Low-Energy Neutron Resonances in Sm^{149}†

H. MARSHAK AND V. L. SAILOR
Brookhaven National Laboratory, Upton, New York
(Received October 18, 1957)

The total neutron cross section of Sm^{149} has been measured in the energy range from 0.06 to ~20 ev using a crystal spectrometer with resolution 0.17 μsec/meter. The Breit-Wigner parameters have been obtained for four of the larger resonances at energies of 0.0976±0.0005, 0.870±0.003, 4.93±0.03, and 8.9±0.1 ev. The radiation widths for these four resonances are, respectively, in units of 10^{-3} ev: 63.6±1.0, 59.8±1.0, 66.7±3.0, and 66.6±6.0. Other resonances were found at energies of 6.4±0.1, 12.0±0.5, 14.8 ±0.5, and 17.0±0.5 ev.

INTRODUCTION

RECENT investigations of the trend in radiation widths, which characterize the decay of a single isotope after neutron capture, have shown that in some cases there are two distinct values.[1,2] It has been suggested[1] that the two groupings of radiation widths correspond to the two possible spin states for s-wave neutrons. Since there is very little information on the spins of resonances,[3] this hypothesis is difficult to test directly.

Only in the last few years; with the advent of the increased resolution in crystal spectrometers, has it been possible to measure resonance parameters carefully enough (to within a few percent) to notice these differences in radiation widths. In the three cases, In^{115}, Eu^{151}, and Hf^{177}, where the differences in radiation widths have been observed, only Eu^{151} showed the two distinct groupings for more than two resonances. There is no information on the spins of the resonances in Eu^{151}. This is also true for the two resonances in Hf^{177}. In In^{115} the spin of the lowest resonance ($E_0=1.456$ ev) is known ($J=I+\frac{1}{2}=5$).[4,5] If the hypothesis is correct, the resonance ($E_0=3.85$ ev) with the different radiation width would have a spin $J=I-\frac{1}{2}=4$. As yet this spin has not been measured.

In order to investigate this problem further, the total neutron cross section of Sm^{149} was measured. This isotope of samarium was chosen because preliminary work[6] had indicated that there were 5 resonances below 10 ev, and thus the high resolution of the crystal spectrometer could be used to obtain accurate values of the radiation widths. A second point of preference was that the spin of the first resonance ($E_0=0.0976$ ev) has been measured.[4,7]

EXPERIMENTAL DETAILS

The measurement of total neutron cross sections with the BNL crystal spectrometer has been described previously.[8,9] The resolution of the spectrometer is 0.17 μsec/meter. The crystals used for the monochromator were: 0.06 to 0.2 ev, NaCl (220); 0.6 to ~20 ev, Be (1231).

The samarium samples were prepared from enriched stable isotopes.[10] The Sm^{149} isotope was enriched to 81.46%. Two deuterated samarium nitrate samples dissolved in D_2O were prepared. For the thick sample the value of $1/N$ was 3599 barns, while for the thin one it was 18 235 barns. These thicknesses were known to better than 1%.

ANALYSIS AND RESULTS

The methods used in analyzing the cross-section data for resonance parameters have been thoroughly discussed

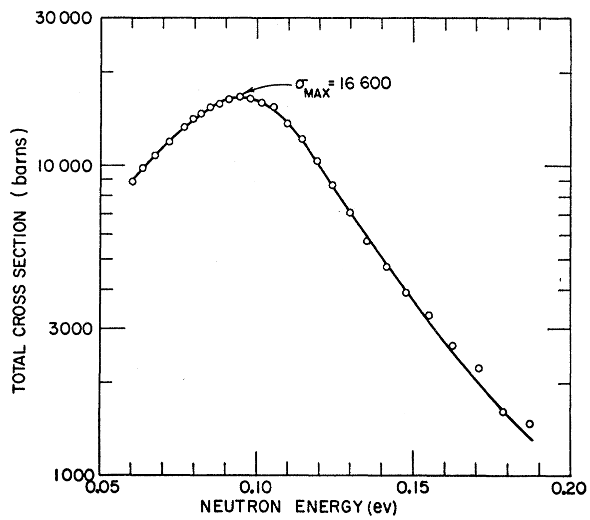

FIG. 1. Total neutron cross section of elemental samarium in the region of the 0.0976-ev resonance.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. H. Landon and V. L. Sailor, Phys. Rev. **98**, 1267 (1955).
[2] G. Igo and H. H. Landon, Phys. Rev. **101**, 726 (1955).
[3] For a summary of the spins measured, see V. L. Sailor, Phys. Rev. **104**, 736 (1956).
[4] B. N. Brockhouse, Can. J. Phys. **31**, 432 (1953).
[5] Dabbs, Roberts, and Bernstein, Phys. Rev. **98**, 1512 (1955).
[6] Sailor, Landon, and Foote, Phys. Rev. **96**, 1014 (1954).
[7] Roberts, Bernstein, Dabbs, and Stanford, Phys. Rev. **95**, 105 (1954).
[8] L. B. Borst and V. L. Sailor, Rev. Sci. Instr. **24**, 141 (1953).
[9] Sailor, Foote, Landon, and Wood, Rev. Sci. Instr. **27**, 26 (1956).
[10] These samples were obtained on loan from the Isotope Research and Production Division of the Oak Ridge National Laboratory, Oak Ridge, Tennessee.

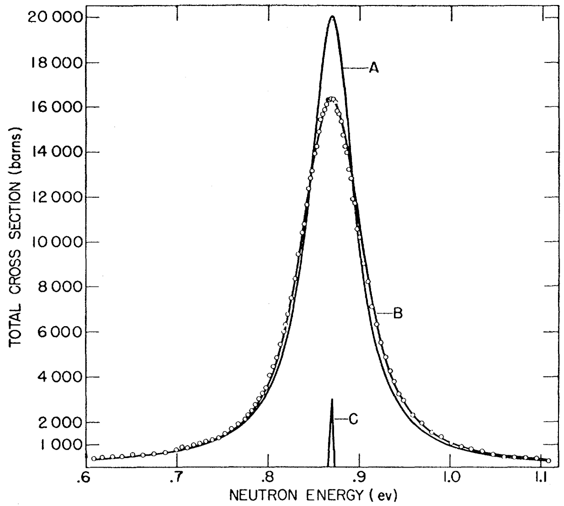

FIG. 2. Total neutron cross section of Sm^{149} in the region of the 0.870-ev resonance.

in previous papers.[11,12] The first resonance in Sm^{149} ($E_0=0.0976$ ev) was fitted directly to the single level formula, since Doppler and resolution corrections can be neglected at this energy. This fit is shown in Fig. 1. The parameters for the second and third resonance ($E_0=0.870$ ev and $E_0=4.93$ ev) were determined by applying the methods of shape analysis to the cross-section data. The resolution correction for the second resonance is negligible, whereas the Doppler correction has to be taken into account. In Fig. 2, curve A represents the true Breit-Wigner shape, curve B is the Doppler broadened Breit-Wigner, and curve C is the resolution triangle. The experimental points are in good agreement with curve B. In the case of the third resonance the resolution correction is 6% at the peak. This correction is made before the method of shape analysis, incorporating the Doppler correction, is applied to the data. The results of this fit are shown in Fig. 3. The agreement between the experimental points and curve B is not as good as that of the previous resonance because of the larger statistical error. Single-level parameters for one other resonance ($E_0=8.9$ ev) were obtained by the method of area analysis[13] using transmission data from a thick and thin sample. This resonance is shown in Fig. 4. Four other resonances below 20 ev were observed, but could not be analyzed. A summary of all the parameters obtained is given in Table I.

DISCUSSION

A. Radiation Widths

The four radiation widths measured do not obviously fall into two distinct groups. The weighted average of these four widths is 62.7×10^{-3} ev, and each one is within 6% of this value. If one attempted to distribute these four radiation widths into two groups, one group would be composed of the first, third, and fourth resonance, and the other group would include only the second resonance. If this grouping is correct, and assuming the spin hypothesis mentioned earlier, the resonances in the first group would have a spin of $J=I+\frac{1}{2}=4$, since the spin of the first resonance is

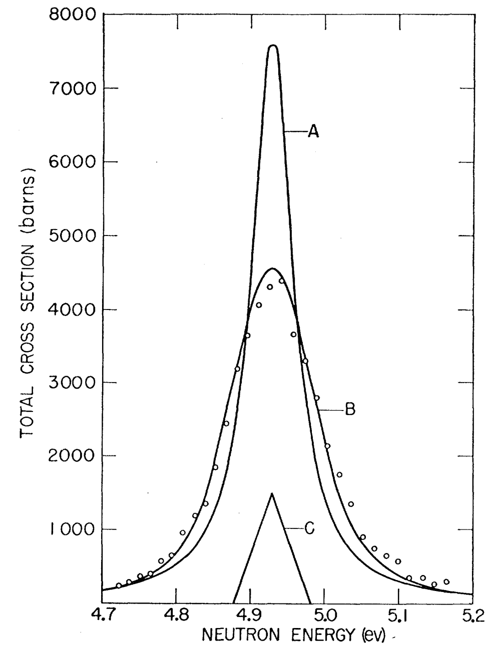

FIG. 3. Total neutron cross section of Sm^{149} in the region of the 4.93-ev resonance.

known. The second resonance, which makes up the second group, would have a spin of $J=I-\frac{1}{2}=3$. In order to check the above conclusions the spins of the three higher resonances would have to be measured.

In order to investigate the problem of the variation in radiation widths, a detailed study of the capture γ-ray spectrum at each resonant energy should be made. The value of the radiation width is determined by the γ-ray decay scheme. The γ-ray spectrum will usually be very complicated due to the high excitation energy and density of energy levels of the compound nucleus. In the case of Sm^{150} the neutron binding energy is 8.00 ± 0.03 Mev.[14] The capture γ-ray spectrum at thermal energies is known,[14] and is due predominantly to the first resonance. The two predominant lines are transitions from the first excited state to the ground state ($2^+\rightarrow0^+$), and from the second excited state to

[11] V. L. Sailor, Phys. Rev. **91**, 53 (1953).
[12] H. H. Landon and V. L. Sailor, Phys. Rev. **98**, 1267 (1955).
[13] D. J. Hughes, J. Nuclear Energy **1**, 237 (1955).

[14] Ad'yasevich, Groshev, and Demidov, *Proceedings of the Academy of Sciences of the U.S.S.R. on the Peaceful Uses of Atomic Energy, Moscow, July, 1955* (Akademiia Nauk, S.S.S.R., Moscow, 1955) [English translation by Consultants Bureau, New York: U. S. Atomic Energy Commission Report TR-2435, 1956], page 278.

the first excited state $(3^+, 4^+ \rightarrow 2^+)$.[14] The energies of these transitions are 330 kev and 440 kev, respectively.[14] Using a high-intensity neutron crystal spectrometer with poor resolution (1.6 μsec/meter) and a NaI scintillation spectrometer the low-energy γ rays were investigated for the first two resonances. The ratio of the intensities for the 330-kev and 440-kev transitions was roughly the same for both resonances, which is in good agreement with the results of Rosler and Fenstermacher.[15] These results are consistent with the viewpoint that differences in the radiation widths would tend to show up in the initial transitions (high-energy γ rays), rather than those near the ground state. Any effect due to spin differences in the capturing state would disappear after a few transitions, and the population of the low-lying states would be the same for each resonance.

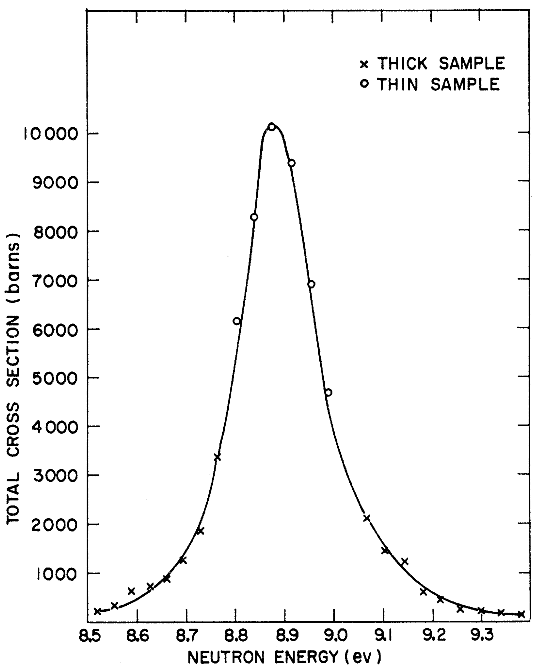

FIG. 4. Total neutron cross section of Sm^{149} in the region of the 8.9-ev resonance.

TABLE I. A summary of the resonance parameters in Sm^{149}. The tabulated values are for the isotope.

E_0(ev)	σ_0(barns)	$\Gamma(10^{-3}$ ev)	$\Gamma_\gamma(10^{-3}$ ev)	$\Gamma_n^0(10^{-3}$ ev)[a]
0.0976 ±0.0005	119 570 ±1200	64.1 ±1.0	63.6 ±1.0	1.6 ±0.1
0.870 ±0.03	20 040 ± 300	60.6 ±1.0	59.8 ±1.0	0.87 ±0.1
4.93 ±0.03	7580 ± 200	68.7 ±3.0	66.7 ±3.0	0.89 ±0.2
6.40 ±0.1	...	...	...	...
8.9 ±0.1	10 200 ± 300	67.8 ±6.0	66.6 ±6.0	0.39 ±0.1
12.0 ±0.5	...	...	...	...
14.8 ±0.5	...	...	...	...
17.0 ±0.5	...	...	...	...

[a] The reduced neutron widths (Γ_n^0) were calculated by assuming that $g=\frac{1}{2}$, except for the first resonance where g is known to be $\frac{9}{16}$.

B. Strength Function

Although only four values of the reduced neutron width, Γ_n^0, are available, it is still interesting to calculate the strength function, $\bar{\Gamma}_n^0/D$. The weighted average of Γ_n^0 is 0.94×10^{-3} ev. When one uses the eight levels found below 20 ev, the average level spacing per spin state, D, is 4.8 ev. The value obtained for $\bar{\Gamma}_n^0/D$ is 2.0×10^{-4}. This can be compared with the value of $(3.3\pm1.4)\times10^{-4}$ obtained by Block *et al.*[16] for the same energy interval. Simpson and Fluharty[17] obtain a higher value of 5×10^{-4} for $\bar{\Gamma}_n^0/D$ using the energy interval from 10 to 100 ev. The value of D obtained by the latter is about the same as our value, but the value of $\bar{\Gamma}_n^0$ is much higher. This discrepancy may be due to the fact that Γ_n^0 are randomly distributed, and the average obtained on the basis of four levels is inadequate.

ACKNOWLEDGMENTS

The authors wish to acknowledge the helpful discussions with Dr. H. H. Landon and Dr. H. T. Motz.

[15] L. Rosler and C. A. Fenstermacher, Bull. Am. Phys. Soc. Ser. II, **2**, 268 (1957).

[16] Block, Slaughter, and Harvey, Bull. Am. Phys. Soc. Ser. II, **2**, 218 (1957).

[17] F. B. Simpson and R. G. Fluharty, Bull. Am. Phys. Soc. Ser. II, **2**, 42 (1957).