Neutron Resonances of Mo Isotopes*

HLA SHWE† AND R. E. COTÉ‡
Argonne National Laboratory, Argonne, Illinois 60439
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The neutron transmission of Mo isotopes for neutron energy $E_n \lesssim 1.5$ keV has been measured with the Argonne fast chopper. The use of samples enriched in Mo^{95} and in Mo^{97} as well as samples of natural Mo has made possible the unambiguous isotopic assignment of the resonances. Some ten new resonances have been detected and measured; all of these have been assigned to either Mo^{95} or Mo^{97}. On the basis of a probability approach recently suggested by Bollinger, a great majority of these newly observed resonances have been interpreted as being due to p-wave neutrons. For Mo^{95}, the mean radiation width calculated from the measurements for the resonances at $E_0 = 44.7$ and 159.6 eV is $\langle\Gamma_\gamma\rangle_{l=0} = 185 \pm 15$ meV. This is to be compared with $\langle\Gamma_\gamma\rangle_{l=1} = 277 \pm 67$ meV for the two p-wave resonances at $E_0 = 110.3$ and 117.9 eV. For Mo^{96}, the widths are $(\Gamma_\gamma)_{l=0} = 330 \pm 50$ meV for the resonance at 131.3 eV, and $(\Gamma_\gamma)_{l=1} = 530 \pm 100$ meV for the resonance at $E_0 = 113.5$ eV. For Mo^{97}, the radiation widths are $(\Gamma_\gamma)_{l=0} = 127 \pm 13$ meV for the s-wave resonance at $E_0 = 70.9$ eV, and $\langle\Gamma_\gamma\rangle_{l=1} = 154 \pm 20$ meV for four of the p-wave resonances detected in this experiment. The values for Mo^{98} are $(\Gamma_\gamma)_{l=0} = 170 \pm 80$ meV for the s-wave resonance at $E_0 = 428.9$ eV, and $(\Gamma_\gamma)_{l=1} = 110 \pm 15$ meV for the p-wave resonance at $E_0 = 12.1$ eV. The strength functions calculated for these nuclides are $S_0(Mo^{95}) = (0.5_{-0.2}^{+0.5}) \times 10^{-4}$, $S_1(Mo^{95}) = (5_{-3}^{+10}) \times 10^{-4}$; $S_0(Mo^{97}) = (0.5_{-0.2}^{+0.4}) \times 10^{-4}$, $S_1(Mo^{97}) = (6_{-2}^{+11}) \times 10^{-4}$; and $S_0(Mo^{98}) = (2_{-1}^{+4}) \times 10^{-4}$. The resonance-capture integral for natural Mo has been calculated to be 27 ± 2 b.

I. INTRODUCTION

THE purposes of this experiment were (1) to gain a better understanding of the relative values of the radiation widths of s- and p-wave resonances and (2) to determine the strength functions S_0 and S_1 for the s- and p-wave resonances, respectively. These strength functions for the Mo isotopes are of special interest because the p-wave strength function S_1 has a relative maximum in the region $A \approx 100$, where the s-wave function S_0 has a relative minimum.[1,2]

II. EXPERIMENTAL PROCEDURE

The measurements were made by the transmission method with the Argonne fast chopper.[3] The experimental details were identical to those in our eariler work[4] on La. The data were gathered with a neutron flight path of either 60 or 120 m and with the high-resolution rotor[3] turning at 18 500 rpm. The over-all time-of-flight resolution of the spectrometer was about 11 and 23 nsec/m for the 120- and 60-m flight paths, respectively.

The samples consisted of natural Mo, molybdenum enriched to 96.8% in Mo^{95}, and molybdenum enriched to 92.8% in Mo^{97}. The thicknesses ranged from 1.686 to 13.489 g/cm^2 for the three natural samples, from 0.738 to 25.625 g/cm^2 for the four Mo^{95} samples, and about the same for the four Mo^{97} samples.

On examining the data, it was found that there were minor chemical impurities in some of the samples. Since one of our primary objectives was to detect weak resonances due to p-wave neutrons, it was important that the resonances due to impurities be identified. To do this, the strengths and energies of the resonances suspected of being due to impurities were compared with what would be expected from various impurities, as determined from the parameters listed in BNL-325.[5] This procedure led us to conclude that the impurities were 0.04% Ta and 0.005% W in the samples enriched in Mo^{97}, and 0.02% W in the natural Mo samples. There was no evidence of other impurities having strong resonances in the energy region of interest. Also, there was no evidence for impurities in Mo^{95}.

III. EXPERIMENTAL RESULTS

Figure 1 shows an example of the experimental transmission for the 25.6 g/cm^2 sample enriched in Mo^{97}. The neutron flight path was 60 m. The resonances due to Ta and W impurities are properly identified. The numbers in parentheses are the isotopic assignments of the resonances.

Table I gives the energies and other parameters of the resonances measured in this experiment. The isotopic assignment for each resonance (column 2 of Table I) was based on the relative strengths with which the resonance showed up in samples with varying quantities of the particular isotope. Our isotopic assignments of all previously detected resonances are consistent with those in BNL-325.[5]

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† Permanent address: Department of Physics, East Stroudsburg State College, East Stroudsburg, Pa. 18301.
‡ Deceased.

[1] C. A. Uttley, C. M. Newstead, and K. M. Diment, in *Nuclear Data for Reactors* (International Atomic Energy Agency, Vienna, 1967), Vol. I, p. 165.

[2] H. W. Newson, in *Proceedings of the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, 1965*, edited by M. Nève de Mévergnies, P. Van Assche, and J. Vervier (North-Holland Publishing Co., Amsterdam, 1966), p. 195.

[3] 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.

[4] Hla Shwe, R. E. Coté, and W. V. Prestwich, Phys. Rev. **159**, 1050 (1967).

[5] *Brookhaven National Laboratory Report No. 325* (U.S. Government Printing Office, Washington, D.C., 1960), 2nd ed., Suppl. No. 2 (1966).

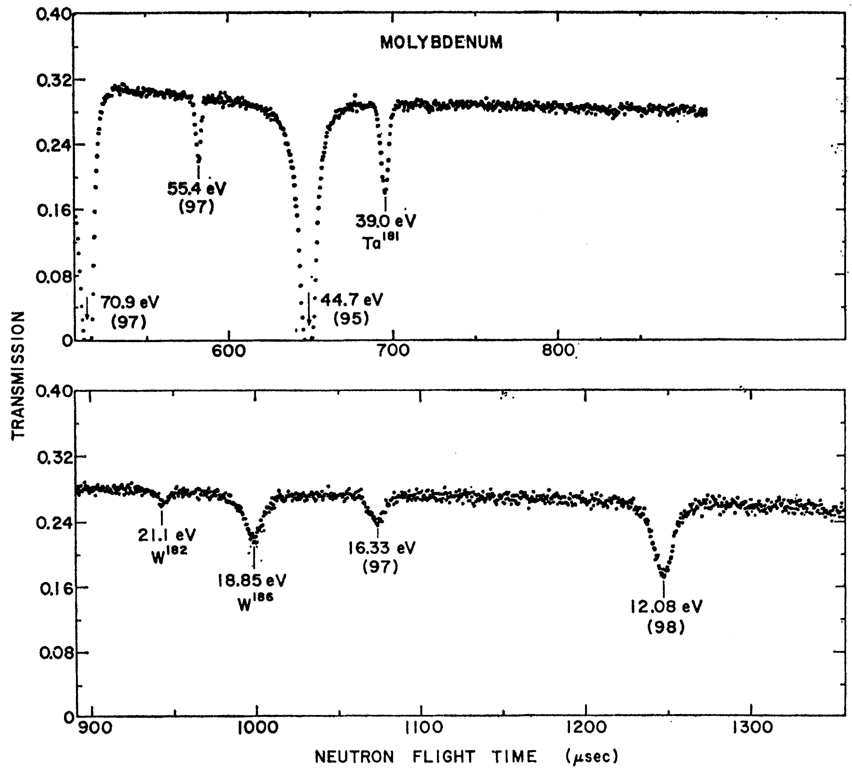

FIG. 1. Neutron transmission of a Mo sample, 25.6 g/cm² thick and enriched in Mo^{97}, as obtained with the 60-m neutron flight path. The numbers in parentheses are the isotopic assignments of the resonances.

The time-of-flight resolution of the spectrometer was good enough to permit a fairly complete analysis of resonances up to an energy of 160 eV. The strong resonances in this energy range showed up in runs with a variety of sample thicknesses, so that resonance parameters could be determined both by the partial area method[6] and by curve fitting. The weak resonances, which showed up well only in the runs with thick samples, were analyzed by curve fitting. The theoretical curve fitted to the experimental transmission was based on the well-known Breit-Wigner shape[7,8] for the resonance; the fit was obtained by varying the resonance parameters over a range consistent with either the value of $\sigma_0\Gamma$ or $\sigma_0\Gamma^2$ obtained from the area above the transmission dip. The theoretical calculation included the effects of both Doppler and resolution broadening. For resonances at neutron energies above 160 eV, the relatively poor resolution of the spectrometer and the lack of a sufficiently wide range of sample thickness limited the analysis to a determination of the neutron width Γ_n. The only exception was the Mo^{98} resonance at 428.9 eV, for which the method of curve fitting was used to determine Γ_γ.

For those resonances for which the spin J of the capture state had been determined by other investigations,[9–12] the values we used for the statistical factor g were consistent with the values of J from these sources. For the rest of the resonances, the errors quoted for Γ_γ in Table I include the uncertainty involved in the assumed value of g.

Figure 2 shows the best fit to the experimental data for the Mo^{98} resonance at $E_0=12.1$ eV. The potential-scattering radius R', as obtained from Harvey,[13] was taken to be $R'=6.8$ F. The value for the statistical factor g was based on the capture-state spin assignment[12] $J^\pi=\frac{3}{2}^-$. The theoretical calculation (solid curve) that best fitted the experimental data was obtained by using the resonance parameters listed in Table I.

Information about the orbital-angular-momentum quantum number l of a resonance can be inferred from its shape and also from the measured value of $g\Gamma_n$. The resonances that clearly exhibit the asymmetric shape that is characteristic of an s-wave ($l=0$) interaction are shown in column 6 of Table I. As expected, these are the more prominent resonances. For the weak

[6] L. M. Bollinger and J. P. Marion, Argonne National Laboratory Report No. ANL-5754 (1957), p. 11.

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[9] S. F. Mughabghab, R. E. Chrien, O. A. Wasson, and M. R. Bhat, Bull. Am. Phys. Soc. **12**, 1199 (1967).

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[12] S. F. Mughabghab, M. R. Bhat, O. A. Wasson, D. I. Garber, and R. E. Chrien, Bull. Am. Phys. Soc. **13**, 721 (1968).

[13] 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.

TABLE I. Parameters of neutron resonances in molybdenum.

E_0 (eV)	Mo isotope	Γ_n (meV)	Γ_γ (meV)	$P(p, g\Gamma_n)$	Asym-metry	l value Present	l value Other	Spin J
12.1±0.1	98	0.061±0.006	110±15	0.89	···	(1)	1[a]	$\frac{3}{2}$[a]
16.3±0.1[b]	97	0.0026±0.0004[c]	140±30	0.99	···	1	···	···
44.7±0.3	95	191±10	180±15	≈0[d]	yes	0	0[e,f,g]	3[e,f]
55.4±0.1[b]	97	0.035±0.004[c]	170±30	0.99	···	1	···	···
70.9±0.1	97	17.5±0.8	127±13	≈0[d]	yes	0	0[f,h]	2[f]
79.8±0.2[b]	97	0.047±0.005[c]	120±60	0.98	···	1	···	···
97.4±0.4	100	0.41±0.10[c]	250±100	0.94	···	(1)	···	···
109.6±0.3[b]	97	0.114±0.013[c]	300±150	0.97	···	1	···	···
110.3±0.3	95	0.137±0.020	310±80	0.98	···	1	1[e,g]	1[e,g]
113.5±0.3	96	0.504±0.050	530±100	0.94	···	(1)	1[e]	$\frac{3}{2}$[e]
117.9±0.3	95	0.151±0.012[c]	200±120	0.98	···	1	(0)[f]	2[f]
131.3±0.4	96	244±12	330±50	≈0[d]	yes	0	0[h]	···
159.6±0.4	95	12±1	260±60	0.11	yes	0	0[e,f]	3[e,f]
210.1±0.7	97	0.6±0.3[c]	···	0.96	···	1	···	···
217.9±0.4	95	1.10±0.11[c]	···	0.95	···	1	1[g]	···
227.7±0.6	97	2.3±0.6[c]	···	0.90	···	(1)	(0)[f]	3[f]
245.7±0.6	95	0.52±0.05[c]	···	0.96	···	1	···	···
248.5±0.6[b]	97	2.85±0.71[c]	···	0.88	···	(1)	···	···
263.7±0.7	95	1.2±0.3[c]	···	0.94	···	(1)	(1)[f]	···
267.8±0.5	97	14±2	···	0.08	yes	0	(0)[f]	3[f]
286.3±0.7	97	49±8[c]	···	≈0[d]	yes	0	(1)[f]	···
311.5±1.0	97	9.0±1.5	···	0.57	yes	0	(0)[f]	3[f]
331.2±1.0	95	2.6±1.2[c]	···	0.94	···	(1)	1[g]	···
346.9±0.9	92	4.8±0.9[c]	···	0.94	···	(1)	···	···
358.5±0.9	95	290±30	(180)[i]	≈0[d]	yes	0	(0)[f]	3[f]
397.2±1.0	97	75±8	(127)[i]	≈0[d]	yes	0	(0)[f]	3[f]
428.9±1.1	98	79±14	170±80	≈0[d]	yes	0	···	···
467.4±1.2	98	695±70	···	≈0[d]	yes	0	···	···
468.0±1.2	95	9±2[c]	···	0.90	···	(1)	···	···
505.4±1.3	97	48±7[c]	···	0.01	yes	0	···	···
554.6±1.6	95	90±15	···	0.03	yes	0	(0)[f]	2[f]
558.3±1.5	97	620±50	(127)[i]	≈0[d]	yes	0	(0)[f]	3[f]
612.4±1.8	98	40±8	(170)[i]	≈0[d]	yes	0	···	···
630.0±2.0	95	13±4[c]	···	0.90	···	(1)	···	···
661.5±2.1	95	64±6	(180)[i]	0.02	yes	0	(0)[f]	3[f]
676.2±2.2	97	385±50[c]	(127)[i]	≈0[d]	yes	0	(1)[f]	···
681.2±2.5	95	1100±200	(180)[i]	≈0[d]	yes	0	(0)[f]	3[f]
744.6±2.4[b]	95	3.2±0.6[c]	···	0.94	···	(1)	···	···
771.0±2.8	95	7.6±0.8[c]	···	0.92	···	(1)	(0)[f]	3[f]
787.3±2.6	97	510±80	(127)[i]	≈0[d]	yes	0	(0)[f]	3[f]
817.4±2.9	98	148±15	(170)[i]	1×10^{-4}	yes	0	···	···
865±4	97	45±14	···	0.39	···	(0)	(0)[f]	2[f]
899±5	95	300±50	(180)[i]	5×10^{-4}	yes	0	(0)[f]	2[f]
983±7	95	25±3[c]	(180)[i]	0.87	···	(1)	(0)[f]	2[f]
1027±14	95	110±20	(180)[i]	0.38	···	(0)	(0)[f]	3[f]
1109±13	98	3100±400	(170)[i]	≈0[d]	yes	0	···	···
1145±16	95	300±60	(180)[i]	0.01	yes	0	(0)[f]	2[f]
1254±16	97	1500±150	(127)[i]	≈0[d]	yes	0	(0)[f]	3[f]
1343±21[b]	95	47±8[c]	···	0.84	···	(1)	···	···
1420±22	95	620±70[c]	(180)[i]	3×10^{-4}	yes	0	···	···
1535±27	97	1320±90[c]	(127)[i]	≈0[d]	yes	0	···	···

[a] Reference 12.
[b] Previously undetected.
[c] This is the value of $2g\Gamma_n$ rather than Γ_n itself.
[d] For a value $P<1\times10^{-4}$, it is stated as ≈0.
[e] Reference 9.
[f] Reference 10.
[g] Reference 11.
[h] Kim Hi San, L. B. Pikel'ner, Kh. Sirazhet, and E. I. Sharapov, Zh. Eksperim. i. Teor. Fiz. **49**, 410 (1965) [English transl.: Soviet Phys.—JETP **22**, 288 (1966)].
[i] This value for Γ_γ was assumed.

TABLE II. Radiation widths (meV) of molybdenum.

Mo isotope	l	E_0 (eV)	Measured Γ_γ Present work	Measured Γ_γ Other work	Calculated Γ_γ Cameron[a]	Calculated Γ_γ Stolovy and Harvey[b]
95	0	44.7	180±15	180±40[c]	160	140[d]
				210±60[e]		
				206±60[f]		
	0	159.6	260±60	180±30[c]		
				260±50[e]		
			$\langle\Gamma_\gamma\rangle_{l=0}=185\pm15$			
	1	110.3	310±80	...		
		117.9	200±120	...		
			$\langle\Gamma_\gamma\rangle_{l=1}=277\pm67$			
96	0	131.3	330±50	175±25[c] 260±50[e]	100	90[g]
	1	113.5	530±100	...		
97	0	70.9	127±13	200±30[c]	110	100[h]
				330±80[f]		
	1	16.3	140±30	...		
	1	55.4	170±30	...		
	1	79.8	120±60	...		
	1	109.6	300±150	...		
			$\langle\Gamma_\gamma\rangle_{l=1}=154\pm20$			
98	0	428.9	170±80	...	56	30[i]
	1	12.1	110±15	200±60[e]		
100	1	97.4	250±100	...	...	...

[a] Reference 16.
[b] Reference 17.
[c] Kim Hi San, L. B. Pikel'ner, Kh. Sirazhet, and E. I. Sharapov, Zh. Eksperim. i. Teor. Fiz. **49**, 410 (1965) [English transl.: Soviet Phys.—JETP **22**, 288 (1966).]
[d] $D=284$ eV is used.
[e] M. I. Pevzner, Yu V. Adamchuk, L. S. Danelyan, B. V. Efimov, S. S. Moskalev, and G. V. Muradyan, Zh. Eksperim. i. Teor. Fiz. **44**, 1187 (1963) [English transl.: Soviet Phys.—JETP **17**, 803 (1963)].
[f] J. A. Harvey, D. J. Hughes, R. S. Carter, and V. E. Pilcher, Phys. Rev. **99**, 10 (1955).
[g] $D=800$ eV is used.
[h] $D=178$ eV is used.
[i] $D=140$ eV is used.

resonances, no information could be obtained from the shape, since the difference between the calculated shapes for *s*- and *p*-wave interactions is small.

A probable *l*-value assignment for most of the resonances can be made on the basis of the measured value of $g\Gamma_n$ since, at the low neutron energies with which we are concerned, the average value of the neutron width is very much smaller for *p* waves than it is for *s* waves. An objective way in which to calculate the probability $P(p, g\Gamma_n)$ that a resonance with a measured value of $g\Gamma_n$ is a *p*-wave resonance has recently been described by Bollinger and Thomas.[14] In this approach one needs to know only the strength functions S_0 and S_1 for *s*- and *p*-wave resonances, respectively. For the isotopes with mass numbers $A=92$, 95, 96, and 97, we have used the values $S_0=0.5\times10^{-4}$ and $S_1=5\times10^{-4}$, which are consistent with the published results.[1,2,15] For the isotopes $A=98$ and 100, the values[1] used were $S_0(98)=0.42\times10^{-4}$, $S_1(98)=6.8\times10^{-4}$, $S_0(100)=0.55\times10^{-4}$, and $S_1(100)=4.6\times10^{-4}$.

The calculated values of $P(p, g\Gamma_n)$ are given in column 5 of Table I. From these values one sees that the very weak resonances are very probably excited by *p* waves and that the strong resonances are almost surely excited by *s* waves.

The *l* values deduced from our data are given in column 7. The $l=0$ assignments based on an observed asymmetry are definite, of course. The other assignments (all $l=1$) are probable assignments with a

[14] L. M. Bollinger and G. E. Thomas, Phys. Rev. **171**, 1293 (1968).

[15] K. K. Seth, R. H. Tabony, E. G. Bilpuch, and H. W. Newson, Phys. Letters **13**, 70 (1964).

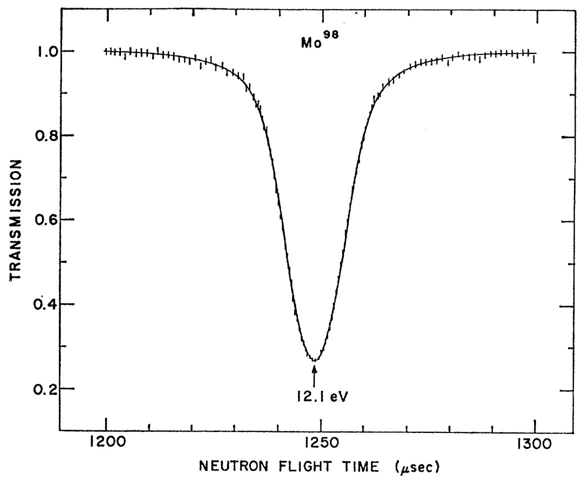

FIG. 2. p-wave resonance of Mo^{98} at neutron energy $E_0=12.1$ eV, as seen in the neutron transmission of natural Mo. The neutron flight path was 60 m. The vertical error bar on each experimental point indicates the standard statistical error. The resonance parameters that give the best theoretical fit (solid curve) are listed in Table I.

degree of certainty specified by the value of $P(p, g\Gamma_n)$. The $l=1$ assignments that are considered especially uncertain because of the small value of $P(p, g\Gamma_n)$ are enclosed in parentheses. In this connection, it should be noted that uncertainties in the strength functions S_0 and S_1 cause an uncertainty in the difference $[1-P(p, g\Gamma_n)]$ that in the case of small differences is approximately equal to the difference itself. The $l=1$ assignments without parentheses are those whose chance of being correct is $>90\%$.

IV. DISCUSSION

A comparison of the energy levels in Table I with those listed by Coceva *et al.*[10] shows that we miss a significant fraction of the small resonances at energies greater than about 300 eV. Thus, in this high-energy range, the isotopic and l-value assignments obtained in our analysis are those of the resonances with large values of $g\Gamma_n$. Also, the isotopic and l-value assignments obtained from our high-energy work are believed to be reliable (although incomplete) since weak resonances that are not resolved do not influence the derived value of $g\Gamma_n$ very much.

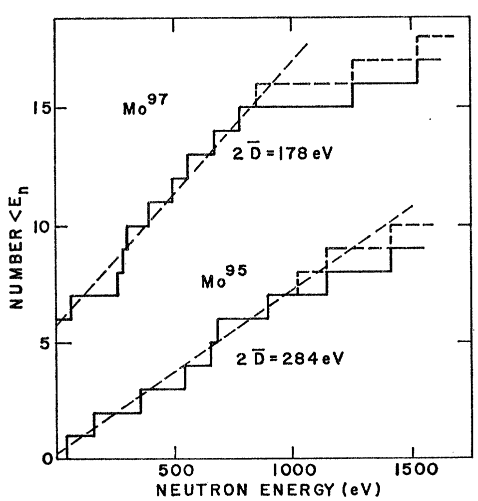

FIG. 3. Number of observed s-wave resonances at neutron energy smaller than E_n, plotted as a function of the neutron energy E_n.

The l values obtained in previous investigations are given in column 8. These assignments are consistent with those obtained by us, in so far as the more certain assignments are concerned. However, there are some discrepancies in the assignments given in parentheses. The parity (l-value) assignments of Coceva *et al.*, as they point out, are not to be taken as conclusive.

Table II compares the radiation widths Γ_γ measured in this experiment with those from other investigations. For each isotope, there is little or no difference between the mean radiation width for s-wave resonances and that for p-wave resonances. The last two columns

TABLE III. The strength functions for the s- and p-wave resonances of Mo isotopes.

Isotope	Strength function S_0 (s-wave)	Strength function S_1 (p-wave)
Mo^{95}	$0.5_{-0.2}^{+0.5}\times10^{-4}$	$5_{-3}^{+10}\times10^{-4}$
Mo^{97}	$0.5_{-0.2}^{+0.4}\times10^{-4}$	$6_{-2}^{+11}\times10^{-4}$
Mo^{98}	$2_{-1}^{+4}\times10^{-4}$	...

of Table II list the values of Γ_γ calculated by use of the formulas of Cameron,[16] and Stolovy and Harvey.[17] It should be pointed out that the formula of Stolovy and Harvey has $\Gamma_\gamma\propto D^{1/4}$, where D is the level spacing.

In order to derive the s-wave level spacing D for Mo^{95} and Mo^{97}, the number of observed resonances at neutron energy smaller than E_n as a function of the neutron energy E_n is plotted for each isotope. These are shown in Fig. 3. From these plots, we concluded that the mean spacing D per spin state is

$$D=284 \text{ eV for } Mo^{95},$$
$$=178 \text{ eV for } Mo^{97}.$$

The value for $D(Mo^{95})$ is consistent with the value calculated by use of Newton's formula,[18] which predicts $D\approx210$ eV for the compound state with $J=3$ and a value of about 295 eV for the compound state with $J=2$. For Mo^{97}, the measured s-wave level spacing per spin state is $D\approx178$. This again is consistent with the value predicted by Newton's formula,[18] which gives a value of 160 eV for the compound state with $J=3$ and 220 for $J=2$.

[16] A. G. W. Cameron, Can. J. Phys. **35**, 666 (1957).
[17] A. Stolovy and J. A. Harvey, Phys. Rev. **108**, 353 (1957).
[18] T. D. Newton, Can. J. Phys. **34**, 804 (1956).

With the measured parameters for the resonances listed in Table I, the resonance-capture integral RI for natural Mo is calculated to be

$$\mathrm{RI}=27\pm 2\mathrm{b}.$$

This value includes the $1/v$ contribution (1.2b) and the contributions ($\sim$1b) from resonances at energies higher than about 1.5 keV. The latter contributions have been calculated according to formulas derived by Dresner.[19] Our calculated value for the resonance-capture integral agrees resonably well with the values 33.2 ± 3.1b measured by Long,[20] and 25 ± 1b measured by Kapchigashev and Popov.[21]

Using the parameters of the resonances measured in this experiment, we calculated the strength functions for the s- and p-wave resonances of Mo isotopes. As pointed out at the beginning of this section, we feel that a significant fraction of the small resonances have been missed at energies greater than about 300 eV. Therefore, in calculating the p-wave strength functions, only that portion of the data obtained for $E_n<300$ eV have been used. For the calculation of the s-wave strength function S_0, on the other hand, we used the parameters of all the resonances measured in this experiment, since a failure to detect or identify a weak s-wave resonance would not significantly influence the result. The results are shown in Table III. The errors designate 80% confidence limits calculated under the assumption that the reduced neutron width $g\Gamma_n^1$ follows the Porter-Thomas distribution. Our results agree closely with the values $S_0\approx 0.5\times 10^{-4}$ and $S_1\approx 5\times 10^{-4}$ reported previously.[1,2,15]

[19] L. Dresner, J. Nucl. Energy **2**, 118 (1955); E. Kuhn and L. Dresner, *ibid.* **7**, 69 (1958).
[20] R. L. Long, Argonne National Laboratory Report No. ANL-6580 (1962), p. 32.
[21] S. P. Kapchigashev and Y. P. Popov, Soviet J. Atomic Energy **15**, 808 (1964).

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Spins and Widths of Energy Levels in the 5–9-MeV Region*

S. Ramchandran† and J. A. McIntyre

Texas A&M University, College Station, Texas

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Neutron-capture γ rays from the Texas A&M research reactor have been used to excite one nuclear energy level each in ^{90}Zr, Cd, Sn, Hg, ^{205}Tl, and ^{208}Pb, and two in ^{209}Bi, in the 5–9-MeV region. Angular-distribution measurements of the scattered γ rays showed that the transitions were all consistent with dipole radiation. However, for various reasons, the data could also be reproduced in most cases by assuming a mixture of dipole and quadrupole radiation. Three further measurements were made for the ^{90}Zr, the ^{205}Tl, the ^{208}Pb, and one ^{209}Bi excitation: (1) an absolute differential cross-section measurement on the resonance scattering, (2) a resonance absorption measurement, and (3) a differential cross-section measurement at liquid-nitrogen temperature. From these data, values were found for Γ_0 (the excited level width for an electromagnetic transition to the ground state), Γ (the excited level total electromagnetic width), and ϵ (the energy displacement between the neutron-capture γ-ray energy and the resonance energy). The values of Γ_0 (between 0.14 and 1.0 eV) were found to be about 10 times larger than the values usually found for γ-ray widths in this energy region as determined from neutron-capture reactions.

I. INTRODUCTION

Many properties of a nuclear energy level can be studied through the excitation of the level by the electromagnetic resonance fluorescence process. A number of techniques have been developed for exciting nuclear levels by electromagnetic radiation; one of the most recent, and still relatively unexploited, is that of using the extremely monoenergetic neutron-capture γ rays to excite the nucleus to be studied. The use of neutron-capture γ rays permits, for the first time, the study of properties of energy levels in heavy nuclei at excitation energies just below the neutron threshold where the level density is high and good energy resolution is essential.

In this paper, the study of energy levels is reported using methods that have already been described in the literature. Neutron-capture γ rays of a few eV energy resolution strike a target whose nuclei are excited by the resonance fluorescence process since the energy of the γ

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