ANALYSIS OF AVERAGED CROSS SECTIONS FOR NEUTRON CAPTURE

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A method is described which can be used to analyze the averaged neutron capture cross sections for energies between 1 and 50 keV with the purpose of determining the characteristics of the interaction between p-neutrons and nuclei. The capture cross sections measured by a lead-slowing-down-time neutron spectrometer for Br, Rb^{85}, Nb, Mo^{98}, Rh, Ag, In, Sb, I, Cs, and Ir nuclei are analyzed. The values obtained for the p-neutron strength functions are compared with the data of other authors and with the predictions of the optical model of the atomic nucleus.

1. INTRODUCTION

THE extensive development of neutron spectrometry in the resonant region has already advanced from the stage of mere accumulation of experimental data to the derivation of general laws and comparison with models of the atomic nucleus. The data obtained, however, pertain essentially to interaction between atomic nuclei and neutrons with zero orbital momentum (s-neutrons). Individual information on the interaction between neutrons with larger orbital momenta [1-3] cannot be regarded as reliable since they are based essentially on the separation of the resonances belonging to the s- and p-neutrons on the basis of the reduced neutron width. However, the large width of the neutron-width distribution [4] and the small number of the observed levels makes such a separation of the resonances not quite unambiguous.

At the present time we can apparently obtain more essential information on the interaction of p-neutrons with nuclei from an analysis of the averaged neutron capture cross sections in the energy range 1—100 keV. The strength functions obtained for the p-neutrons (S_1) as a result of such an analysis [5,6] confirm the presence of giant resonance in the dependence of S_1 on the atomic number A, predicted by the atomic model of the nucleus [7,8], and point to the presence of noticeable spin-orbit interaction. However, the difference between the values of S_1 obtained at Oak Ridge (USA) [6] and at Duke University (USA) [5] for the majority of elements in the giant-resonance region reaches a factor of two or three. This does not inspire confidence in the value of the spin-orbit interaction given by Weston et al. [5] or in the choice of the parameters of the potential with surface absorption of Krueger and Margolis [9], obtained by comparison with the data of [5].

Nemirovskiĭ [10] and Mossin-Kotin et al [11] solved the problem conversely. They calculated the averaged neutron capture cross sections by starting from definite model representations and parameters of the low-lying neutron resonances, and compared them with the experimental results. For many nuclei the agreement was found to be good. At the same time, attempts to calculate the cross sections in the kilovolt region for nuclei with widely spaced levels do not always give reliable results [12].

In the present paper we analyze the experimental data on the energy dependence of averaged neutron capture cross sections, obtained at the P. N. Lebedev Physics Institute using a lead-slowing-down-time neutron spectrometer [13-15] in the $\sim$ 1—50 keV energy region. The purpose of the analysis was to determine the average resonance parameters that describe the capture of neutrons with orbital momentum $l = 1$. The contribution of the p-neutrons in this energy region is on the one hand comparable with the contribution of the s-neutrons and on the other hand much larger than the contribution of the neutrons with higher orbital momenta. The procedure of such an analysis was already described [5,6] (for more details see [16]). We stop to discuss only individual details of the analysis.

2. METHOD OF ANALYSIS

We consider the averaged cross section $\bar{\sigma}_\gamma$ for radiative neutron capture in the kilovolt energy re-

gion. We shall assume that the contribution of the direct processes to this cross section is small. Exceptions can be expected only for the magic and near-magic nuclei (for example, Rb). In the case when $D^J \ll \Delta E \ll E$ we can describe $\bar{\sigma}_\gamma$ well by the Breit-Wigner formula for isolated resonances, averaged over the energy interval ΔE (see, for example, [10]):

$$\bar{\sigma}_\gamma = \sum_{l,J,j} \bar{\sigma}_\gamma^{lJj} = 2\pi^2\lambda\!\!\!^{-2} \sum_{l,J} \frac{2J+1}{2(2I+1)} \sum_j \frac{\overline{\Gamma_n^{lJj}\Gamma_\gamma^l}}{D^J \Gamma^{lJ}}, \quad (1)$$

where $\lambda\!\!\!^{-}$ is the wavelength of the neutron of energy E, I and J are the spins of the target nucleus and of the compound nucleus, and j is the total momentum of the neutron, equal to $(l \pm 1/2)$; Γ_n^{lJj}, Γ_γ^l, and Γ^{lJ} are respectively the partial neutron width corresponding to a definite value of j, the radiation width, and the total width of the resonance level; D^J is the average distance between levels with identical values of J.

The superior bar in formula (1) denotes averaging over the distributions of the widths from resonance to resonance. For the neutron widths we used the Porter-Thomas distribution [4] with n = 1 degrees of freedom, which is universally accepted and agrees well with experiment. We do not consider inelastic scattering of neutrons, for this process does not occur in the investigated region of energies and nuclei [1)], i.e., the total width consists only of the neutron and radiative parts.

Inasmuch as formula (1) contains a large number of unknown parameters and all cannot be determined from the experimental data at our disposal, we attempt to simplify formula (1) so as to reduce the number of unknown parameters to a minimum.

1. As in [5,6], in our region $E \ll E_b$ (binding energy of the neutron) we neglect the energy dependence of the level density $\rho(E^*, J) = 1/D^J$, since the excitation energy of the nucleus is $E^* \sim E_b$. By the same token we can assume that Γ_γ likewise does not depend on the energy. We have used for $\rho(J)$ and $\Gamma_\gamma(J)$ the J-dependence described by the statistical model [18], which does not contradict the experimental data [2,19]. According to our estimates the values of Γ_γ for the maximum and minimum of J differ by not more than 15—20%, so that within the limits of this quantity we can assume Γ_γ to be independent of J. In addition, the radiative capture is usually accompanied by a large number of γ transitions to different levels of the compound nucleus (we do not consider direct processes, since their contribution is small for the nonmagic nuclei). We can therefore expect that Γ_γ varies little from resonance to resonance: $\Gamma_\gamma = \bar{\Gamma}_\gamma$.

2. Since we do not know the distributions of the average neutron widths over J and j, it is natural to introduce certain quantities averaged over J and j with which to describe the cross section and to compare these quantities with parameters calculated in accordance with some model.

Let us determine (for the averages over E) the value of $\langle \Gamma_n(l_J) \rangle$ averaged over j:

$$\Gamma_n^{lJ} = \langle \Gamma_n (lJ) \rangle \varepsilon_J^{ll},$$

where ϵ_J^{ll} is equal to 2 if

$$|J - I| \leqslant l \pm 1/2 \leqslant J + I,$$

is equal to 1 if only one of the conditions

$$|J - I| \leqslant l + 1/2 \leqslant J + I$$

or

$$|J - I| \leqslant l - 1/2 \leqslant J + I$$

is satisfied, and is equal to zero in all other cases. We then introduce the parameter $\langle \Gamma_n(l)/D \rangle$ averaged over J, corresponding to $\langle \Gamma_n(lJ) \rangle / D^J$, such that

$$\bar{\sigma}_\gamma = 2\pi^2\lambda\!\!\!^{-2} \sum_{l,J} \frac{2J+1}{2(2I+1)} \frac{\varepsilon_J^{ll} \langle \Gamma_n(l)/D \rangle (\Gamma_\gamma^l / D^J)}{\varepsilon_J^{ll} \langle \Gamma_n(l)/D \rangle + (\Gamma_\gamma^l / D^J)} \times F\left(\frac{\Gamma_\gamma^l / D^J}{2\varepsilon_J^{ll} \langle \Gamma_n(l)/D \rangle} \right), \quad (2)$$

where averaging over the Porter-Thomas distribution [20] gives rise to

$$F(a) = \overline{\left(\frac{\Gamma_n}{\Gamma}\right)} \frac{\bar{\Gamma}}{\bar{\Gamma}_n} = (1+2a)\{1 - \sqrt{\pi a} e^a [1 - \operatorname{erf}(\sqrt{a})]\},$$

$$\operatorname{erf}(\sqrt{a}) = \frac{2}{\sqrt{\pi}} \int_0^{\sqrt{a}} e^{-t^2} dt.$$

$F \equiv 1$ when $\Gamma_n \equiv \bar{\Gamma}_n$ or when $\bar{\Gamma}_n \ll \Gamma_\gamma$, i.e., as $a \to \infty$.

The introduction of a parameter $\langle \Gamma_n(l)/D \rangle$ which does not depend on J does not contradict many experimental data. Thus, Waters et al [19] found that for W^{183} the value of $\langle \Gamma_n(0J) \rangle / D^J$ does not depend on J. In addition, if we consider the experimental strength functions of the s-neutrons (which are proportional to $\langle \Gamma_n(0)/D \rangle$), we can

[1)] An exception is the 29-keV Nb^{93} level with spin $1/2^-$. However, since the spin of the ground state is $9/2^+$, the inelastic process can proceed for neutrons with larger momenta, the minimum required being the capture of p-neutrons with emission of a d-neutron or vice versa. Such a process has low probability and, according to estimates based on the sticking coefficients given by Nemirovskiĭ [17], it amounts to less than 1% of the capture cross section of the p-neutrons.

note that for neighboring nuclei in the region A = 232—243, which differ greatly in I (and consequently also in J), the average values of the strength functions $\bar{f}_0$ [21] differ merely by a factor of $1\frac{1}{2}$ or 2. When $I = \frac{5}{2}$ we have $\bar{f}_0 = 1.1 \times 10^{-4}$, when $I = \frac{1}{2}$ we have $\bar{f}_0 = 1.0 \times 10^{-4}$, and when $I = 0$ we get $\bar{f}_0 = 1.8 \times 10^{-4}$. If we disregard the value $f_0 = 3.7 \times 10^{-4}$ for Pu^{242}, which differs sharply from the other values of f_0 for nuclei with $I = 0$, we get $\bar{f}_0 = 1.4 \times 10^{-4}$.

Let us introduce a parameter that does not depend on E, $S_l = \langle \Gamma_n(l)/D \rangle (\sqrt{E} v_l)^{-1}$, where $v_0 = 1$ and $v_1 = (R/\lambda\!\!\!^{-})^2/[1 + (R/\lambda\!\!\!^{-})^2]$. Then from a comparison of expression (2) with the experimental values of $\bar{\sigma}_\gamma$ we can obtain S_0, S_1, $(\Gamma_\gamma/D)_0$, and $(\Gamma_\gamma/D)_1$ for the given target nucleus. Here $D = D^J(2J + 1)$ does not depend on J.

Comparing (2) for $\Gamma_\gamma \gg \Gamma_n$ with the expression for the cross section for the production of the compound nucleus, which is obtained in the optical model of the nucleus [17], we find that the value obtained by us for S_l is the strength function [2)]

$$S_l = [(l + 1) T_{l+1/2} + l T_{l-1/2}]/2\pi (2l + 1) \sqrt{E} v_l,$$

where the T_j are the sticking coefficients calculated in the optical model. Since S_l is obtained not merely from the limited region in which $\Gamma_\gamma \gg \Gamma_n$, it can generally speaking differ somewhat from the strength function determined in the optical model. However, when Γ_n increases the capture cross section becomes less and less sensitive to S_l, and does not depend on S_l at all when $\Gamma_n \gg \Gamma_\gamma$. Thus, the most suitable region for the determination of the corresponding strength function is that of small energies, where $\Gamma_\gamma^l > \Gamma_n^l$.

3. In the neutron energy region up to 60 keV, where the analyzed experimental points are located, the main contribution to the cross section is made by neutrons with $l = 0$ and $l = 1$. The contribution of neutrons with $l = 2$, which increases at low energies as $E^{5/2}$, can be estimated by taking the corresponding sticking coefficients in accordance with the optical model. For E ~ 50 keV we have $\langle \Gamma_n(l)/D \rangle \gg (\Gamma_\gamma/D)_l$ for $l = 0$ and $l = 1$, and therefore [see expression (2)] the cross section is determined by the values of $(\Gamma_\gamma/D)_l$. For d-neutrons the situation is reversed, and their contribution to the cross section is determined by the sticking coefficient. In this approximation we have estimated for each nucleus the energy boundary, starting with which the contribution of the d-neutrons to the summary capture cross section exceeds 10%. It turned out that for the analyzed nuclei such a limiting energy is located at E ~ 50 keV. Thus, the most favorable region of neutron energies for the analysis of the parameters of s- and p-neutrons is the interval ~ 1—50 keV.

3. RESULTS OF ANALYSIS AND DISCUSSION

The theoretical formula (2) was compared with the experimental cross-section curves for $Br^{79,81}$, Rb^{85}, Nb^{93}, Rh^{103}, $In^{113,115}$, $Sb^{121,123}$, I^{127}, Cs^{133}, $Ir^{191,193}$ [13], Mo^{94}, Mo^{100} [14] and $Ag^{107,109}$ [15] (the data on silver have been made more precise in the diploma project of S. Romanov, Physics Institute of the Academy of Sciences, 1962.) It was assumed that $R = 1.45 A^{1/3} \times 10^{-13}$ cm.

An electronic computer and the least-squares method were used to determine a set of parameters yielding the best agreement with experiment. Parameters such as S_0, $(\Gamma_\gamma/D)_0$, S_1, or $(\Gamma_\gamma/D)_1$ could be varied. In the analysis we took account only of random experimental errors (~ 3—5%). The possible error in normalization (~ 10%) leads only to a parallel shift of the entire curve, which influences little the least-squares accuracy. Calculations made for I^{127} have shown that when the experimental points are shifted by ±10% the parameters remain within the limits of their errors. The weak dependence on the normalization was already noticed earlier [5].

Inasmuch as the averaged cross sections are smooth functions of the energy (see Figs. 1, 2) we can determine uniquely only a small number of parameters. In our case, as a rule, even three

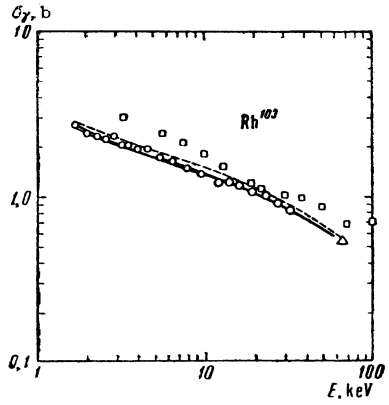

FIG. 1. Comparison of the experimental cross sections for neutron capture in Rh^{103} with the theoretical curves. The solid curve was calculated from the parameters given in the table. The averaged cross-section curves coincided for the parameters of all three series of calculations. The dashed curve corresponds to the second series of calculations, but with S_1 modified by the amount of the error: $S_1 = 7 \times 10^{-4}$. o – experimental points from [13], □ – from [5], Δ – from [6].

[2)] This is correct accurate to $\pi/2 \langle \Gamma_n(l)/D \rangle$, which in our energy region does not exceed 10%. [17]

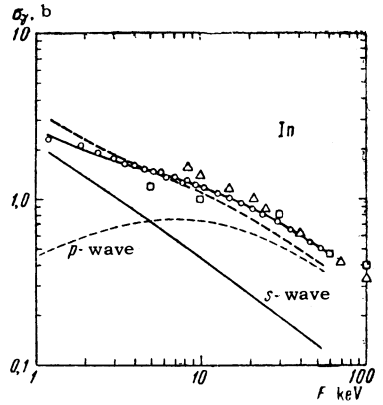

FIG. 2. Comparison of the experimental cross sections for neutron capture in In with the theoretical curves. The solid curve is calculated from the results of the second in the series of calculations (see the table), while the dashed curve is from the results of the first series. We also give the partial capture cross sections due to s- and p-neutrons (second series of calculations): o – experimental points from [13], □ – from [5], and Δ – from [6].

of the varied parameters guarantee agreement with the experimental curve within the limits of the specified errors, so that the introduction of additional varied parameters can lead only to ambiguity in the results. The most interesting from the physical point of view is apparently the determination of the strength function for the p-neutrons, $S_1 \sim \langle \Gamma_n(1)/D \rangle$.

In the first series of the calculations we assumed $(\Gamma_\gamma/D)_0 = (\Gamma_\gamma/D)_1 = S_\gamma$, and the strength function S_0 was taken from the results by others [21]. This yielded the two parameters S_1 and S_γ. It must be noted, however, that when $A \approx 100$, i.e., in the region of the minimum of $S_0(A)$, the accuracy with which S_0 is determined is still very poor, and that there are no experimental data whatever for some nuclei, so that it has been necessary to extrapolate S_0 from values obtained for neighboring nuclei. In this connection, a second series of calculations was made, in which the three parameters S_0, S_1, and S, were determined. Finally, inasmuch as we cannot consider it finally demonstrated that $(\Gamma_\gamma/D)_0 = (\Gamma_\gamma/D)_1$ even for nuclei with odd Z, although an indication of this fact does exist [5], a third series of calculations was made with fixed value of S_0, where S_1, $(\Gamma_\gamma/D)_0$, and $(\Gamma_\gamma/D)_1$ were determined. The results of all three series of calculations are listed in the table.

Columns 2–4 of the table give the values of the parameters and references to the information sources. The columns that follow give the parameters obtained by us, each line pertaining to a definite series of calculations.

If we consider the results of different series of calculations from the point of view of determining the strength function for p-neutrons, it turns out that in all three series the values of S_1 coincide, within the limits of their errors (exceptions are $Ag^{107,109}$ and Rb^{85} [3)]), in spite of the fact that the values of S_0, and also the ratios $(\Gamma_\gamma/D)_0$ and $(\Gamma_\gamma/D)_1$ can sometimes change appreciably (see the table). Such a position enables us to speak of a unique determination of S_1 by analysis of the averaged capture cross sections in the energy range ~ 1–50 keV. For the final values of S_1 we took the average of the three series of calculations, while the error interval was determined by the limits of the errors in the extreme values of S_1 (the last column of the table).

An analysis of the results of the determination of the remaining parameters, given in the table, shows that the values obtained by us for S_0 are as a rule close to the results of other measurements and the extrapolation from the neighboring elements, although there are also systematic deviations by a factor of $1\frac{1}{2}$–2 (In, Sb, I). It probably does not pay to dwell here on these differences, since the present analysis does not claim a reliable determination of S_0 for the most suitable energy ranges for this purpose, where $\Gamma_n < \Gamma_\gamma$ for the s-wave, is missing from the analyzed energy region.

Owing to the correlation between S_0 and $(\Gamma_\gamma/D)_0$, these discrepancies affect also the analysis results when $(\Gamma_\gamma/D)_0$ and $(\Gamma_\gamma/D)_1$ are varied separately, so that we obtain for these nuclei $(\Gamma_\gamma/D)_0 < (\Gamma_\gamma/D)_1$. It is quite probable that this inequality reflects not the physical aspect of the phenomenon, but more likely the inaccurate specification of the value of S_0.

A comparison of the absolute magnitudes of the radiative strength functions with neutron-spectroscopy results in the resonant region (for example, [22]) shows that they are close. It is still too early to expect more, for the majority of the nuclei the accuracy with which (Γ_γ/D) is determined from the parameters of the individual resonances is patently inadequate.

An important factor for further refinement of the p-neutron strength functions (both neutron and radiative) obtained from an analysis of the averaged capture cross sections, in addition to a re-

[3)]For several reasons, the results of the analysis of the averaged capture cross sections for Rb^{85} are less reliable than for the remaining nuclei. The Rb^{86} nucleus is near-magic with a low level density, i.e., direct transitions can make a large contribution here, and in the region of several keV the condition $D^J \ll \Delta E \ll E$ is not well satisfied.

Results of analysis of averaged capture cross sections*

Element	Data of other authors			S_0	$(\Gamma_\gamma/D)_0$	$(\Gamma_\gamma/D)_1$	S_1	$\overline{S_1}$
	S_0	Γ_γ/D	S_1					
$Br^{79, 81}$	1.4 2.3	24 6.7[22]	0.05[6]	1.4 1.9±0.4 1.4	6.5±0.3 5.6±0.6 6.40±0.34 | 5.6±0.7		2.3±0.3 3.0±0.7 2.7±0.5	$2.7^{+1.0}_{-0.7}$
Rb^{85}	2.5	~0.15[22]		0.5 0.11±0.07	1.33±0.06 1.35±0.04		4.5±0.5 10.2±3.3	7^{+6}_{-4}
Nb^{93}	0.35 0.1	0.9 1.0[22]	12±5[6] 6.0±0.2[23] 4.6±1[1]	0.35 0.37±0.1 0.35	1.21±0.03 1.21±0.03 1.1±0.3 | 1.23±0.06		10.7±0.7 10.3±1.9 11.5±2.5	$10.8^{+3.2}_{-2.4}$
Mo^{98}				0.5 0.06±0.16 0.5	1.1±0.2 1.0±0.1 0.5±0.7 | 1.0±0.1		1.3±0.6 2.4±2 2.6±2.2	$2.1^{+2.7}_{-1.7}$
Mo^{100}	0.5	1.0	1±1[5]	0.5 6±12 0.5	2.9±0.1 1.7±0.3 2.7±0.2 | 1.7±0.4		0.48±0.05 0.9±0.3 0.7±0.2	$0.7^{+0.5}_{-0.3}$
Rh^{103}	0.5±0.1 0.5 0.44[25] 0.7	20 15[22]	4^{+4}_{-2}[24] 2.5±1.5[5]	0.44 0.53±0.04 0.44	13.2±0.9 14±1 18.6±2.5 | 13.7±1.2		6.4±0.6 5.2±0.6 4.7±0.7	$5.4^{+1.6}_{-1.4}$
$Ag^{107, 109}$	0.8 0.51±0.09[3]	14.3	10±3[6]	1.0 0.51 0.79±0.05 1.0 0.51	9.6±0.5 28.3±1.6 11.6±0.9 9.3±0.4 | 11.5±0.8 23.1±1.8 | 11.4±1.2		8.6±0.8 2.6±0.2 7.2±0.8 8.1±0.7 5.1±0.7	6.5^{+3}_{-4}
$In^{113, 115}$	0.5 0.31 0.31±0.06[26]	3.9 6.0	8^{+2}_{-2}[6] $2^{+2}_{-0.8}$ [5]	0.5 0.24±0.01 0.5	3.1±0.2 4.3±0.2 1.49±0.12 | 4.66±0.2		4.1±0.5 5.1±0.4 6.5±0.5	$5.2^{+1.8}_{-1.6}$
$Sb^{121, 123}$	0.52 1.1	3.0 3.7[22]	4±1[6]	0.5 0.30±0.03 0.5	2.4±0.2 3.9±0.6 2.2±0.2 | 4.3±0.6		1.8±0.4 1.3±0.3 1.7±0.3	$1.6^{+0.6}_{-0.6}$
I^{127}	0.84 1.2±0.4[26]	6.7 4.8[22]	3.0±1.5[6] 1.5±0.7[5]	0.84 0.49±0.02 0.84	5.4±0.2 7.4±0.4 4.0±0.2 | 7.9±0.4		3.8±0.4 3.4±0.3 4.3±0.4	$3.8^{+0.9}_{-0.7}$
Cs^{133}	1.0±0.2[26] 2.6	3.9[22]		1.0 1.1±0.1 1.0	3.0±0.1 2.8±0.2 3.0±0.14 | 2.8±0.24		2.7±0.3 3.0±0.5 2.8±0.4	$2.8^{+0.3}_{-0.4}$
$Ir^{191, 193}$	2.2±0.2[26] 2.3	14[22]		2.4 2.2±0.2 2.4	26.8±0.6 29±3 26.0±0.7 | 17.8±7.7		1.75±0.2 1.5±0.3 1.9±0.5	$1.7^{+0.7}_{-0.5}$

*All the parameters are listed in the present table in units of 10^{-4}.

finement of the capture cross section curve, is also the knowledge of the exact values of S_0 and $(\Gamma_\gamma/D)_0$, which judging from many of the latest investigations in neutron spectroscopy in the resonant region[3,27,25,28] can be obtained with good accuracy.

Comparison of our results on the determination of the strength function for p-neutrons with other data is shown in Fig. 3. It is seen that our values are in good agreement with the data of Gibbons et al[6] (with the exception of Sb and Br) and, as a rule, deviate from the data of Weston et al[5]. This discrepancy cannot be attributed to the difference in the procedures for determining S_1 from the capture cross section curves (the authors of [5] made a longhand analysis of the cross sections, considering this method to be clearer), inasmuch as our calculations based on the experimental points from [5] yielded values of S_1 close to those given by Weston et al.

The general dependence of our values of S_1 on the atomic number is described in first approxi-

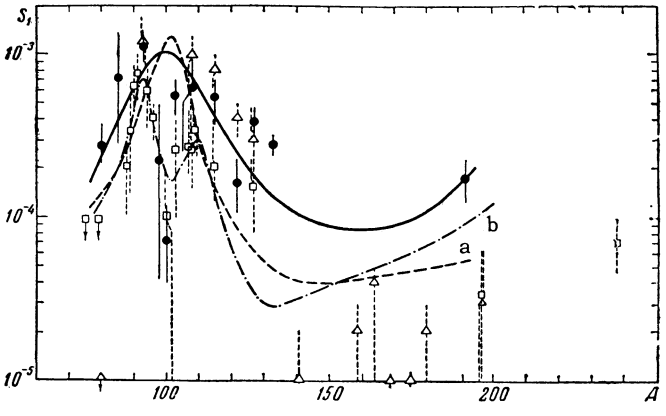

FIG. 3. Dependence of the strength function for p-neutrons on the atomic weight of the target nucleus. ● – results of the present work, □ – taken from [5], △ – from [6]. The continuous curve is calculated from the sticking coefficients taken from [17] (potential with smeared edge, volume absorption). The dashed curves are taken from [9] (potential with smeared edge, surface absorption). Curve b corresponds to twice the value of spin-orbit interaction than curve a and the solid curve[17]. The symbols with downward arrows show the upper limit of S_1.

mation by a theoretical curve calculated from the sticking coefficients given in Nemirovskiĭ's book [17]. The most significant deviation from the theoretical curves observed near $A \approx 100$ where the experimental values of S_1 for Rh and particularly for Mo^{98} and Mo^{100} lie below the curve. The small values of S_1 for Mo^{98} and Mo^{100} cannot be related only with the fact that unlike the remaining odd-even isotopes these are even-even. As was already noted above (in the analysis of the dependence of the strength function S_0 on J), S_0 does not depend in practice on whether the number of protons or neutrons in the nucleus is even or odd; there are no grounds for assuming that the situation is different for S_1.

It must be noted at the same time that measurements with small amounts of separated Mo^{98} and Mo^{100} isotopes, which capture neutrons weakly, have been made with worse accuracy than those for the other elements [14]. In addition, the low level density of these isotopes does not guarantee reliable averaging of the cross section in the low-energy region, although the fluctuation in the level density, which would lead to a five or ten fold decrease in S_1 for both isotopes, is little likely. The error in the determination of S_1 due to the poor averaging of the cross sections cannot be estimated so that the only errors assigned to the values of $\bar{S}_1$ for Mo^{98} and Mo^{100} are those due to the calculation results.

Thus, the dip in S_1 at $A \approx 100$ can point to a stronger spin-orbit interaction than is assumed in [17] (in [5] the spin-orbit interaction is taken to be much larger), or else to the need for an even greater detailing of the optical potential, for example an account of collective effects[29] or introduction of surface absorption, as was done by Margolis and Krueger[9]. At the same time it must be noted that the introduction of surface absorption and the use of the spin-orbit interaction obtained from the splitting of the lower levels of the nucleus still does not yield the splitting of the giant resonance $S_1(A)$ at $A \approx 100$[9].

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