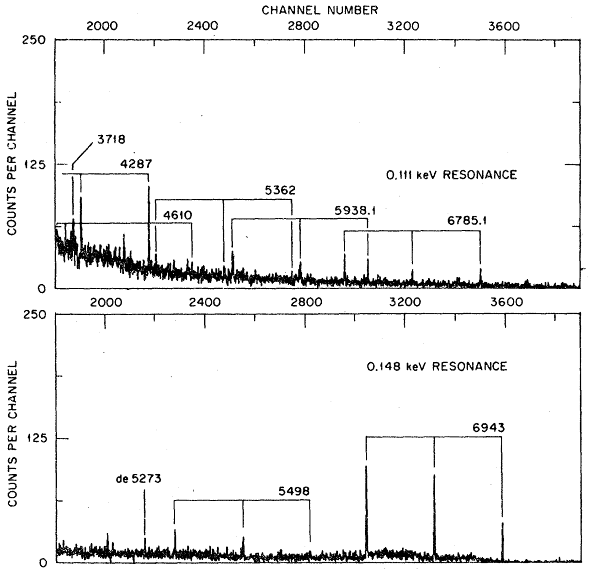

FIG. 7. High-energy portions of γ-ray spectra from 2 neutron resonances in ^{116}Sn. All γ-ray energies are in keV.

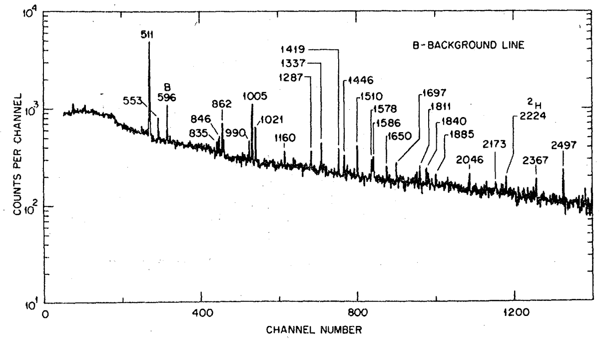

FIG. 8. Low-energy portion of γ-ray spectrum from the 0.111 keV resonance in ^{116}Sn. All γ-ray energies are in keV.

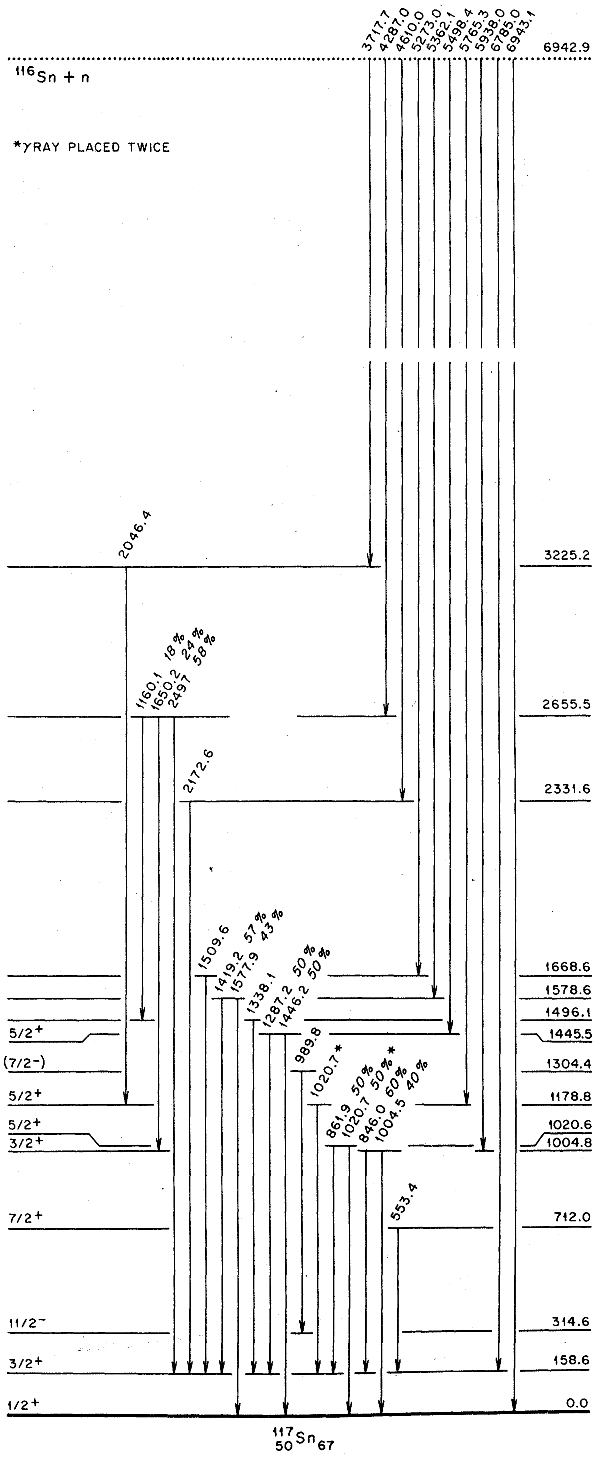

FIG. 9. Level scheme for ^{117}Sn from present experiment. All energies are in keV. The γ branching ratios are based on data obtained at only 90°.

Table VI. Relative photon intensities of the primary γ rays from the ^{116}Sn(n,γ)^{117}Sn reaction

	Neutron resonance energy (keV) 0.111	0.148	0.663[c]
E_γ[a] (keV)	I_γ[b]	I_γ[b]	I_γ[b]
6943.1 *20*		200 *12*	
6785.0 *20*	17 *3*		160 *8*
5938.0 *20*	19 *3*		30 *10*
5765.3 *25*			250 *25*
5498.4 *20*	6 *2*	43 *6*	
5362.1 *25*	12 *3*		
5273.0 *25*		15 *5*	
4610.0 *25*	5 *2*		
4287.0 *25*	54 *10*		
3717.7 *25*	23 *4*		

[a] In our notation 6943.1 *20* ≡ 6943.1 ± 2.0, etc. The γ-ray energies correspond to thermal neutron energy.

[b] Relative photon intensity based on a value of 1000 for the sum of Ge(Li) detector counts between 2.25 and 3.5 MeV for each resonance. In our notation 17 *3* ≡ 17 ± 3, etc.

[c] Useful data were obtained up to 1.6 keV neutron energy but no new γ transitions were found.

TABLE VII. Secondary γ rays from the ^{116}Sn(n,γ)^{117}Sn reaction

E_γ[a] (keV)	E_γ[a] (keV)	E_γ[a] (keV)
553.4 *25*	1337.1 *20*	1810.5[b] *25*
846.0 *15*	1419.2 *20*	1840.4[b] *25*
861.9 *25*	1446.2 *20*	1885.3[b] *25*
989.8 *15*	1509.6 *15*	2046.4 *20*
1004.5 *15*	1577.7 *25*	2172.6 *15*
1020.7 *15*	1586.2[b] *25*	2367.3[b] *25*
1160.1 *20*	1650.2 *15*	2497.0 *20*
1287.2 *20*		

[a] In our notation 553.4 *25* ≡ 553.4 ± 2.5, etc.

[b] Not placed on the level scheme

TABLE VIII. Energy levels in ^{117}Sn

Other works[a] Energy (keV)	Present work Energy (keV)	J^{π}	Reasons for J^{π} assignments[b]
0.0	0.0	$1/2^+$	Atomic beam; $\ell_n = 0$ in $(\vec{d},t)$
158.6 *1*	(158.6 *1*)	$3/2^+$	Log *ft* = 4.8 from $5/2^+$, ^{117}Sb^g decay; 158.6 keV γ ray is *M1*; $\ell_n = 2$ and vector analyzing power in $(\vec{d},t)$
314.60 *15*	(314.60 *15*)	$11/2^-$	$\ell_n = 5$ and vector analyzing power in $(\vec{d},t)$; 156.0 keV γ ray is *M4*
711.7 *4*	712.0 *1*	$7/2^+$	$\ell_n = 4$ and vector analyzing power in $(\vec{d},t)$
1004.6 *5*	1004.8 *9*	$3/2^+$	Angular distribution in Coulomb excitation
1020.2 *6*	1020.8 *12*	$5/2^+$	Triple correlation in Coulomb excitation; $\ell_n = 2$ and vector analyzing power in $(\vec{d},t)$
1179.6 *10*	1178.8 *13*	$5/2^+$	$\ell_n = 2$ and vector analyzing power in $(\vec{d},t)$
1304.3 *5*	1304.4 *15*	$(7/2^-)$	$\ell_n = (3)$ in (d,p); Shell model
1446.4 *5*	1445.5 *12*	$5/2^+$	Triple correlation in Coulomb excitation
1468.6 *3*			
1497.2 *10*	1496.1 *16*		
1578.3 *3*	1578.6 *14*		
1677 *10*	1668.6 *13*		
...	...		
...	...		
	2331.6 *13*		
	2655.5 *11*		
	3225.2 *18*		
	...		
	...		
	6942.9[c] *20*		

[a] Mainly from $(d,p\gamma)$ - Ref. 9; [$5/2^+$, ^{117}Sb^g decay] - Ref. 14; and (d,p) - Ref. 15. In our notation for level energy 158.6 *1* ≡ 158.6 ± 0.1, etc. Above 1.7 MeV excitation, this column is not complete. See for example, Refs. 10 and 15.

[b] The atomic beam measurements are by W. J. Childs and L. S. Goodman, Phys. Rev. 137, A35 (1965); multipolarity determinations are from J. P. Bocquet, Y. Y. Chu, G. T. Emery and M. L. Perlman, Phys. Rev. 167, 1117 (1968). The other data referred to in this column are from the following references: $(\vec{d},t)$ and vector analyzing power - Ref. 16; Log *ft* values - Ref. 14; Coulomb excitation - Ref. 6; (d,p) - Ref. 8.

[c] Neutron separation energy.

primary γ rays to the $3/2^+$ levels at 159 and 1005 keV, respectively, is further evidence for the unusually strong *M1* transitions previously reported in the tin isotopes.[28]

C. Levels in ^{115}Sn

The neutron time-of-flight spectrum is shown in Fig. 10. The γ-ray spectra from those resonances

TABLE IX. Relative photon intensities of the primary γ rays from the $^{114}Sn(n,\gamma)^{115}Sn$ reaction

	Neutron resonance energy (keV)				
	0.158	0.420	0.667	0.678	0.811[c]
E_γ[a] (keV)	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]	I_γ[b]
7543.7 *20*				1.6 *4*	
7047.7 *25*			0.35 *15*		
6561.5 *20*		3.6 *4*			
6265.7 *20*					2.5 *6*
6127.5 *20*	2.7 *5*				
5910.9 *20*				3.1 *8*	

[a] In our notation 7543.7 *20* ≡ 7543.7 ± 2.0, etc. The γ ray energies correspond to thermal neutron energy.

[b] Relative photon intensity based on a value of 100 for the sum of Ge(Li) detector counts between 2.5 and 3.5 MeV for each resonance. In our notation 1.6 *4* ≡ 1.6 ± 0.4, etc.

[c] Additional neutron resonances were located at the following energies: 0.278, 0.755, 0.985, 1.370, 1.396, 1.527, 1.984, 2.249 and 2.372 keV. These resonances however provided no new γ transitions.

ascribed to ^{114}Sn contained γ rays associated with the deexcitation of known low-lying levels in ^{115}Sn. The spectra (not shown) from five resonances were analyzed to obtain the γ ray energies (and relative intensities) given in Tables IX and X. Fourteen resonances were identified in ^{114}Sn below 2.4 keV (see footnote *c* of Table IX). The 0.667, 0.985, 1.370 and 1.984 keV resonances have been previously identified from transmission studies.[24] The level

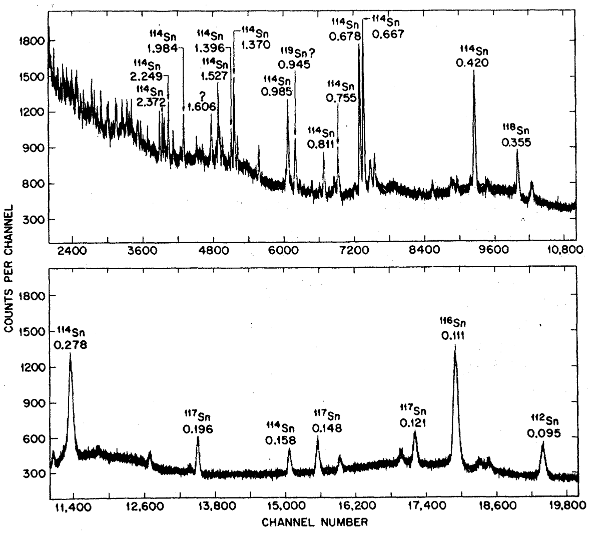

FIG. 10. Time-of-flight plot of events in the Ge(Li) detector. The peaks are labelled with neutron energies in keV (uncertainty ± 0.5%).

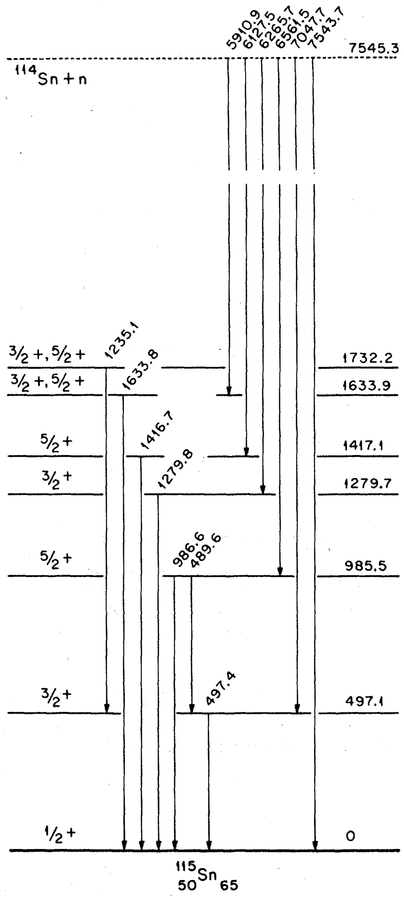

FIG. 11. Level scheme for ^{115}Sn from present experiment. All energies are in keV.

scheme based on the observed γ rays is shown in Fig. 11. In Table XI, we have collected all well-established levels in ^{115}Sn below 1.8 MeV. The neutron separation energy, S_n, was determined to be 7545.3 ± 2.0 keV.

TABLE X. Secondary γ rays from the ^{114}Sn(n,γ) ^{115}Sn reaction

$E_\gamma{}^a$ (keV)	$E_\gamma{}^a$ (keV)	$E_\gamma{}^a$ (keV)
489.6 *25*	1416.7 *20*	1868.0^b *20*
497.4 *15*	1633.8 *15*	1965.5^b *20*
986.6 *20*	1666.1^b *20*	2190.0^b *20*
1235.1 *20*	1732.8^b *20*	2259.3^b *20*
1279.8 *15*	1832.6^b *20*	2371.2^b *20*

[a] In our notation 489.6 *25* ≡ 489.6 ± 2.5, etc.
[b] Not placed on the level scheme.

IV. MODEL CALCULATIONS

A. Level Systematics

The known levels below 1.5 MeV in six odd isotopes of tin are shown in Fig. 12. The low-lying $1/2^+$, $3/2^+$ and $11/2^-$ states are believed to be predominantly one-quasiparticle states. Their energies change in a regular way with neutron number. The $7/2^+$ hole state rises in energy with increasing neutron number as expected. The tentative identification of $7/2^-$ and $9/2^-$ states in the heavier (A>119) Sn isotopes was accomplished only recently.[8,9,29]

B. Weak-coupling model

It has been suggested that the odd-mass Sn isotopes may be described within the framework of a weak-coupling model.[6] We have performed calculations on ^{115}Sn, ^{117}Sn and ^{119}Sn in order to test this hypothesis. Our assumption is that the low-lying states of the odd-mass Sn isotopes (E < 1.5 MeV) may be described by coupling a single quasiparticle, which may occupy the $3s_{1/2}$, $2d_{3/2}$, $2d_{5/2}$, $1g_{7/2}$, $1h_{11/2}$ states, to the ground-state or first excited state of the neighboring even-mass core.

TABLE XI. Energy levels in ^{115}Sn

Other works^a Energy (keV)	Present work Energy (keV)	$J^{\pi b}$	Reasons for J^π assignments^c
0.0	0.0	$1/2^+$	Atomic beam; Magnetic moment; $\ell_n = 0$ in (d,p), (p,d) and (d,t)
497.35 *5*	497.1 *12*	$3/2^+$	Angular distribution in Coulomb excitation
612.79 *6*		$(7/2)^+$	$\ell_n = 4$ in (d,p), (p,d) and (d,t); γ transition to 497 level is $E2$
713.2 *2*		$(11/2)^-$	$\ell_n = 5$ in (d,p), (p,d) and (d,t); γ transition to 613 keV level is $M2$
986.54 *8*	985.5 *14*	$5/2^+$	Angular distribution in Coulomb excitation; $\ell_n = 2$ in (d,p), (p,d) and (d,t)
1280.1 *2*	1279.7 *13*	$3/2^+$	Angular distribution in Coulomb excitation; $\ell_n = 2$ in (d,p), (p,d) and (d,t)
1416.8 *1*	1417.1 *15*	$5/2^+$	Angular distribution in Coulomb excitation; $\ell_n = 2$ in (p,d) and (d,t)
1633.8 *1*	1633.9 *13*	$3/2^+$, $5/2^+$	$\ell_n = 2$ in (p,d) and (d,t)
1734.1 *1*	1732.2 *24*	$3/2^+$, $5/2^+$	$\ell_n = 2$ in (p,d) and (d,t)
	•••		
	•••		
	7545.3^d *20*		

[a] Mainly from Coulomb excitation - Ref. 20; and [$5/2^+$, 32-m ^{115}Sb decay] - Ref. 19. In our notation for level energy 497.35 *5* ≡ 497.35 ± 0.05, etc.
[b] Parentheses around a J-value imply that the assignment is probable but not certain beyond reasonable doubt.
[c] The atomic beam measurements are by W. J. Childs and L. S. Goodman, Phys. Rev. 137, A35 (1965). The other data referred to in this column are from the following references: (d,p) - Ref. 7; (p,d) - Ref. 10; (d,t) - Ref. 23; Coulomb excitation - Ref. 20; multipolarities - Ref. 21.
[d] Neutron separation energy.

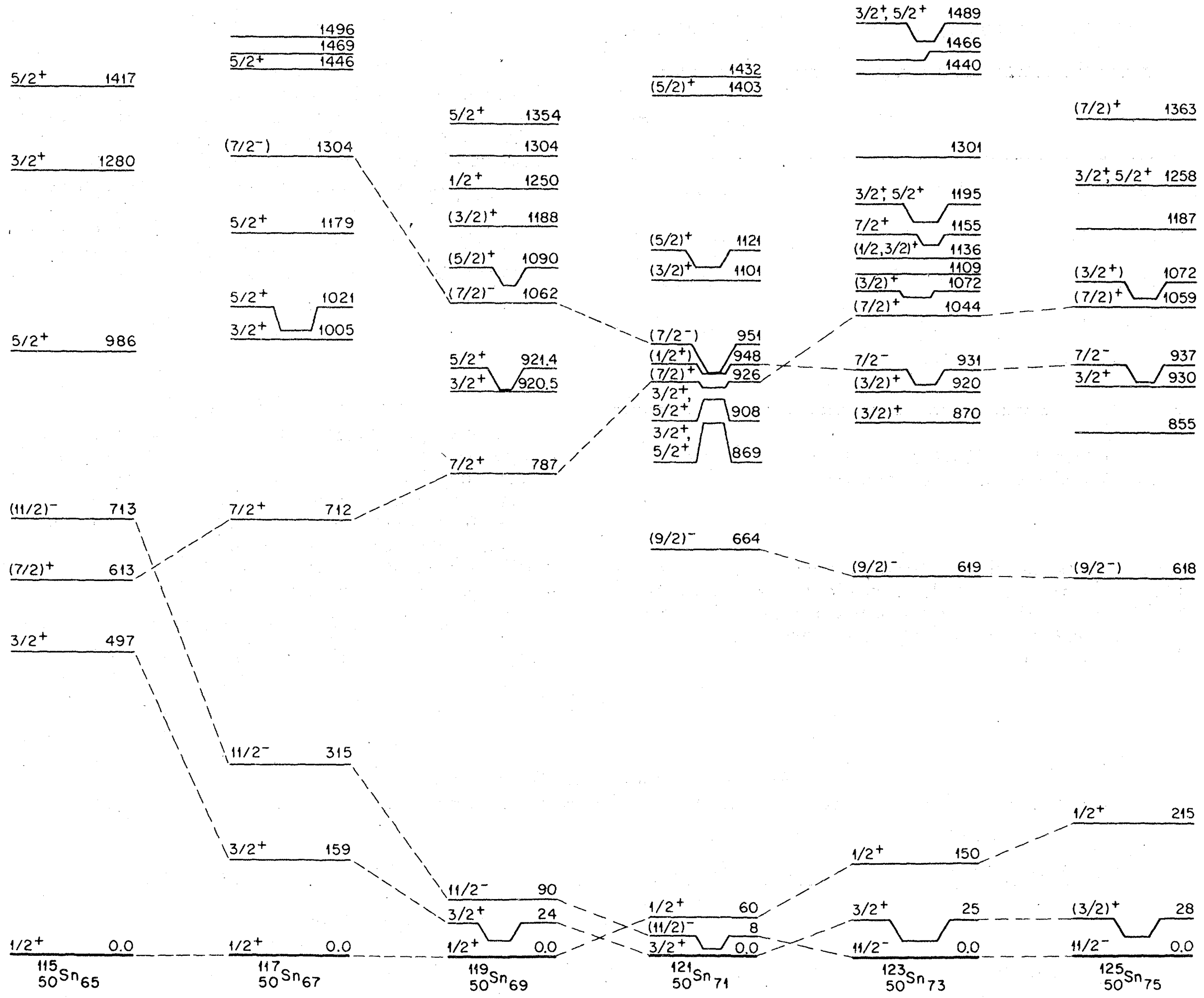

FIG. 12. A comparison of the energy levels below 1.5 MeV in six odd Sn isotopes. The ^{121}Sn level scheme is from Ref. 1. However, we have changed the $(3/2)^+$ and $(5/2)^+$ assignments for the 869- and 908-keV levels, respectively in Ref. 1 to a $3/2^+$ or $5/2^+$ assignment for both levels as being more representative of the data. A $5/2^+$ assignment for the 869-keV level and a $(9/2)^-$ assignment for the 664-keV level are preferred in Ref. 29. The ^{123}Sn and ^{125}Sn level schemes are from Ref. 2. [The J^π value for the 619-keV level is incorrectly printed as $(9/2)^+$ in Table III of Ref. 2, whereas it should read $(9/2)^-$.]

The properties of these states have been calculated using a model which is essentially equivalent to the core-excitation model of Thankappan and True.[30] Thus we shall confine ourselves to a brief description of the model, noting the differences between the present model of calculation and that in Ref. 30.

The Hamiltonian of the odd-mass system is taken to be

$$H = H_c + H_p + H_{int} \tag{1}$$

where H_c and H_p are the Hamiltonians describing the core and single quasiparticle, respectively. The interaction between the core and quasiparticle is assumed to have the form

$$H_{int} = -\chi_1 \mathbf{J}_c \cdot (\mathbf{s}_p + \xi \boldsymbol{\ell}_p) - \chi_2 \sum_\mu Q_\mu(c)^\dagger Q_\mu(p) \tag{2}$$

where $\mathbf{J}_c$ is the angular momentum, $\mathbf{s}_p$ and $\boldsymbol{\ell}_p$ are the quasiparticle spin and orbital angular momentum, respectively; $Q_\mu(c)$ and $Q_\mu(p)$ are quadrupole operators assumed to have the same functional form as the corresponding electromagnetic quadrupole operators, and χ_1, χ_2, and ξ are strength parameters (ξ is assumed to be 1 in Ref. 30). We define a new strength parameter, the one actually used in the calculation, $\hat{\chi}_2 = \chi_2 \langle 0^+ \| Q(c) \| 2^+ \rangle$.

The matrix elements needed to construct the Hamiltonian were taken from experiment wherever possible. The energies of the core states and the ratio $\langle 2^+ \| Q(c) \| 2^+ \rangle / \langle 0^+ \| Q(c) \| 2^+ \rangle$ (the latter quantity was assumed to be an adjustable parameter in Ref. 30) were taken from Ref. 31. The energies and occupation numbers of the quasiparticle states were taken from Ref. 7. Harmonic oscillator wave functions were used in calculating the matrix elements of $Q(p)$ with an oscillator parameter, $\alpha = 1/A^{1/3}$.

The Hamiltonian matrix was then diagonalized and the *M1* and *E2* moments and transition rates were calculated using the resulting wave functions. For the *M1* calculations it was assumed that the core gyromagnetic ratio was $0.4 \approx Z/A$, the quasiparticle spin g factor was taken to be half that of a free neutron for all allowed single particle transitions, and finally a value of $0.7\mu_N$ was given to the ℓ-forbidden reduced matrix element, $\langle s_{1/2} | M1 | d_{3/2} \rangle$, in order to reproduce the first excited state to ground state experimental transition rates. In calculating the *E2* moments and transition rates, the core matrix elements were taken from Ref. 31 and an effective charge of 1.5 e was assigned to the quasiparticle. For ^{114}Sn, the following values were assumed in the calculations: quadrupole moment = 0.0 e fm^2 and $B(E2,\ 2^+ \to 0^+) = 420\ e^2$ fm^4 (Ref. 32).

The three parameters χ_1, $\hat{\chi}_2$, and ξ were varied to give the best fit to all the available data on energies, moments, and transition rates for ^{115,117,119}Sn. Initially a single set of parameters was sought for all three nuclei; however this effort was only partially successful. It was found that $\chi_1 = -0.1$ MeV, $\hat{\chi}_2 = -0.1$ MeV/fm^2 and $\xi = 0.15$ gave a satisfactory fit for ^{117,119}Sn and for the negative parity states of ^{115}Sn. However, the *E2* transition rates in ^{115}Sn suggest that the basis state $|2^+ g_{7/2};\ J\rangle$ is an important component of many of the low-lying states.[20] In order to produce a sufficient admixture of this component it was necessary to set $\chi_1 = -0.078$ MeV, $\hat{\chi}_2 = -0.121$ MeV/fm^2, and $\xi = 1$ for the positive parity states of ^{115}Sn.

C. Results of model calculations

The results of the calculations of the static properties of the low-lying levels in ^{115}Sn, ^{117}Sn, and ^{119}Sn are presented in Tables XII, XIII and XIV, respectively. In each of these tables the calculated levels are juxtaposed with the experimental level to which it was assumed to correspond in the fitting procedure. On the basis of the argument in section III A, it was assumed that the 1090 keV level in ^{119}Sn (Table XIV) has a spin of $5/2^+$. The wave functions of the positive parity states are given in Table XV.

The energies of the first three excited states are in good agreement with experiment for all three nuclei. Each of these states and the ground state are found to be strongly single particle in character. Hence the agreement between experiment and calculation arises largely because the single particle energies have been taken from experiment. Beyond the third excited state one finds the agreement to be less satisfactory. In particular one finds that the model generates more states than are seen experimentally, particularly negative parity states.

The calculated magnetic moment of the ground state is in good agreement with experiment for all

TABLE XII. Properties of levels in ^{115}Sn

Level energy (MeV) Calc.	Exp.	J^π Calc.	Exp.	Magnetic moment (μ_N) Calc.	Exp.	Quadrupole moment (e fm^2) Calc.	Exp.
0.0	0.0	$1/2^+$	$1/2^+$	-0.92	$-(0.92^a \pm 0.01)$		
0.461	0.497	$3/2_1^+$	$3/2_1^+$	+0.61		-14.0	
0.570	0.613	$7/2^+$	$7/2^+$	+0.79		+38.8	$\pm(26^b \pm 3)$
0.688	0.713	$11/2^-$	$11/2^-$	-0.94	$-(1.3^c \pm 0.02)$	-44.9	$\pm(38^d \pm 6)$
1.241	1.280	$3/2_2^+$	$3/2_2^+$	+0.63		+4.3	
1.272		$3/2_3^+$					
1.374	0.986	$5/2_1^+$	$5/2_1^+$	-0.19		+8.4	
1.424	1.417	$5/2_2^+$	$5/2_2^+$	+0.02		+2.1	

[a] W. G. Proctor, Phys. Rev. 79, 35 (1950).

[b] H. Bertschat, O. Echt, H. Haas, E. Ivanov, E. Recknagel, E. Schlodder, B. Spellmeyer, M. Ionescu-Bujor, A. Iordachescu, G. Pascovici, D. Plostenaru and S. Vajda, Hyperfine Interactions 2, 326 (1976).

[c] N. Bräuer, B. Focke, B. Lehmann, E. Matthias and D. Riegel, Phys. Lett. 34B, 54 (1971); E. A. Ivanov, A. Iordachescu and G. Pascovici, Rev. Roum. Phys. 20, 141 (1975).

[d] D. Riegel, Phys. Scr. 11, 228 (1975).

TABLE XIII. Properties of levels in ^{117}Sn

Level energy (MeV)		J^π		Magnetic moment (μ_N)		Quadrupole moment (e fm^2)	
Calc.	Exp.	Calc.	Exp.	Calc.	Exp.	Calc.	Exp.
0.0	0.0	$1/2^+$	$1/2^+$	-0.98	$-(1.00^a \pm 0.01)$		
0.168	0.159	$3/2^+_1$	$3/2^+_1$	+0.55	$+(0.68^b {}^{+0.22}_{-0.45})$	-8.3	
0.294	0.315	$11/2^-$	$11/2^-$	-0.94		-38.7	
0.681	0.712	$7/2^+$	$7/2^+$	+0.74		+34.2	
1.159	1.021	$5/2^+_1$	$5/2^+_1$	-0.77		+22.8	
1.162	1.005	$3/2^+_2$	$3/2^+_2$	+1.32		+5.0	
1.372	1.304	$7/2^-$	$7/2^-$	-1.50		-12.4	
1.438		$9/2^-$		-1.04		-19.0	
1.450	1.179	$5/2^+_2$	$5/2^+_2$	+0.72		+4.6	
1.481	1.446	$5/2^+_3$	$5/2^+_3$	+0.01		+9.5	

[a] W. G. Proctor, Phys. Rev. 79, 35 (1950).
[b] P. John, B. Reuse and H. Schneider, Z. Physik 254, 142 (1972).

TABLE XIV. Properties of levels in ^{119}Sn

Level energy (MeV)		J^π		Magnetic moment (μ_N)		Quadrupole moment (e fm^2)	
Calc.	Exp.	Calc.	Exp.	Calc.	Exp.	Calc.	Exp.
0.0	0.0	$1/2^+_1$	$1/2^+_1$	-1.00	$-(1.05^a \pm 0.01)$		
0.053	0.024	$3/2^+_1$	$3/2^+_1$	+0.56	$+(0.63^b \pm 0.01)$	-3.4	$-(6.5^c \pm 0.5)$ $-(9.4^d \pm 0.4)$
0.102	0.090	$11/2^-$	$11/2^-$	-0.95	$-(1.40^e \pm 0.08)$	-20.7	$-(13^f \pm 4)$ $-(21^d \pm 2)$
0.772	0.787	$7/2^+_1$	$7/2^+_1$	+0.71		+29.3	
1.063	1.062	$7/2^-$	$(7/2)^-$				
1.116	0.920	$3/2^+_2$	$3/2^+_2$	+1.30		+3.7	
1.152	1.304	$9/2^-$	$>7/2$				
1.208	0.921	$5/2^+_1$	$5/2^+_1$	-0.35		+15.7	
1.281		$11/2^-$					
1.290	1.090	$5/2^+_2$	$(5/2)^+_2$	+0.81		+2.8	
1.296		$7/2^+_2$					
1.297	1.188	$3/2^+_3$	$(3/2)^+_3$	+0.68		+18.7	
1.307	1.250	$1/2^+_2$	$1/2^+_2$	+0.25			
1.417		$13/2^-$					
1.554	1.354	$5/2^+_3$	$5/2^+_3$	-0.57		+8.7	

[a] W. G. Proctor, Phys. Rev. 79, 35 (1950).
[b] G. Crecelius, Z. Phys. 258, 56 (1973).
[c] H. Micklitz and P. H. Barrett, Phys. Rev. B 5, 1704 (1972).
[d] F. Dimmling, D. Riegel, K.-G. Rensfelt and C.-J. Herrlander, Phys. Lett. 55B, 293 (1975).
[e] D. F. Gumprecht, T. E. Katila, L. C. Moberg and P. O. Lipas, Phys. Lett. 40A, 297 (1972).
[f] G. N. Beloserski, D. Gumprecht and P. Steiner, Phys. Lett. 42B, 349 (1972).

TABLE XV. Wave functions of positive parity states in ^{115}Sn, ^{117}Sn and ^{119}Sn

Nucleus	Level energy (MeV)	J	$\|0^+\ j = J\rangle$	$\|2^+\ s_{1/2}\rangle$	$\|2^+\ d_{3/2}\rangle$	$\|2^+\ d_{5/2}\rangle$	$\|2^+\ g_{7/2}\rangle$
^{115}Sn	0.0	1/2	0.987	...	0.161	0.025	...
	0.461	3/2	0.962	0.216	0.141	0.006	-0.090
	0.570	7/2	-0.967	...	0.034	0.024	0.251
	1.241	3/2	-0.069	0.648	-0.032	-0.001	0.758
	1.272	3/2	-0.208	0.728	-0.106	-0.002	-0.645
	1.374	5/2	0.641	0.476	-0.015	-0.067	0.598
	1.424	5/2	0.152	-0.847	-0.004	-0.017	0.509
^{117}Sn	0.0	1/2	-0.995	...	0.027	0.096	...
	0.168	3/2	-0.995	-0.026	-0.070	0.016	0.059
	0.681	7/2	-0.976	...	0.099	0.038	0.189
	1.159	5/2	0.874	-0.452	0.051	-0.152	0.079
	1.162	3/2	0.024	-0.999	0.019	-0.012	-0.003
	1.450	5/2	0.133	0.348	0.926	0.058	0.037
	1.481	5/2	0.422	0.821	-0.365	-0.016	0.054
^{119}Sn	0.0	1/2	-0.993	...	-0.029	0.117	...
	0.053	3/2	-0.997	0.028	-0.029	0.027	0.059
	0.772	7/2	-0.972	...	0.162	0.040	0.167
	1.116	3/2	0.027	0.999	0.029	0.010	-0.003
	1.208	5/2	0.635	-0.690	0.325	-0.104	0.060
	1.290	5/2	-0.135	0.303	0.938	0.097	-0.003
	1.297	3/2	-0.027	-0.029	0.998	0.057	0.011
	1.307	1/2	-0.024	...	0.999	0.037	...
	1.554	5/2	-0.721	-0.657	0.090	0.167	-0.111

three nuclei both in magnitude and in the systematic variation from ^{115}Sn to ^{117}Sn to ^{119}Sn. These small differences in the calculated moments arise from very small admixtures of core excited multiplets into the almost purely single particle ground state. The calculated magnetic moment of the first excited $3/2^+$ state is somewhat lower than the available experimental values and the lowest energy $11/2^-$ state moments are considerably lower than experiment. Therefore the assumption made that the quenching of all the magnetic dipole single particle matrix elements could be accounted for by a 50% reduction of the bare neutron spin g factor is an oversimplification.

The data available on electric quadrupole moments are sparse. However, agreement between calculation and experiment is reasonable in the four cases where comparison is possible. The experimental values exist only for predominantly (>95%) single particle states, yet in each case approximately 50% of the calculated moment is due to the small admixture of core-excited states in the wave functions. Thus these moments are quite sensitive to the interaction strengths.

The results of the calculation of the reduced electromagnetic transition rates between positive parity states in ^{115}Sn, ^{117}Sn and ^{119}Sn and the available experimental data are presented in Tables XVI, XVII and XVIII, respectively. One finds that the agreement with experiment is in general much better for the electric quadrupole rates than for the magnetic dipole rates. There is a marked tendency for the model to underestimate $B(M1)$, at times by many orders of magnitude. Since $M1$ transitions occur only between states belonging to the same core multiplet, the underestimation of the $M1$ transition rates may be due to insufficient mixing among these multiplets. The calculated quadrupole transition rates are, on the other hand, qualitatively and often quantitatively in agreement with the experimental data. For instance, the experimental $B(E2)$ for the transition between the first excited state and the ground state drops from $70e^2\mathrm{fm}^4$ in ^{115}Sn to $3.1e^2\mathrm{fm}^4$ in ^{117}Sn and is $<22e^2\mathrm{fm}^4$ in ^{119}Sn while the calculated values are 124, 3.1, and 3.9 $e^2\mathrm{fm}^4$, respectively. If one makes similar comparisons for other transitions, one finds that, although there may not be precise quantitative agreement between calculation and experiment, the trends in the $B(E2)$ data are reproduced by the calculation.

In summary the model is successful in describing

TABLE XVI. Reduced electromagnetic transition rates between positive parity states of ^{115}Sn

Transition[a]	$B(E2)$ (e^2 fm^4)		$B(M1)$ (μ_N^2)	
$J_i \to J_f$	Calc.	Exp.[b]	Calc.	Exp.[b]
$3/2_1 \to 1/2$	124	70 ± 4	2.81×10^{-2}	or $(2.72 \pm 0.40) \times 10^{-2}$ $(1.33 \pm 0.20) \times 10^{-4}$
$7/2 \to 3/2_1$	11.0	$12.2^{c} \pm 0.3$		
$3/2_2 \to 1/2$	153	222 ± 19	5.44×10^{-7}	or $(5.2 \pm 0.8) \times 10^{-3}$ (3.1 ± 0.6)
$3/2_2 \to 3/2_1$	0.5	$105 ^{+120}_{-83}$	4.61×10^{-3}	$(7.5 ^{+3.4}_{-4.1}) \times 10^{-3}$
$3/2_2 \to 7/2$	241	244 ± 57		
$5/2_1 \to 1/2$	113	76 ± 4		
$5/2_1 \to 3/2_1$	0.2	or 11 ± 9 6500 ± 40	1.57×10^{-1}	or $(1.14 \pm 0.06) \times 10^{-1}$ $(6.7 \pm 0.9) \times 10^{-3}$
$5/2_1 \to 7/2$	158	or 87 ± 28 1130 ± 110	4.07×10^{-4}	or $(1.20 \pm 0.11) \times 10^{-2}$ $(1.90 \pm 0.40) \times 10^{-3}$
$5/2_2 \to 1/2$	298	199 ± 11		
$5/2_2 \to 3/2_1$	0.3	or 14 ± 4 500 ± 60	4.18×10^{-3}	or $(2.9 \pm 0.3) \times 10^{-2}$ $(4.3 \pm 1.8) \times 10^{-4}$
$5/2_2 \to 7/2$	93		6.80×10^{-4}	
$5/2_2 \to 5/2_1$	3.4	$150 ^{+400}_{-150}$	5.94×10^{-3}	$(6.2 ^{+1.8}_{-4.8}) \times 10^{-3}$

[a] See also Table XII.
[b] From Coulomb excitation measurements (Ref. 20).
[c] Calculated from the mean lifetime for this level measured by E. A. Ivanov, A. Iordachescu and G. Pascovici, Rev. Roum. Phys. 13, 879 (1968).

TABLE XVII. Reduced electromagnetic transition rates between positive parity states of ^{117}Sn.

Transition[a]	$B(E2)$ (e^2 fm^4)		$B(M1)$ (μ_N^2)	
$J_i \to J_f$	Calc.	Exp.[b]	Calc.	Exp.[b]
$3/2_1 \to 1/2$	3.1	3.1 ± 0.4	2.8×10^{-2}	$(2.7 \pm 0.3) \times 10^{-2}$
$5/2_1 \to 1/2$	185	207 ± 10		
$5/2_1 \to 3/2$	5.0	44 ± 10	1.9×10^{-1}	$(1.12 \pm 0.07) \times 10^{-1}$
$3/2_2 \to 1/2$	396	365 ± 15	3.6×10^{-8}	$\approx 5 \times 10^{-5}$
$3/2_2 \to 3/2_1$	0.24	3.2 ± 0.9	4.9×10^{-6}	$(8.6 \pm 0.5) \times 10^{-3}$
$5/2_2 \to 1/2$	39	23 ± 2		
$5/2_2 \to 3/2_1$	348	>230	6.0×10^{-3}	$>7 \times 10^{-2}$
$5/2_3 \to 1/2$	193	120 ± 7		
$5/2_3 \to 3/2_1$	44	21 ± 7	5.5×10^{-2}	$(1.55 \pm 0.13) \times 10^{-2}$
$5/2_3 \to 7/2$	5	<90	5.7×10^{-4}	

[a] See also Table XIII.
[b] From Coulomb excitation measurements (Ref. 6).

TABLE XVIII. Reduced electromagnetic transition rates between positive parity states of ^{119}Sn

Transition[a] $J_i \rightarrow J_f$	$B(E2)$ (e^2 fm^4) Calc.	$B(E2)$ (e^2 fm^4) Exp.[b]	$B(M1)$ (μ_N^2) Calc.	$B(M1)$ (μ_N^2) Exp.[b]
$3/2_1 \rightarrow 1/2_1$	3.9	<22	2.8×10^{-2}	2.7×10^{-2}
$3/2_2 \rightarrow 1/2_1$	408	360 ± 35	1.3×10^{-6}	$\approx 2 \times 10^{-4}$
$3/2_2 \rightarrow 3/2_1$	0.7	3	3.1×10^{-4}	8×10^{-3}
$5/2_1 \rightarrow 1/2_1$	329	200 ± 25		
$5/2_1 \rightarrow 3/2_1$	63	56	3.0×10^{-1}	3.5×10^{-2}
$5/2_2 \rightarrow 1/2_1$	50	103 ± 5		
$5/2_2 \rightarrow 3/2_1$	341	116 ± 24	1.3×10^{-2}	$(1.4 \pm 0.2) \times 10^{-1}$
$5/2_3 \rightarrow 1/2_1$	64	77 ± 5		
$5/2_3 \rightarrow 3/2_1$	0.01	24 ± 5 or 182 ± 20	1.5×10^{-1}	$(3.1 \pm 0.3) \times 10^{-2}$ or $(1.1 \pm 0.2) \times 10^{-2}$

[a] See also Table XIV.
[b] From Coulomb excitation measurements (Ref. 6).

^{115}Sn, ^{117}Sn and ^{119}Sn in a qualitative manner. When one makes detailed comparisons between experiment and calculation, however, there are often large discrepancies.

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