SPIN-PARITY ASSIGNMENTS VIA NEUTRON DECAY OF ANALOG RESONANCE*

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Since an analog state is isospin forbidden to decay by neutron emission, an experimentally observed "analog resonance" in the (p,n) reaction is due to mixing[1] of the resonant state with densely populated nearby compound states of the same spin and parity J^π. That many compound states are involved in the mixing and that they do have the same J^π's implies that the degree of enhancement in the cross section of a (p,n) transition to a particular state of the residual nucleus depends on the spin and parity of that state in a simple way. Thus, a measurement of this enhancement is anticipated to be a useful spectroscopic tool.

If the spin and parity of the analog state is 0^+ (an analog of the ground state of an even-even nucleus), the situation is particularly simple. Then the spin and parity I^π of a residual state is uniquely given by the single values of the allowed orbital and total angular momenta $[I=j, \pi=(-1)^l]$ of the neutrons due to the decay of the analog resonance.

The potentiality of this technique is demonstrated in the present Letter by the study of the low-lying levels in ^{119}Sb via the reaction ^{119}Sn$(p,n)^{119}$Sb. The (p,n) reaction cross sections, as measured with a 4π-geometry neutron detection system,[2] are shown in Fig. 1. Those for ^{117}Sn are also given for comparison. The sharp anomalies shown in Fig. 1 occur at the incident energies where the $J^\pi = 0^+$ analogs of the ground states of ^{118}Sn and ^{120}Sn are expected. The neutron spectra were obtained by the time-of-flight method. The neutron spectra obtained at 90° for the ^{119}Sn target at the proton energies of 4.642 MeV (on resonance) and 4.709 MeV (off resonance) are shown in Fig. 2. The numbered peaks, n_1 through n_{13}, are readily identified with the reaction ^{119}Sn$(p,n)^{119}$Sb feeding known states of ^{119}Sb. The known information on the states excited is summarized in Table I. Since the enhanced differential cross sections are isotopic ($J^\pi = 0^+$),

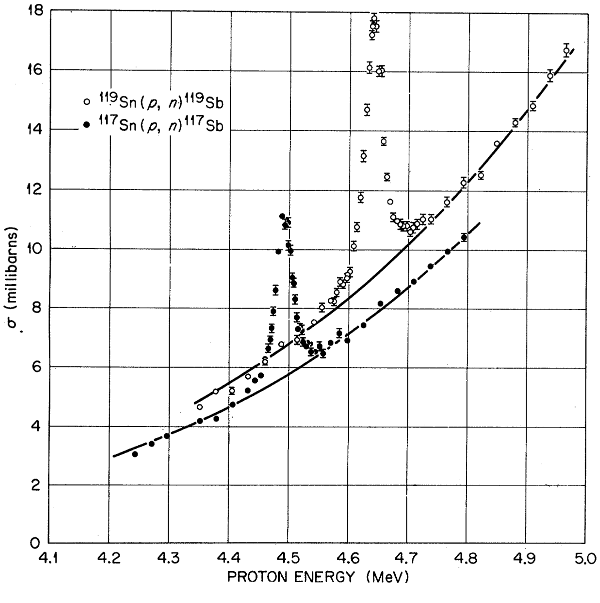

FIG. 1. (p,n) reaction cross sections for ^{117}Sn and ^{119}Sn in the vicinity of 0^+ analog resonance. The solid curves are drawn as a visual guide only.

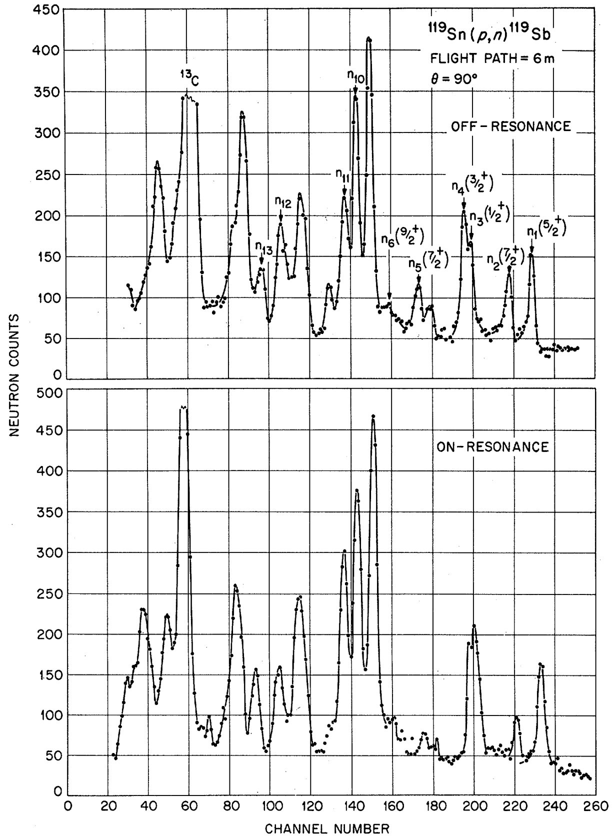

FIG. 2. Neutron time-of-flight spectra. The flight time increases with increasing channel number.

Table I. Information concerning the spin and parity of low-lying states of ^{119}Sb.

Neutron group	Level energy (MeV)	I^π	$j(l)$	Neutron energy[d] (MeV)	$\Delta\sigma$
$1^{a,b,c}$	0	$\frac{5}{2}^+$	$\frac{5}{2}(2)$	3.280	640 ± 30
$2^{a,b,c}$	0.270	$\frac{7}{2}^+$	$\frac{7}{2}(4)$	3.013	0 ± 20
$3^{a,b,c}$	0.644	$\frac{1}{2}^+$	$\frac{1}{2}(0)$	2.642	270 ± 30
$4^{a,b,c}$	0.700	$\frac{3}{2}^+$	$\frac{3}{2}(2)$	2.586	260 ± 30
$5^{b,c}$	1.048	$\frac{7}{2}^+$	$\frac{7}{2}(4)$	2.241	0 ± 20
$6^{b,c}$	1.213	$\frac{9}{2}^+$	$\frac{9}{2}(4)$	2.078	
10^{c}	1.413	$(\frac{1}{2}, \frac{3}{2})$	$[\frac{1}{2}(0), \frac{1}{2}(1), \frac{3}{2}(1), \frac{3}{2}(2)]$	1.879	520 ± 40
11^{c}	1.487	$(\frac{1}{2}, \frac{3}{2})$	$[\frac{1}{2}(0), \frac{1}{2}(1), \frac{3}{2}(1), \frac{3}{2}(2)]$	1.806	570 ± 50
$12^{b,c}$	1.749	$(\frac{1}{2}, \frac{3}{2})$	$[\frac{1}{2}(0), \frac{1}{2}(1), \frac{3}{2}(1), \frac{3}{2}(2)]$	1.546	140 ± 30
13^{c}	1.820	$(\frac{1}{2}, \frac{3}{2})$	$[\frac{1}{2}(0), \frac{1}{2}(1), \frac{3}{2}(1), \frac{3}{2}(2)]$	1.476	230 ± 40

[a] G. Bassani *et al.*, Phys. Letters 22, 189 (1966).

[b] J. Kantele and R. W. Fink, Nucl. Phys. 43, 187 (1963).

[c] G. Berzins and H. W. Kelly, Nucl. Phys. A92, 65 (1967).

[d] Neutron energy for 4.709 MeV incident energy.

each enhancement $\Delta\sigma$, which gives the relative decay probability of the 0^+ compound states to a particular state of ^{119}Sb, was obtained simply by subtracting the normalized off-resonance 90° differential yield from the on-resonance yield. These $\Delta\sigma$'s are included in Table I.

According to several[3] analog resonance theories, the "resonance" in an isospin-forbidden process, such as (p,n) process, is the manifestation of the Coulomb mixing (external mixing) of the analog state with nearby compound states. Therefore, the observed enhancement of the (p,n) cross section in the vicinity of the analog state is via the resonance in the formation of $J^\pi = 0^+$ compound states. Since it is reasonable to assume that the dominant reaction mechanism for these low proton energies is the statistical compound-nuclear reaction,[4] the enhancement at the analog resonance for neutron emission with angular momenta l and j and with energy E_n is given by

$$\Delta\sigma \propto S(l,j) P_l(E_n'), \tag{1}$$

where the strength function $S(l,j)$ is the ratio of the average values of the neutron reduced width and the level spacing, and $P_l(E_n)$ is the neutron penetration factor. It follows that the ratio of enhancements of two neutron groups decaying to states of the same spin parity in the residual nucleus is

$$\frac{\Delta\sigma'}{\Delta\sigma} = \frac{P_l(E_n')}{P_l(E_n)}. \tag{2}$$

Since the spin and parity of the 644- and 700-keV states of ^{119}Sb are known to be $\frac{1}{2}^+$ and $\frac{3}{2}^+$, Eq. (2) along with the measured enhancement $\Delta\sigma_{\text{exp}}$ for the neutron groups to these two states can be used to predict the enhancement of any neutron group with $l = 0$ or 2. These calculated enhancements $\Delta\sigma_{\text{cal}}$ are shown for the neutron groups to the levels at 1.413, 1.487, 1.749, and 1.820 MeV in Table II. Each of these states has been previously reported to have a spin of $\frac{1}{2}$ or $\frac{3}{2}$. A comparison of $\Delta\sigma_{\text{exp}}$ with $\Delta\sigma_{\text{cal}}$ indicates the neutron groups n_{12} and n_{13} have $l = 0$ and 2, respectively. Thus a spin and parity of $\frac{1}{2}^+$ is assigned to the 1.749-MeV state and $\frac{3}{2}^+$ to the 1.820-MeV state.

The very strong enhancements observed for the 1.339- and 1.413-MeV states rule out $l = 0$ or 2 neutron transitions. The only remaining l value consistent with the possible spins of these states is 1. Thus, these states are assigned negative parity.

Although these spin-parity assignments are based on an untested assumption, there were several results in the present study which do support it. Briefly, these are the following: (1) The spin-parity assignments of the 1.749-

Table II. Table of calculated and observed $\Delta\sigma$.

Neutron group	Level energy (MeV)	I^π	$l(j)$	$\Delta\sigma_{\rm exp}$	$\Delta\sigma_{\rm cal}$[a] ($l=2$)	$\Delta\sigma_{\rm cal}$ ($l=0$)	$\sigma(30°)/\sigma(90°)$
n_3	0.644	$\frac{1}{2}^+$	$0(\frac{1}{2})$	270 ± 30			1.43 ± 0.20
n_4	0.700	$\frac{3}{2}^+$	$2(\frac{3}{2})$	260 ± 30			1.00 ± 0.20
n_{10}	1.413	$\frac{1}{2}$ or $\frac{3}{2}$	Unknown	540 ± 40	205 ± 40	230 ± 26	
n_{11}	1.487	$\frac{1}{2}$ or $\frac{3}{2}$	Unknown	570 ± 50	200 ± 23	224 ± 25	
n_{12}	1.749	$\frac{1}{2}$ or $\frac{3}{2}$	Unknown	140 ± 30	161 ± 19	208 ± 23	1.00 ± 0.20
n_{13}	1.820	$\frac{1}{2}$ or $\frac{3}{2}$	Unknown	230 ± 40	151 ± 18	203 ± 23	1.58 ± 0.20

[a] Nuclear radius of 6.6 F is used.

and 1.820-MeV states based on the enhancements are consistent with the off-resonance angular distribution result. That is, as shown in Table II, the same anisotropy $\sigma(30°)/\sigma(90°)$ is obtained for the 0.700- and 1.749-MeV states and for the 0.644- and 1.820-MeV states. (2) The p-wave ($l=1$) neutron strength function is known[5] to be about four times larger than the s-wave ($l=0$) strength function for Sn. Thus, the expected $l=1$ enhancements for neutron groups n_{10} and n_{11} are about 600. The experimental enhancements of 520 ± 40 and 570 ± 50 for n_{10} and n_{11} are consistent with this predicted value. (3) The effect of the angular momentum barrier on the enhancement, as given in Eq. (1) by $P_l(E_n)$, can be seen in Table I, i.e., transitions which involve $l=0$, 1, and 2 are strongly enhanced, whereas the transitions which require $l=4$ are only weakly enhanced. (4) The enhancements of the neutron groups to the $\frac{5}{2}^+$ (ground state) and the $\frac{3}{2}^+$ (700-keV state), with Eq. (1), can be used to deduce a value of 1.6 ± 0.3 for the ratio of their strength functions. This is in good agreement with the optical-model values[6] of 1.32 and 1.61 calculated, respectively, by Perey and Auerbach. (In passing, it is interesting to note that this ratio should be unity if there were no spin-orbit interaction.)

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[1] D. Robson, Phys. Rev. 137, B535 (1965).

[2] R. L. Macklin, Nucl. Method Instr. 1, 335 (1957).

[3] D. Robson, J. D. Fox, P. Richard, and C. F. Moore, Phys. Letters 18, 86 (1965); D. Robson, in Proceedings of the Conference on Research with Tandem Accelerator, Heidelberg, Germany, 1966 (to be published); R. O. Stephen, Nucl. Phys. A94, 192 (1967); P. A. Mello, to be published.

[4] There are several features observed in this study which support this assumption: The off-resonance angular distributions [R. L. Kernell, C. H. Johnson, H. J. Kim, and R. L. Robinson, Bull. Am. Phys. Soc. 12, 545 (1967)] of neutrons feeding low-lying states are symmetric around $\theta_{\rm c.m.}=90°$; the (p,n) yield increases monotonically and smoothly with energy (see Fig. 1); the off-resonance yield favors those (p,n) transitions to the residual states requiring small spin change (see upper spectrum of Fig. 2, target spin is $\frac{1}{2}$); for two residual states (n_2 and n_5 in Fig. 2) with the same $I^\pi=\frac{7}{2}^+$, the differential yield favors the state fed by more energetic neutrons (n_2).

[5] H. W. Newson, in Proceedings of Conference on Nuclear Structure with Neutrons, edited by M. N. Mevergnies, P. Van Assche, and J. Vervier (North-Holland Publishing Company, Amsterdam, 1966), p. 195.

[6] E. H. Auerbach and F. G. J. Perey, Brookhaven National Laboratory Report No. BNL 765(T-286), 1962 (unpublished).