Total Neutron Cross Section of Lanthanum*

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The total neutron cross section of lanthanum has been measured from 0.1 to 1000 eV with the Argonne fast chopper. In order to explain its variation over the entire range, it is necessary to assume contributions by bound states together with contributions by the measured resonances at positive energies. The data could be fitted by assuming a bound level whose resonance parameters are the resonance energy $E_0=-37.5$ eV, the reduced neutron width $\Gamma_n^0=0.115$ eV, and the radiation width $\Gamma_\gamma=0.0565$ eV. The parameters for the resonances at 0.734, 2.994, 20.5, 72.3, 618, and 1182 eV have been measured. The state of La^{139}+neutron at the neutron energy of 72.3 eV has been identified to be $J^\pi=3^+$ on the basis of the observed γ-ray spectrum. The potential-scattering radius is measured to be 5.2 ± 1.0 F. Resonances at energies up to about 11 keV have been detected. On the basis of the measured positive-energy resonances and the negative-energy bound level, the thermal capture cross section has been calculated to be 9.6 ± 0.7 b. The resonance-capture integral is 12.1 ±1.0 b. The s-wave neutron strength function S_0 for La^{139} is $(0.7_{-0.3}^{+1.0})\times10^{-4}$.

I. INTRODUCTION

THE total neutron cross section of lanthanum had not been measured with good accuracy in the region from about 0.1 to about 1000 eV. The existing data[1] show that the total cross section near 0.1 eV cannot be accounted for by the contribution from the potential-scattering cross section $4\pi R'^2$ if one uses the measured value[2] of R' for nuclei with $A\approx139$, the contributions from the measured positive energy resonances,[3,4] and the $1/v$ extrapolation of the thermal-capture cross section. In order to obtain the parameters of a bound level that fit the data, the parameters of the resonances in the region from 0.1 eV to about 1 keV must be known.

The measured values of the potential-scattering radius R', as well as those predicted by the various nuclear models, have a definite minimum[2] in the region of mass number $A\approx139$. The asymmetry, arising from the interference between the potential and resonance scattering, displayed by the well-isolated resonance at 72.3 eV allows the determination of R'.

In addition, this experiment provides further information on the relative values of the radiation widths for the s- and p-wave resonances.[3–5]

II. METHOD

The measurements were made by the transmission method with the Argonne fast chopper[6] at the CP-5 reactor. The high-resolution rotor (rotor No. II), which has a burst width of 1.2 μsec (full width at half-maximum, FWHM) for a speed of 15 000 rpm was used for all the measurements. The neutrons were detected with boron-loaded liquid scintillators[7] placed after neutron flights paths of 26, 60, and 120 m. The majority of the data were gathered at the 60- and 120-m flight paths and all were recorded in a 4096-channel time analyzer.[8] The best over-all time-of-flight resolution of the system was about 11 nsec/m.

For most of the data, the sample-in and open-beam counts were recorded alternately with a 4-min cycle over periods of 15–20 h, a procedure that eliminates the systematic errors arising from possible variation of the neutron spectrum.

Samples of high-purity (99.99%) La_2O_3 were used. A spectrographic analysis of the samples showed that there were impurities such as Ca, K, Li, and Na in the amounts of 140, 36, 450, and 550 ppm, respectively. The impurity levels for all other elements were less than 10 ppm. The samples were heated to about 800°C for 4–6 h to minimize the effect of H_2O, transferred to a dry atmosphere, and loaded in vacuum-tight aluminum containers. The four sample thicknesses used, which were verified by chemical analysis, were 0.000324, 0.00226, 0.02898, and 0.05274 La atoms/b. The thinnest sample was obtained by diluting La_2O_3 with aluminum powder. There was no evidence for impurities having strong resonances in the energy region of interest.

III. EXPERIMENTAL RESULTS

Figure 1 shows an over-all view of the total cross section of lanthanum as a function of neutron energy. The experimental points shown, together with their

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[1] *Brookhaven National Laboratory Report No. 325* (U. S. Government Printing and Publishing Office, Washington, D. C., 1960), 2nd ed.

[2] J. A. Harvey, in *Proceedings of the Symposium on Neutron Time-of-Flight Methods Organized by the European-American Nuclear Data Committee, 1961* edited by J. Spaepen (European Atomic Energy Community, Brussels, 1961), p. 23.

[3] J. A. Harvey, R. C. Block, and G. G. Slaughter, Bull. Am. Phys. Soc. 4, 385 (1959).

[4] A. Stolovy and J. A. Harvey, Phys. Rev. **108**, 353 (1957).

[5] G. Bianchi, J. Colmin, C. Corge, V. D. Huynh, J. Julien, J. Morgenstern, F. Netter, and M. Vastel, J. Phys. Radium **24**, 997 (1963).

[6] L. M. Bollinger, R. E. Coté, and G. E. Thomas, in *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958* (United Nations, Geneva, 1958), Vol. 14, p. 239.

[7] L. M. Bollinger and G. E. Thomas, Rev. Sci. Instr. **28**, 489 (1957).

[8] Curtis C. Rockwood, Rev. Sci. Instr. **36**, 1161 (1965).
134, B1047 (1964).

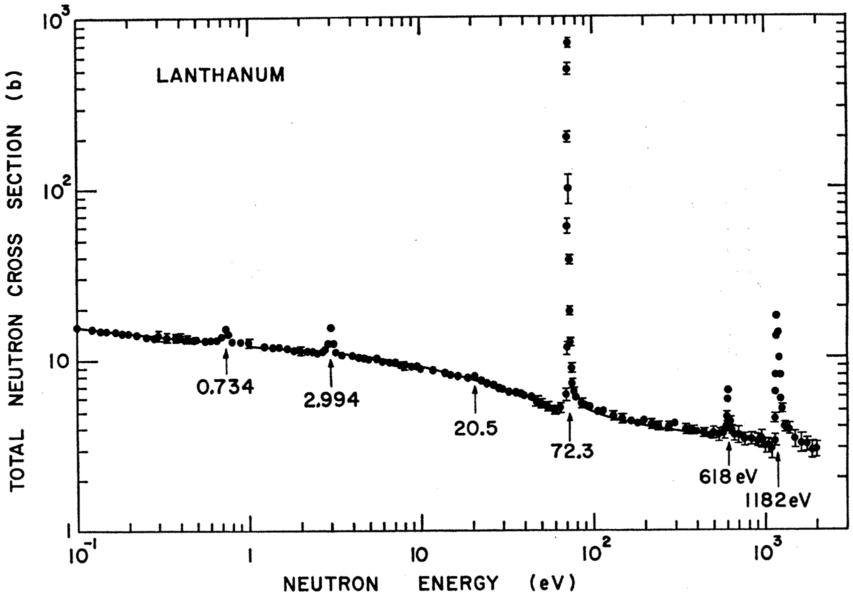

FIG. 1. The observed total neutron cross section of lanthanum. The solid curve was computed with the values of the parameters listed in Table II, plus a negative-energy bound level. See text for further description of the theoretical calculation. The error bars represent standard statistical errors. Where errors are not shown, they are the size of the dots or smaller. The experimental points shown are composites of the total measurements made. Many points have been omitted for clarity.

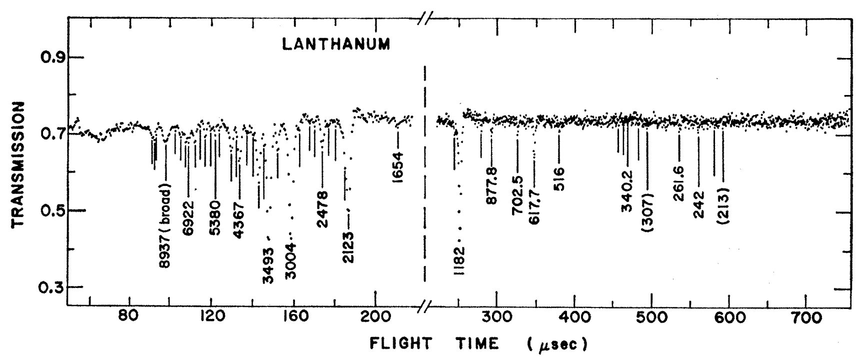

FIG. 2. The neutron transmission of La (0.02898 atoms/b) as observed with the 120-m flight path and the chopper rotor speed of 17 300 rpm. The numbers associated with transmission dips are resonance energies in eV. The resonances whose energies are in parentheses are considered uncertain because they showed up very weakly in our experiment.

standard statistical errors, are a composite of the total measurements made. Many points have been omitted for clarity. The procedure adopted for deriving the experimental total cross section from the primary results of transmission as a function of the neutron energy has been discussed in an earlier paper by Coté *et al.*[9] The measured total cross section includes a contribution from the oxygen in the La_2O_3 sample, but this contribution has been subtracted. The total neutron cross section of oxygen for the energy region of interest has been derived from the compilation of Hughes and Schwartz.[1] In the region of very low neutron energy, some uncertainty may arise from coherent scattering by the molecule La_2O_3. Above a few eV, where coherence effects become negligible, our measured total neutron cross section of La is several barns lower than the previously measured values.[1] The solid curve is described at the end of Sec. IV.

The energies E_0 of all the resonances detected in this experiment are listed in Table I, along with those reported by others.[3–5,10] The transmission data from which many of these resonance energies are derived are shown in Fig. 2. It is interesting to note that the resonances between 260 and 600 eV have not been detected previously.[3–5,10] In our experiment, the resonances at 321 and 340.2 eV are as prominent as the one at 261.6 eV. Harvey *et al.*[10] and Block *et al.*[10] detected the latter in their work with samples enriched in La^{138} and assigned it to this isotope.

IV. ANALYSIS

The resonance parameters have been obtained for only a limited number of resonances, because one of the primary interests was to extract the radiation widths for the *s*- and *p*-wave resonances at low energies. At higher energies, because of the limited resolution of the spectrometer, the isotopic identification and resonance parameters were obtained only for the two prominent resonances below 1200 eV. The standard method of area

[9] R. E. Coté, L. M. Bollinger, and G. E. Thomas, Phys. Rev. **134**, B1047 (1964).

[10] *Brookhaven National Laboratory Report No. 325* (U. S. Government Printing and Publishing Office, Washington, D. C., 1960), 2nd ed., Suppl. No. 2.

TABLE I. Neutron resonances of lanthanum. All energies are in eV.

Present experiment	Bianchi *et al.*[a]	Garg *et al.*[b]	Harvey *et al.*[b]	Block *et al.*[b]	Isotopic assignment
0.734± 0.005			0.752±0.011[c]		139
2.994± 0.005			3.08 ±0.03		138
20.5 ± 0.2			21.1 ±0.1	21.0	138[d]
...			67.1 ±0.3	67.1	138[d]
72.3 ± 0.1	72.3	72.40± 0.30	73.5[e]		139
...			90.0 ±0.4	90.5	138[d]
...			131.2 ±0.7	132	138[d]
...		171.00± 0.30			139[d]
(213)[f]					...[g]
(222)[f]			220 ±1	220	138[d]
...			240 ±2	240	138[d]
242 ± 1		244.00± 0.30			139[d]
261.6 ± 0.5			261 ±2	261	138[d]
...		305.20± 0.30			139[d]
(307)[f]			306 ±3	308	138[d]
321 ± 1					...[g]
340.2 ± 0.8					...[g]
(348)[f]					...[g]
(358)[f]			356 ±3	357	138[d]
516 ± 1					...[g]
...		588.64± 0.40			139[d]
617.7 ± 0.9		617.40± 0.42			139
702.5 ± 1.1		702.56± 0.50			139[d]
877.8 ± 1.5		875.32± 0.75			139[d]
...		905.12± 0.75			139[d]
964.8 ± 1.7		962.29± 0.80			139[d]
1182 ± 2	1190	1179.28± 1.10			139
...		1208.63± 1.15			139[d]
1261 ± 5		1255.98± 1.20			139[d]
...		1274.45± 1.25			139[d]
...		1428.10± 0.75			139[d]
...		1639.10± 0.90			139[d]
1654 ± 8		1651.88± 0.90			139[d]
2123 ± 6	2130	2119.00± 1.35			139[d]
2169 ± 10	2160	2154.14± 1.40			139[d]
...		2178.98± 1.40			139[d]
2290 ± 10		2215.62± 1.45			139[d]
2394 ± 13		2384.55± 1.60			139[d]
2478 ± 7	2490	2472.98± 1.65			139[d]
(2596)[f]		2522.51± 1.75			139[d]
(2690)[f]		2669.03± 1.90			139[d]
2858 ± 18	2872	2859.83± 2.10			139[d]
3004 ± 10	3013	2998.62± 2.20			139[d]
...		3055.6 ± 2.3			139[d]
3300 ± 11	3309	3292.8 ± 2.6			139[d]
3493 ± 11	3506	3490.0 ± 2.8			139[d]
3641 ± 25		3733.3 ± 3.1			139[d]
3771 ± 13	3776	3755.3 ± 3.2			139[d]
3965 ± 30					...[g]
4143 ± 30		4094.7 ± 3.6			139[d]
...		4280.1 ± 3.8			139[d]
4367 ± 17	4393	4369.6 ± 3.9			139[d]
...		4425.5 ± 4.0			139[d]
4504 ± 35		4449.8 ± 4.1			139[d]
4683 ± 19	4680	4651.3 ± 4.3			139[d]
...		4712.7 ± 4.4			139[d]
...		4730.4 ± 4.5			139[d]
...		4816.2 ± 4.8			139[d]
5203 ± 45		5183.6 ± 5.1			139[d]
5380 ± 40		5350.9 ± 5.3			139[d]
5615 ± 50		5526.5 ± 5.6			139[d]
...		5837.0 ± 6.1			139[d]
5892 ± 27		5886.1 ± 6.2			139[d]
6189 ± 60		5973.6 ± 6.3			139[d]
6480 ± 60	6516	6455.9 ± 7.1			139[d]
...		6556.4 ± 7.3			139[d]
...		6864.7 ± 7.8			139[d]
6922 ± 60		6991.0 ± 8.0			139[d]
...		7047.3 ± 8.0			139[d]
...		7096.1 ± 8.2			139[d]
7126 ± 60		7137.2 ± 8.2			139[d]
7486 ±120		7461.4 ± 8.8			139[d]
7955 ± 60		7903.4 ± 9.6			139[d]

TABLE I (*continued*)

Present experiment	Bianchi *et al.*[a]	Garg *et al.*[b]	Harvey *et al.*[b]	Block *et al.*[b]	Isotopic assignment
...		8029.9 ± 9.8			139[d]
...		8254.5 ± 10.5			139[d]
...		8524.5 ± 10.5			139[d]
...	8600	8600.0 ± 11.0			139[d]
...		8677.0 ± 11.0			139[d]
8937 (broad)	9000	8914.0 ± 11.5			139[d]
...		9307 ± 12			139[d]
...		9596 ± 13			139[d]
...		9674 ± 13			139[d]
9883 ± 80		9885 ± 13			139[d]
...		9994 ± 14			139[d]
10113 ±120		10216 ± 14			139[d]
10352 ±120		10373 ± 15			139[d]
... [h]		11168 ± 16			139[d]
...		36980 ±100			139[d]

[a] Reference 5.
[b] Reference 10.
[c] Reference 3.
[d] This assignment was taken from Ref. 10.
[e] Reference 4.
[f] This resonance is considered uncertain because it shows up very weakly in our experiment.
[g] No isotopic assignment can be made on the basis of our experiment.
[h] Our useful data end at about 11 keV.

TABLE II. Parameters of neutron resonances in lanthanum.

E_0 (eV)	La isotope	σ_0 (b)	Γ (meV)	Γ_γ (meV)	Γ_n (meV)
0.734	139	3.2± 0.4	40±5	40 ±5	$(7.33\pm 0.44)\times 10^{-5}$[a]
2.994	138	6800 ±600	91±8	90 ±8	1.44± 0.07[a]
20.5	138	2380	94	...[b]	3.5 ± 0.6[a]
72.3	139	5650 ±150	88±1	56.5±1.7	31.5 ± 0.4
618	139	642	81	...[c]	24.8 ± 1.4[a]
1182	139	1066	1897	...[c]	1840 ±20[a]

[a] These are values of $2g\Gamma_n$.
[b] Γ_γ is assumed to be 90 meV.
[c] Γ_γ is assumed to be 56.5 meV.

analysis was used to determine the parameters of the La^{139} resonances at 0.734, 72.3, 618, and 1182 eV and the La^{138} resonances at 2.994 and 20.5 eV. The assignment of the resonances at 2.994 and 20.5 eV to La^{138} is based on the work of Harvey *et al.*,[3] Harvey and Slaughter,[10] and Block *et al.*[10] The resonances at 0.734, 72.3, and 1182 eV have been assigned to La^{139} in accordance with previous work.[3–5] Without the knowledge of previous work,[3–5] the resonances at 72.3 and 1182 eV can be assigned to La^{139} on the basis of the strength of each resonance and of the interference between the resonance and potential scattering. Based on the size of the neutron width, the La^{139} resonance at 0.734 eV has been assumed to be p wave in accordance with Harvey *et al.*[3] The assignment of the resonance at 618 eV to La^{139} is discussed below. The results obtained are given in Table II.

Different sample thicknesses, ranging from 0.000324 to 0.05274 La atoms/b, allows us to accurately determine the parameters σ_0 and Γ and therefore Γ_n and Γ_γ for the resonance at 72.3 eV. The γ spectrum from the neutron capture by La^{139} at this resonance energy, observed with a 6-cc Ge(Li) detector, shows that the capturing state is $J^\pi=3^+$. This assignment is based on the observation of strong transitions to the well-established[11] 2^- La^{140} states at 30 and 162 keV, as shown in Fig. 3.

For the La^{139} (p-wave) resonance at 0.734 eV and the 2.994-eV resonance of La^{138}, the following procedure was used: The value for $2g\Gamma_n$ was determined from the area above the transmission dip. With the assumed statistical factor $g=\frac{1}{2}$, the resonance shape was calculated for various assumed values of Γ_γ. The values of Γ_γ giving minimum χ^2 for each resonance are listed in Table II. The errors quoted include the uncertainty involved in the assumed value of g.

On the basis of the measurement for the resonance at 2.994 eV, the radiation width $\Gamma_\gamma=90$ meV has been assumed for the resonance at 20.5 eV. According to the measurement for the 72.3-eV resonance of La^{139},

[11] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington, D. C., 1959).

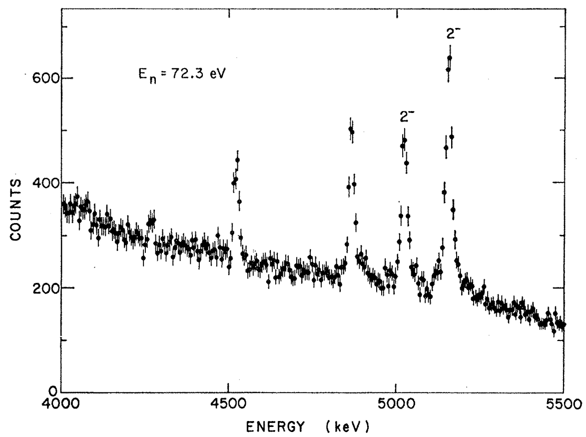

FIG. 3. Gamma-ray spectrum of the 72.3-eV resonance of La[139]. The existence of the strong transitions to the 2^- levels provides a unique assignment of $J^\pi=3^+$ for this resonance.

$\Gamma_\gamma=56.5$ meV has been assumed for the resonance at 1182 eV.

The identification of the resonance at 618 eV was not quite so obvious. The experimental data (Fig. 4) were therefore subjected to additional analysis. The standard statistical error shown for one point is typical for the rest. The solid curve is computed with the assumption that the resonance belongs to La[139] ($g=\frac{1}{2}$, $\Gamma_\gamma=56.5$ meV, $\Gamma_n=24.8$ meV), the dashed curve with the assumption that the resonance belongs to La[138] ($g=\frac{1}{2}$, $\Gamma_\gamma=90$ meV, $\Gamma_n=22$ eV).

The radiation widths for the 0.734-eV (p-wave) and 72.3-eV (s-wave) resonances of La[139] are compared with previously measured values[3–5] in Table III. It should be noted that the radiation widths for the p- and s-wave resonances are not as different as were those obtained by Harvey *et al.*,[3] Stolovy and Harvey,[4] and Bianchi *et al.*[5] Our smaller difference is entirely the result of the much lower value of Γ_γ we obtained for the 72.3-eV resonance. In view of this difference obtained in the first measurements of this series, the measurements were repeated under different conditions. The results were all consistent with the values quoted, and no reason can be found for the difference between the present results and those of previous workers.[4,5]

TABLE III. Radiation widths (meV) of La[139].

E_0 (eV)	l	Present work	Harvey *et al.*[a]	Stolovy and Harvey[b]	Bianchi *et al.*[c]
0.734	1	40 ±5	55±10		
72.3	0	56.5±1.7		150±30	105±15

[a] Reference 3.
[b] Reference 4.
[c] Reference 5.

Knowing the resonance parameters g, Γ_n, and Γ_γ, we determined the potential-scattering radius R' by curve fitting to the 72.3-eV resonance of La[139]. The variation of χ^2 with the various assumed values of R' is shown in Fig. 5. The best estimate of the value obtained is

$$R'=5.2\pm1.0\ \text{F}.$$

Figure 6 shows the best fit to the experimental data with $R'=5.2$ F along with the poorer fits for $R'=3.2$ F and 7.2 F. The theoretical cauculations include the effects of Doppler broadening and the finite resolution of the spectrometer. The resolution corrections are negligible at the wings of the resonance where the effect of the interference between the potential scattering and resonance scattering is most important.

The solid curve in Fig. 1 is computed by using the well-known Breit-Wigner shape[12,13] for the resonances,

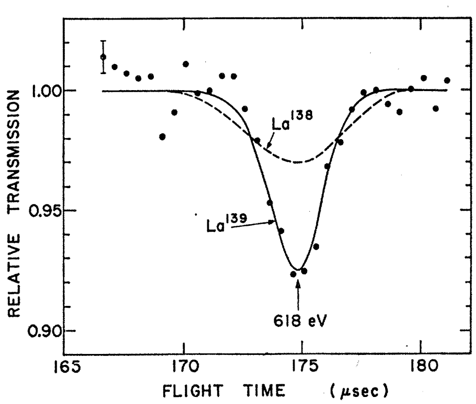

FIG. 4. Transmission of La as a function of neutron flight time for a flight path of 60 m. The energy range covered is approximately from 575 to 680 eV. The standard statistical error shown for one experimental point is typical for the rest. The solid curve is the theoretical transmission calculated on the assumption that the resonance belongs to La[139] ($g=\frac{1}{2}$, $\Gamma_\gamma=56.5$ meV, $\Gamma_n=24.8$ meV). The dashed curve is computed on the assumption that the resonance belongs to La[138] ($g=\frac{1}{2}$, $\Gamma_\gamma=90$ meV, $\Gamma_n=22$ eV). The theoretical calculations include the effect of Doppler broadening and the finite resolution of the spectrometer.

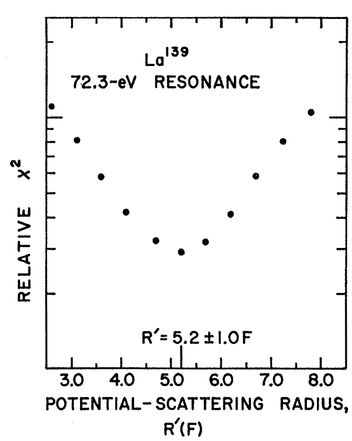

FIG. 5. Variation of χ^2 with various values of the potential-scattering radius R'. The fixed parameters used for this resonance are listed in Table II. The statistical factor $g=0.4375$ corresponds to the neutron capture state with $J^\pi=3^+$.

[12] H. A. Bethe, Rev. Mod. Phys. 9, 69 (1937).
[13] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952).

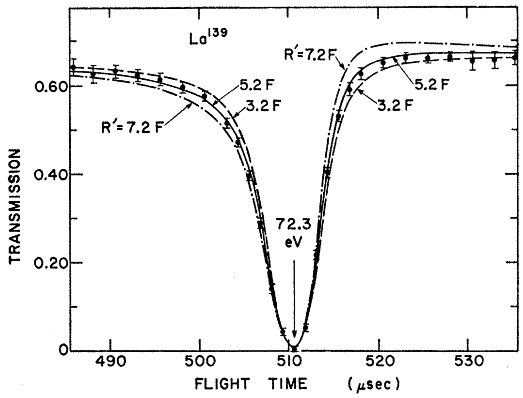

FIG. 6. Transmission of La as a function of neutron flight time for a flight path of 60 m. The energy range covered is approximately from 50 to 85 eV. The experimental points are shown with their standard statistical errors. The three computed curves are shown with the corresponding values of R'. The other parameters (fixed) used for the theoretical calculations are listed in Table II

the measured parameters for the positive-energy resonances, and a bound state at the energy $E_0=-37.5$ eV with reduced neutron width $\Gamma_n^0=0.115$ eV and radiation width $\Gamma_\gamma=0.0565$ eV.

V. SUMMARY

With the assumption of a bound state at $E_0=-37.5$ eV with $\Gamma_n^0=115$ meV and $\Gamma_\gamma=56.5$ meV, the somewhat unusual variation of the total neutron cross section from 0.1 to 1000 eV is well explained.

The value $R'=5.2\pm1.0$ F obtained for the potential-scattering radius is the lowest among all values measured[2] for nuclei with mass numbers around 139. It is consistent with the value $R'=5.8$ F predicted by the optical model with a spherical Saxon potential,[14] and with the value $R'=5.4$ F predicted with a deformed trapezoidal potential.[15]

When the bound level at $E_0=-37.5$ eV and the measured positive-energy resonances are taken into account, the thermal capture cross section $\sigma_\gamma(\text{th})$ is calculated to be 9.6 ± 0.7 b. This is in good agreement with the directly measured value[10] of 8.2 ± 0.8 b. It should be noted that a reasonably good fit to the experimentally measured cross section could still be obtained even if the value of $\sigma_\gamma(\text{th})$ calculated in this work were changed slightly by changing the parameters of the negative-energy bound level. The variation of σ_γ in the thermal region is observed to be proportional to $1/v$ in this experiment.

With the measured parameters for the resonances listed in Table II, the resonance-capture integral is calculated to be 12.1 ± 1.0 b. This value includes the

[14] E. J. Campbell, H. Feshbach, C. E. Porter, and V. F. Weisskopf, Massachusetts Institute of Technology, Laboratory for Nuclear Science, Technical Report No. 73, 1960 (unpublished).

[15] D. M. Chase, L. Wilets, and A. R. Edmonds, Phys. Rev. **110**, 1080 (1958).

TABLE IV. The *s*-wave radiation widths (meV) of lanthanum.

E_0 (eV)	La isotope	Measured Γ_γ Present work	Other work	Calculated Γ_γ Cameron[a]	Stolovy and Harvey[b]
2.994	138	$90\ \pm8$	$99\pm\ 6$[c]	280	275[d]
72.3	139	56.5 ± 1.7	150 ± 30[b]	107	84[f]
			105 ± 15[e]		

[a] A. G. W. Cameron, Can. J. Phys. **35**, 666 (1957).
[b] Reference 4.
[c] Reference 10.
[d] $D=80$ eV is assumed on the basis of observed La^{138} resonances quoted in Ref. 10.
[e] Reference 5.
[f] Our value $D=800$ eV is used.

$1/v$ contributions (4.2 b) and the contributions (0.2 b) from resonances at energies higher than 1182 eV. The latter contributions have been calculated according to formulas derived by Dresner.[16] The 72.3-eV resonance of La^{139} contributes about 60% of the value for the resonance-capture integral. The present measured value agrees reasonably well with the values of 14.0 ± 0.9 b obtained by Konks *et al.*[17] and 11 b by Macklin and Pomerance.[18]

The neutron *s*-wave strength function S_0 for La^{139}, based on the resonance parameters in Table II and including the contribution by the negative-energy bound level, is calculated to be $(0.7_{-0.3}^{+1.0})\times10^{-4}$. This value is lower than those for the neighboring nuclides, but is in good agreement with the suggestion of Bianchi *et al.*[5] However, it is much smaller than those predicted by the various nuclear models.[2]

The level spacing per spin state of La^{139}, based on the three measured *s*-wave resonances and the negative-energy bound level, is roughly 800 eV. This is consistent with the values calculated by use of Newton's formula,[19] which predicts a value of 1080 eV for the compound state with $J=3.0$, and 840 eV for $J=4.0$.

From the observed level structure[20] below 2 MeV, an average level spacing of 25 keV may be obtained in the neighborhood of the ground state. Fitting the relation $D=D_0\exp(-E/T)$ to the combined low-energy and neutron-resonance data requires a nuclear temperature $T\approx1$ MeV. From the systematics of T as a function of mass number A, as given by Gilbert and Cameron,[21] this value is considerably higher than those for the

[16] L. Dresner, J. Nucl. Energy **2**, 118 (1955); E. Kuhn and L. Dresner, *ibid.* **7**, 69 (1958).

[17] V. A. Konks, Yu. P. Popov, and F. L. Shapiro, Zh. Eksperim. i Teor. Fiz. **46**, 80 (1964) [English transl.: Soviet Phys.—JETP **19**, 59 (1964)].

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neighboring nuclei. This effect is consistent with that observed for $A=208$, where shell effects considerably increase the parameter T.

The present experiment offers no strong evidence for a difference between the radiation widths for s- and p-wave resonances in La^{139}. The radiation widths measured in this experiment for the s waves of La^{138} and La^{139} are compared with other measured and calculated values in Table IV. According to the formula of Stolovy and Harvey,[4] $\Gamma_\gamma \propto D^{1/4}$, where D is the level spacing per spin state. Therefore, in using the measured value for D, one is merely calculating an upper limit for the radiation width.

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Beta-Gamma Correlation Measurements on Ir^{192}

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The β-γ directional correlation between β particles in the 536-keV group and the 605- and 612-keV γ rays in the decay of 72-day Ir^{192} has been measured at several β-ray energies. The measured correlation coefficient $\epsilon(W)$ rises from -0.074 ± 0.015 at 185 keV to -0.096 ± 0.010 at 255 keV and then starts falling; near the end-point energy the anisotropy is found to be very small. The large β-γ anisotropy observed conclusively establishes that the parity of Ir^{192} is negative. Attempts have been made to extract information about the relevant matrix-element ratios governing the 536-keV β transition. The β-γ directional correlation between β particles in the outer group of 669-keV and the 469-keV γ ray

$$(4^- \xrightarrow{\beta} 4^+ \xrightarrow{\gamma} 2^+)$$

has also been measured; it shows nearly isotropic correlation in the β energy region 400–650 keV. The β-γ circular-polarization correlation in the above cascade has also been measured. It is concluded that while large cancellation among the vector-type matrix elements is responsible for the observed energy dependence of the β-γ anisotropy in the 536-keV β group, the outer β group of 669 keV apparently satisfies the quasi-allowed approximation. The nature of the 785-keV (4^+) and 921-keV (3^+) states in Pt^{192} is discussed in the light of these findings.

I. INTRODUCTION

An attempt to interpret the spins and parities of the ground and the two isomeric states of the odd-odd Ir^{192} nucleus in terms of the Nilsson model has received considerable interest recently.[1] While the spin is experimentally determined[2] to be $J=4$ for the Ir^{192} ground state, its parity has not so far been unambiguously determined experimentally. A determination of the parity of this state may fix the parities of the other two known isomers[3] in Ir^{192} and hence help in comparing the predictions of any nuclear model.

The decay scheme[4] of Ir^{192} is shown in Fig. 1. The logft values of the 536- and 669-keV β groups decaying to positive-parity states in Pt^{192} are 8.2 and 8.8, respectively. The logft values are large enough to rule out positive parity for Ir^{192}; however, in some regions of the periodic table where selection rules other than spin and parity may be operating, the logft value is sometimes not a good criterion for determining the nature of forbiddenness in a β transition. A direct experimental determination of parity is desirable in such cases.

In this paper we describe a β-γ directional correlation experiment which unambiguously assigned negative parity for the Ir^{192} ground state. The shapes of the 536- and 669-keV β groups are known to be statistical in nature within experimental limits.[5] The β-γ directional correlation between the 536-keV β group and the

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