^{104}Ag Spin Assignments

W.H. Bentley, L. E. Samuelson, R.A. Warner, W.H. Kelly, R. Shamu* and E.M. Bernstein*

Little is known about the structure of medium and heavy mass odd-odd nuclei. This is due to the complexity of the level structure these nuclei display. However, with encouragement from recent knowledge of neighboring even-even and odd mass nuclei, and the present techniques of high resolution γ-ray spectroscopy, a series of studies of selected odd-odd nuclei have been undertaken.

The levels of odd-odd ^{104}Ag have been previously studied by observing γ-rays following the ^{104}Pd(p,nγ) and ^{103}Rh(α,3nγ) reactions. A level scheme derived from the results of these experiments has been reported.[1] However, only a few of the levels had known spins. These were determined by atomic-beam measurements[2] and β-decay studies of the 0^+ ground state of ^{104}Cd.[3] In order that additional spin assignments might be made, a γ-ray angular distribution experiment was performed.

A 5.47 MeV proton beam produced by the Michigan State University cyclotron was used to bombard a self-supporting isotopically enriched foil of ^{104}Pd. States up to 350 keV of excitation energy were populated with this beam. A high resolution Ge(Li) detector mounted on the arm of our goniometer apparatus was used to take γ-ray singles spectra at various random angles. A normalization was provided by observing elastically scattered protons at 45^{o} with a Si surface barrier detector. The resulting distributions were fit to an expansion of Legendre Polynomials to give the experimental A_2 and A_4 coefficeints. These were compared with theoretical values as calculated by the compound nuclear evaporation code MANDY.[4] The known spins and parities of the ground state and first two excited states were then used as a basis of assignment of spins to several of the remaining levels. The results of this experiment are listed in Table I. Transitions which appear in the level scheme of Ref. 1 and do not appear in this table were too weak for reliable intensities to be extracted.

Additional support for the spin assignments was gained by analysis of γ-ray excitation function data. This experiment was performed using the Western Michigan University Tandem Van de Graaff accelerator. Protons ranging in energy from 5.051 to 6.004 MeV (in ~50 keV steps) were used to bombard the same ^{104}Pd target as was used in the angular distribution experiment. The results of this experiment were put in the form of cross-section ratios and then compared with predictions of the code MANDY. The resulting allowed spin values as determined by this comparison are listed in Table II. The 26.71 keV transition between the 157.37 and 130.66 keV levels was too low in energy to be seen in these measurements. Therefore, only lower and upper limits could be determined for these levels respectively. Similarly the 6.88 keV transition was not seen, so nothing could be said about the spin of the 6.88 keV level. The 83.68 keV level was assumed to have a spin of 1.

Combining the results of these two experiments several spin assignments could be made. These are listed in Table III.

*Accelerator Laboratory, Department of Physics and Astronomy, Western Michigan University.

1. L.E. Samuelson, C.B. Morgan, M.F. Slaughter, J.A. Guile, R.A. Warner, William C. McHarris, T.L. Khoo, W.H. Kelly, E.M. Bernstein, and R. Shamu, MSUCL Annual Report, 1973-74, p. 54-55.
2. W.B. Ewbank, L.L. Marino, W.A. Nierenberg, H.A. Shugart, and H.B. Silsbee, Phys. Rev. 115, 614(1959), and O. Ames, A.M. Bernstein, M.H. Brennan, B.A. Haberstroh, and D.R. Hamilton, Phys. Rev. 118, 1599(1960).
3. F. Munnich, A. Khelberg, D.J. Hnatowich, Nucl. Phys. A158, 183(1970).
4. E. Sheldon and R.M. Strang, Computer Phys. Comm. 1, 35(1969), and references cited therein.

Table I.--Experimental A_2 and A_4 angular distribution coefficients with proposed initial and final spins.

Transition Energy (KeV)	A_2	A_4	J_i	J_f
83.68	-0.061±0.024	0.008±0.032	1	2
123.78	-0.214±0.023	0.007±0.029	3	2
66.81	-0.221±0.025	-0.011±0.032	2	1
150.45	-0.048±0.058	0.080±0.079	2	2
73.95	-0.310±0.038	-0.065±0.044	3	2
224.44	-0.272±0.014	0.054±0.018	3	2
139.04	-0.245±0.031	0.092±0.040	4	3
269.70	-0.318±0.072	0.004±0.097	4	5
185.33	0.153±0.049	-0.077±0.069	2	2
212.05	-0.049±0.052	0.043±0.068	2	3
252.12	-0.186±0.030	0.034±0.035	2	1
335.82	0.201±0.037	0.047±0.048	2	2
341.24	-0.052±0.037	0.032±0.054	(1,2)	2

^{118}Sb Spin Assignments

W.H. Bentley, C.B. Morgan, R.A. Warner, W.H. Kelly, R. Shamu* and E.M. Bernstein*

In a continuation of the study of ^{118}Sb, two experiments were performed to determine the spins of the excited states in this nucleus. In addition, a reanalysis of some earlier data revealed needed corrections in the placement of some γ-rays and levels in the previously reported decay scheme.[1]

One of the experiments performed was a γ-ray angular distribution. A 30 MeV proton beam produced by the Michigan State University cyclotron was used to bombard a self-supporting isotopically enriched foil of ^{122}Sn. The proton beam energy was chosen to maximize the production of ^{118}Sb by means of the (p,3nγ) reaction. A high resolution Ge(Li) detector mounted on the arm of our goniometer apparatus was used to take γ-ray singles spectra at various random angles measured with respect to the beam direction. The intensities at each angle were extracted using the peak analysis code SAMPO. These intensities were then normalized using target X-rays. Fitting the resulting data to an expansion of Legendre Polynomials then gave the experimental A_2 and A_4 coefficients. These are listed in Table I. Known ^{118}Sb gamma transitions that do not appear in this table were either part of unresolvable multiplets or else too weak for accurate peak fitting. These coefficients were then compared to theoretical values to aid in assigning spins.

The other experiment also provided results which helped determine spins. This experiment was a γ-ray excitation function measurement. The tandem Van de Graaff located at Western Michigan University was used to provide proton beams ranging in energy from 4.625 MeV to 5.7 MeV. These were used to bombard an isotopically enriched ^{118}Sn foil. The lower energy in this range was near the threshold for production of ^{118}Sb by means of the (p,nγ) reaction. At each energy, a high resolution Ge(Li) detector was used to take γ-ray singles spectra. A normalization was provided by means of elastically scattered protons detected with a Si surface barrier detector. The results of this experiment were put in the form of cross-section ratios and then compared with predictions of the statistical compound nuclear model as calculated with the computer code MANDY.[2] The allowed spin assignments as determined by this comparison are listed in Table II.

Combining the results of these two experiments and previous spin assignments,[3] several new unambiguous spin assignments could be made. In addition, the data allowed tentative assignments to several other levels. The final results

Table II.--Allowed spin assignments as determined by comparing experimental γ-ray excitation function with the statistical compound nuclear model.

Level (KeV)	Allowed Spins
112.47	5,6
130.66	$\leq$ 3
157.37	$\geq$ 3
211.71	6
231.32	3
269.70	3,4
342.70	0,1,2
348.12	0,1,2

Table III.--Results of angular distribution and excitation function measurements on ^{104}Ag combined with previous spin assignments.

Level (KeV)	Spin
0.00	5^+
6.88	2^+
90.56	1^+
112.47	5,6
130.66	3
157.37	2
211.71	(6)
231.32	3
269.70	4
342.70	2
348.12	1,2

of this work are indicated on the level scheme shown in Fig. 1.

Also appearing in this decay scheme are some corrections to the previously reported decay scheme.[1] A more careful analysis of the heavy-ion data discussed in the last annual report revealed 5 additional high spin γ-rays that were added to the decay scheme. In addition, more accurate fitting of some of the multiplets gave improved energies to some of the γ-rays. The most notable difference, however, is the elimination of the 30.9 keV and 81.6 keV levels; and addition of the 238.5 keV level. This correction was made by looking at some previous γ-γ coincidence data. It became evident that the 103.7 keV γ-ray was not in coincidence with the 367.8 keV transition as was previously thought. In addition, it was found that the 238.5 keV transition was in prompt coincidence with the 367.8 keV γ-ray and in delayed coincidence with the other γ-rays now shown feeding the 269.4 keV level. This required that there exists an, as yet unseen, 30.9 keV γ-ray depopulating the delayed 269.5 keV level and feeding the 238.5 keV level. The last change is that the 273.9 keV transition feeds the 50.8 keV level. This increases the energies of all the high spin states built on this transition by 50.8 keV. This change was required by the high spin nature of the 2152.4 keV level, which decays to the 8^- isomer. The resulting level scheme is shown in Fig. 1.

*Accelerator Laboratory, Department of Physics and Astronomy, Western Michigan University.

1. W.H. Bentley, R.A. Warner, Wm. C. McHarris, and W.H. Kelly, MSU Cyclotron Lab Annual Report 1974-76 p. 55-56.
2. E. Sheldon and R.M. Strang, Computer Phys. Comm. 1, 35(1969), and references cited therein.
3. A.P. Jackson, Jr., E. H. Rogers, Jr., G.J. Garrett, Phys. Rev. 175, 75(1968); and P.T. Callaghan, M. Shott, N.J. Stone, Nucl. Phys. A221, 1(1974).

Table I.--Experimental A_2 and A_4 angular distribution coefficients for the transitions in ^{118}Sb.

Transition Energy (KeV)	A_2	A_4
50.8	0.118±0.035	0.076±0.049
103.7	-0.069±0.016	-0.018±0.026
115.4	-0.011±0.006	-0.025±0.011
128.4	-0.105±0.005	-0.013±0.009
153.7	-0.140±0.009	-0.013±0.015
187.7	-0.100±0.016	-0.024±0.027
209.3	-0.222±0.019	-0.017±0.029
216.2	-0.093±0.037	-0.011±0.055
222.4	0.387±0.058	-0.113±0.083
237.2	-0.129±0.019	-0.024±0.031
238.5	-0.057±0.011	-0.042±0.019
260.0	0.129±0.026	-0.021±0.044
273.9	-0.038±0.014	-0.028±0.023
293.8	0.249±0.087	0.123±0.133
303.3	-0.211±0.011	-0.022±0.016
318.2	-0.039±0.013	-0.053±0.022
324.2	-0.124±0.058	-0.008±0.075
396.6	-0.010±0.062	-0.117±0.085

Table II.--Allowed spin assignments as determined by comparing experimental excitation function data with the statistical compound nuclear model.

Level energy (KeV)	Possible Spin and parity
50.8	(3^+)
165.7	$1^{\pm},2^{\pm}$
238.5	$3^+,2^-,0^-$
269.4	$3^{\pm},0^-$
324.0	$1^{\pm},2^+$
397.7	$4^{\pm}$
403.2	$3^+,(0^-)$
540.3	$3^+,(0^-)$
556.9	$4^{\pm}$
568.4	$4^{\pm}$
606.3	$4^{\pm}(3^-)$
618.5	$4^{\pm}(5^+)$

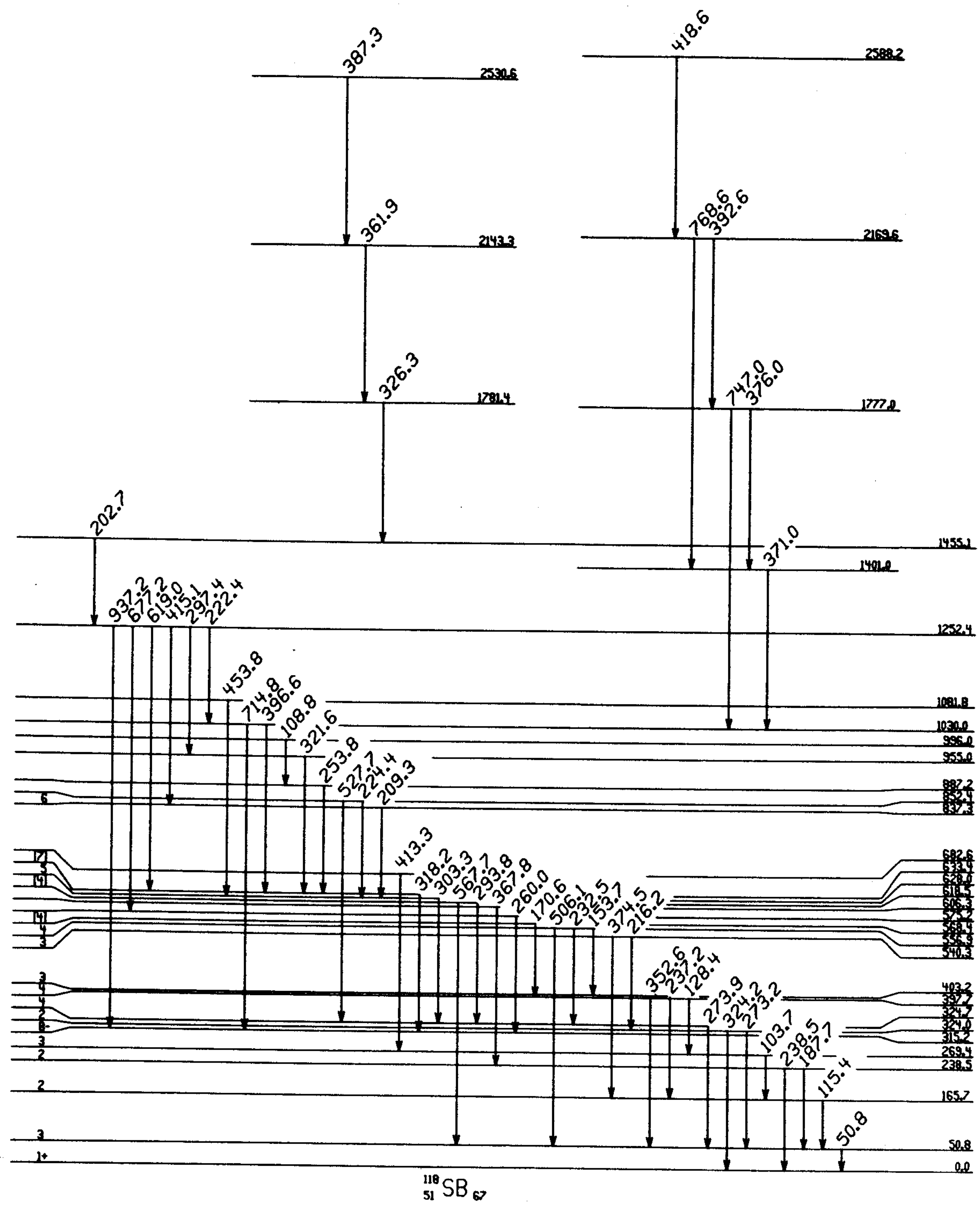


FIG. 1.--Partial level scheme for ^{118}Sb showing those states populated in the $^{114}Cd(^{7}Li,3n\gamma)$ and/or $^{120}Sn(p,3n\gamma)$ reactions.

High Spin States in ^{146}Sm and ^{148}Sm

C.H. King, B.A. Brown and T.L. Khoo

Recently there has been increasing interest in those nuclides with a few nucleons outside of a closed N=82 core because of predictions[1] that such nuclei would be particularly likely to contain yrast traps.[2] In addition, a study of nuclides a few nucleons removed from a closed shell can give insight into the sources of deformation in nuclei. Specific calculations[1] have been performed for the N=84 nuclide ^{146}Sm indicating that oblate deformations may occur at low spins (<10h), and thus we have been studying this nuclide using the reaction ^{146}Nd $(\alpha,4n\gamma)$ to search for rotational structures and possible isomers. In addition the reaction $^{148}Nd(\alpha,4n)$ was used to study ^{148}Sm to provide an isotopic comparison of the energy levels and the yrast trap predictions.

We have done γ-ray angular distributions, γ-γ coincidence measurements, γ-ray timing, and γ-ray excitation functions. γ rays depopulating the ^{146}Sm 2798-keV 9^- level were observed in only the first 5 nsec time bin indicating a lifetime on the order of one ns. Other strong γ rays (those above the 9^- level in ^{146}Sm and all γ rays in ^{148}Sm) were observed to be prompt relative to these.

The ^{146}Sm level scheme from the present experiment is shown in Fig. 1. Up to the 2737 keV 8_1^+ state our decay scheme is in agreement with previous $^{144}Nd(\alpha,2n\gamma)$ work.[3,4] Kownacki <u>et al</u>.[4] assigned the 986-keV γ-ray to a $10_1^+ \rightarrow 8_1^+$ transition, which is in disagreement with our coincidence data. However, the 986-keV transition is much weaker in the $(\alpha,2n\gamma)$ experiment.[3] Most of the decay scheme above 3 MeV has not been previously observed.

The ^{148}Sm decay scheme is shown in Fig. 2. The α beam energy was a little below the peak for the $^{148}Nd(\alpha,4n)$ cross section and fewer γ-γ coincidence data were taken. Thus, fewer transitions were placed in the ^{148}Sm decay scheme than in the ^{146}Sm scheme. Up to the 2545-keV 8^+ level the decay scheme is in agreement with Kownacki <u>et al</u>.; levels above the 8^+ are new in the present experiment.

The ^{146}Sm and ^{148}Sm level schemes are being interpreted as two- and four-particle neutron configurations coupled to a ^{144}Sm core. The high spin orbitals important for the neutrons are $2f_{7/2}$, $1h_{9/2}$ and $1i_{13/2}$. Much of the negative parity structure can be interpreted as an aligned coupling of the 3^- state to the positive parity ground-state band.

The 0^+, 2^+, 4^+ and 6^+ states in ^{148}Sm appear to be more vibrational in structure than in ^{146}Sm. Thus in the Sm isotopes we see the complete variation in nuclear structure from spherical j^2-like configurations in ^{146}Sm to vibrational structure in ^{148}Sm to rotational sequences in the heavier Sm nuclides (see Fig. 3). It will be interesting to see whether the high spin states in ^{146}Sm and ^{148}Sm can be fit into this picture.

1. R. Bengtsson <u>et al</u>., Phys. Lett. <u>57B</u>,301(1975).
2. A. Bohr and B.R. Mottelson, Phys. Script. <u>10A</u>,13(1974).
3. B. Singh and M.W. Johns, Can. J. Phys. <u>53</u>, 391(1975).
4. J. Kownacki <u>et al</u>., <u>Proc. Int. Conf. on Nuclear Structure and Spectroscopy</u>, edited by H.P Blok and A.E.L. Dieperink (Scholar's Press, Amsterdam, 1974), Vol. 1, p. 103.

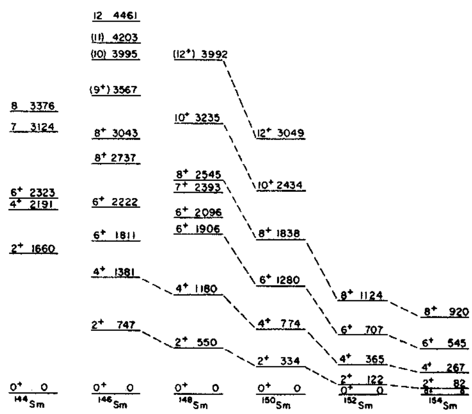
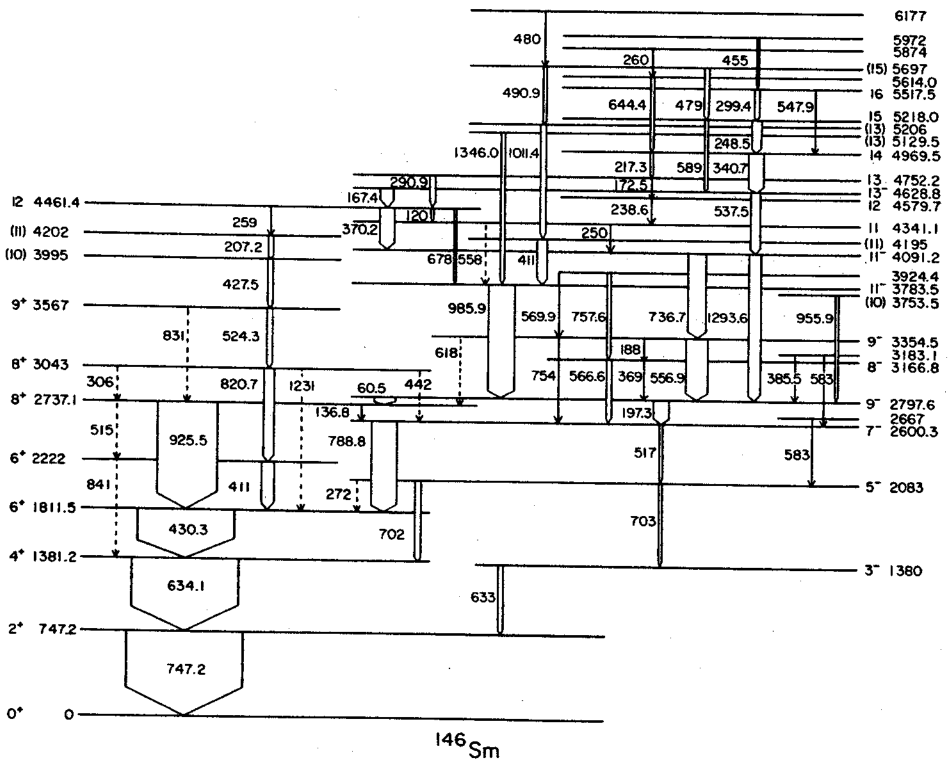
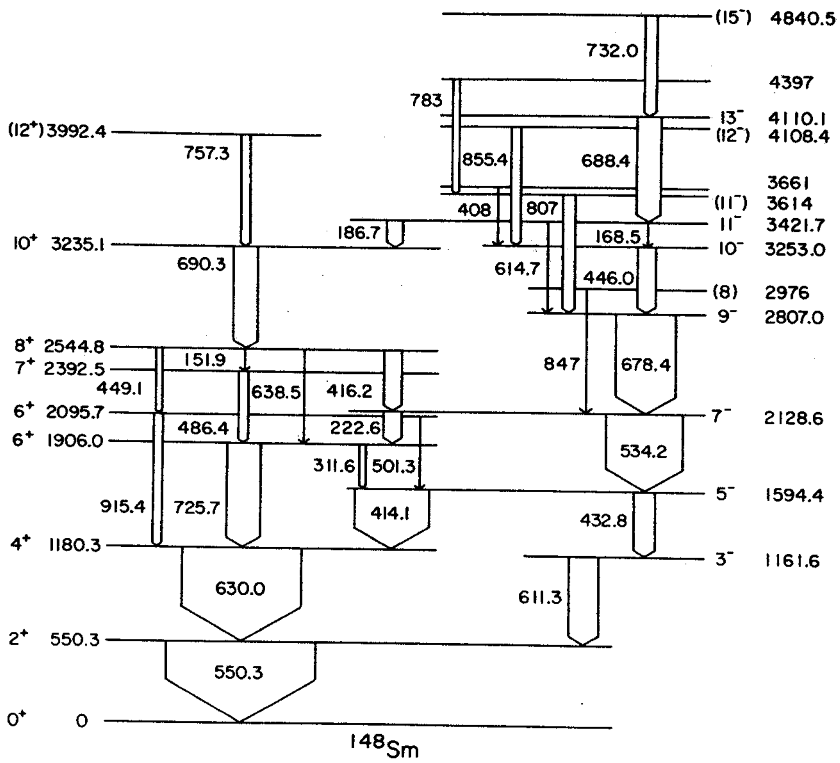


FIG. 3



6177
5972
5874
(15) 5697
5614.0
16 5517.5
15 5218.0
(13) 5206
(13) 5129.5
14 4969.5
13 4752.2
13⁻ 4628.8
12 4579.7
11 4341.1
(11) 4195
11⁻ 4091.2
3924.4
11⁻ 3783.5
(10) 3753.5
9⁻ 3354.5
3183.1
8⁻ 3166.8
9⁻ 2797.6
2667
7⁻ 2600.3
5⁻ 2083
3⁻ 1380
12 4461.4
(11) 4202
(10) 3995
9⁺ 3567
8⁺ 3043
8⁺ 2737.1
6⁺ 2222
6⁺ 1811.5
4⁺ 1381.2
2⁺ 747.2
0⁺ 0
480
490.9
260
455
644.4
479
299.4
547.9
248.5
1346.0
1011.4
217.3
589
340.7
172.5
238.6
537.5
290.9
167.4
120
370.2
250
259
207.2
678
558
411
427.5
985.9
569.9
757.6
736.7
1293.6
955.9
831
524.3
188
618
754
566.6
369
556.9
385.5
583
306
820.7
1231
60.5
442
136.8
197.3
515
925.5
788.8
517
583
411
272
841
430.3
702
703
634.1
633
747.2
146Sm

FIG. 1



(15⁻) 4840.5
732.0
4397
783
13⁻ 4110.1
(12⁻) 4108.4
(12⁺)3992.4
757.3
855.4
688.4
3661
408
807
(11⁻) 3614
186.7
11⁻ 3421.7
168.5
10⁺ 3235.1
10⁻ 3253.0
614.7
690.3
446.0
(8) 2976
9⁻ 2807.0
8⁺ 2544.8
7⁺ 2392.5
151.9
847
678.4
449.1
638.5
416.2
6⁺ 2095.7
6⁺ 1906.0
486.4
222.6
7⁻ 2128.6
534.2
311.6
501.3
5⁻ 1594.4
915.4
725.7
414.1
432.8
4⁺ 1180.3
3⁻ 1161.6
630.0
611.3
2⁺ 550.3
550.3
0⁺ 0
148Sm

FIG. 2

Excited State in the Odd-Odd Nucleus ^{198}Tl

M.J. Marshall, Wm. C. McHarris, R.A. Warner, R.B. Firestone, and W.H. Kelly

We have been investigating the states of the odd-odd nucleus ^{198}Tl populated by electron capture from ^{198}Pb. Since the single particle states in many of the neighboring odd mass nuclei are well characterized, this is a favorable region for studying the properties of relatively non-deformed odd-odd systems.

^{198}Pb was produced by the ^{198}Hg(τ,3n)^{198}Pb reaction on ^{198}HgO with a 28 MeV ^{3}He beam from the Michigan State University (MSU) sector focused cyclotron. The optimum energy of 28 MeV was determined using the neutron evaporation code CS8N.[1] We used large volume Ge(Li) detectors in both singles and coincidence mode to study the γ-ray decay of ^{198}Pb and deduce the states in ^{198}Tl. From the singles spectra we were able to detect three new γ-ray transitions at 275.3-, 665.7-, and 691.9-keV. The coincidence data then led to the additional new γ-ray transitions of 208.6-, 365.0-, 483.3-, and 743- keV and two new levels, 1140.7- and 1230.4- keV. The 1140.7-keV level was placed by coincidence between 397.7 keV and 743 keV γ-rays and the 1230.4 keV level is determined from the coincidence of the 365-keV and the 865-keV γ-rays. These results are summarized in Fig. 1. The singles spectrum obtained from the decay of ^{198}Pb is shown in Fig. 2. The 743- and 865-keV gates are shown in Figs. 3 and 4, respectively.

A simple approach to assigning shell model configurations to the levels in Fig. 1 is to assume the ^{198}Tl wave functions are the simple vector coupled products of the lowest odd proton and odd neutron states. Also, if the p-n interaction is weak in comparison to spin orbit forces, we can utilize jj coupling rules. Obtaining the odd proton configurations from neighboring odd mass Tl isotopes and the odd neutron configurations from the 117 isotones, ^{195}Pt and ^{197}Hg, we were able to make configuration assignments to the ground state and first 3 excited states as shown in Fig. 1. Because of configuration mixing and lack of reliable spin assignments, we were unable to further characterize the higher excited states.

1. CS8N, a program developed at Berkeley and edited for the Michigan State University Cyclotron Laboratory Sigma-7 computer by Clare Morgan.

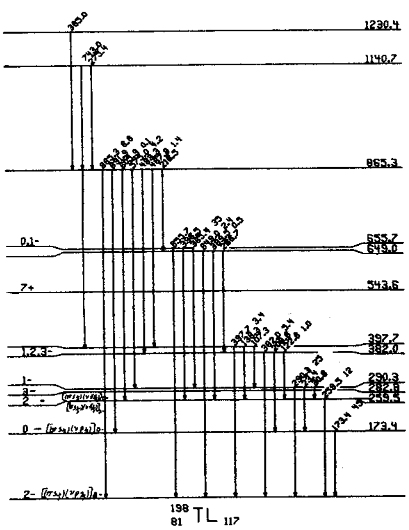


FIG. 1

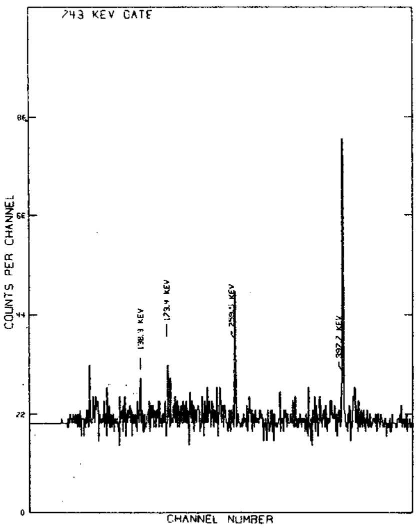


FIG. 3

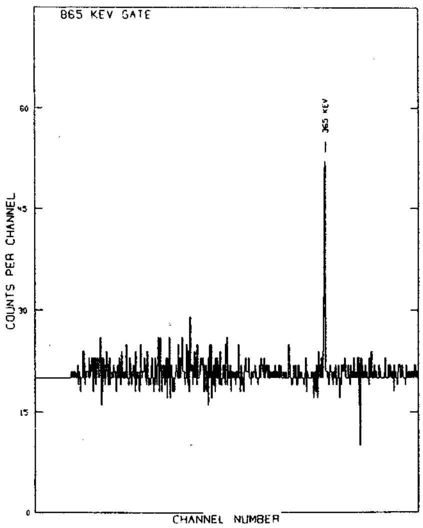


FIG. 4

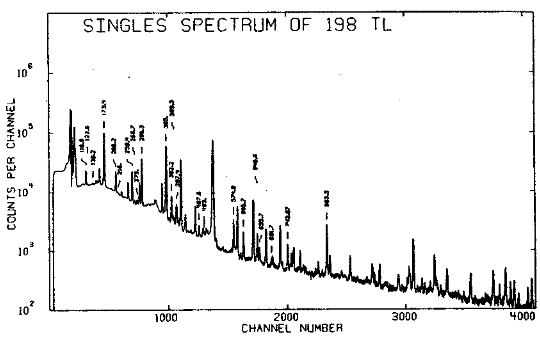


FIG. 2