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**Abstract**

**Full Text**

## **Reports of the Academy of Sciences of the USSR**

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### **PHYSICS**

**E. A. Kolytin, G. B. Yan' kov**

## **STRENGTH FUNCTION FOR THE ISOTOPES Ni<sup>62</sup>, Se<sup>80</sup>, Cd<sup>114</sup>, AND Sn<sup>118</sup> IN THE NEUTRON-ENERGY REGION 50-400 keV**

*(Presented by Academician A. P. Aleksandrov, January 25, 1963)*

**Introduction.** The strength function, or the ratio of the mean reduced level width to the mean spacing between them, characterizes chiefly the properties of the nuclear surface and therefore is of special importance for certain modern nuclear models. According to the strong-interaction model, the strength function does not depend on atomic weight, whereas in the optical model this dependence is pronounced <sup>(1)</sup>. The available experimental data confirm the main conclusions of the optical model. The *s*-wave strength functions  $\bar{\Gamma}_n^0/\bar{D}$  for most elements were determined at small neutron-energy values <sup>(2)</sup>. For *p*-waves, the strength functions  $\bar{\Gamma}_n^1/\bar{D}$  had been measured, by the beginning of the present work, only for certain isotopes <sup>(3)</sup>. In addition, individual results reported by different authors differed substantially.

In the region of tens and hundreds of kiloelectronvolts of neutron energy, the effect of the deviation of the transparency of a sample from a simple exponential decrease with increasing sample thickness can be used to determine strength functions. If the width of the energy spectrum of the neutron source is greater than the mean spacing between nuclear levels, then the influence of these levels will appear in the dependence of transparency on thickness <sup>(4)</sup>. It was shown that the magnitude of the deviation from exponential decrease, for the interaction of *s*-neutrons with the nuclei of a sample containing a single isotope with zero spin (for the case in which neutron-capture processes, inelastic scattering, and Doppler broadening of resonances are insignificant), can be expressed through the sticking coefficient *Q*, which, in turn, is related to the ratio  $\bar{\Gamma}_n/\bar{D}$ . In the region where, besides *s*-neutrons, *p*-neutrons also have an appreciable effect, the deviation from exponential dependence will characterize the *s*- and *p*-strength functions; moreover, the latter can be calculated if the strength function of the *s*-waves is known. By this method, in work <sup>(5)</sup>, the strength functions

of *s*- and *p*-waves were investigated for a number of samples containing the natural mixture of isotopes, thus characterizing the strength function of the most abundant isotope or of their mixture.

For a clearer comparison of the obtained results with theoretical conclusions, it is much better to use samples of separated isotopes. In the present work, the deviation of transparency from exponential dependence was measured on samples of the separated isotopes  ${}_{28}\text{Ni}^{62}$ ,  ${}_{34}\text{Se}^{80}$ ,  ${}_{48}\text{Cd}^{114}$ , and  ${}_{50}\text{Sn}^{118}$ . The values of the strength functions were determined in the energy interval 50–400 keV.

**Apparatus and measurements.** The direct method of measurement consists in comparing the transparencies of “thick” and “thin” samples. It is experimentally more convenient to modify this method somewhat and to measure the transparency of the “thin” sample twice: once to measure the transparency  $T_1$  for neutrons from the target, and a second time the transparency  $T_2$  for neutrons that have first been filtered by a “thick” sample of the same isotope. From the difference between the transparencies  $T_2 - T_1$  of the sample with the filter and without it, the expected deviation can be obtained.

As a neutron source, the reaction  $T(p, n)\text{He}^3$  was used. The protons were accelerated by an electrostatic accelerator <sup>(6)</sup> to energies of 1250 keV and struck a solid target whose thickness was  $\sim 80$  keV. By selecting neutrons emitted from the target at different angles with respect to the proton beam, it was possible to use neutrons of different energies from 50 to 400 keV.

The neutrons were recorded by a recoil-nuclei proportional counter, which had a diameter of 2.5 cm, a length of 28 cm, and was located at a distance of  $\sim 50$  cm from the target.

The samples and filters, 2.5 cm in diameter, were placed approximately midway between the neutron source and the effective center of the detector. The transparency of the samples was  $\sim 85\%$ , and the transparency of the filters for most experiments was  $\sim 25\%$ . The content of the principal isotope in the samples studied was as follows: Ni<sup>62</sup> 90; Se<sup>80</sup> 94; Cd<sup>114</sup> 95 and Sn<sup>118</sup> 70%.

The counter background was very stable for each neutron energy and varied from 6–7% at energies of 50 keV to 1.5–2% at neutron energies of 400 keV. The statistical error in measuring the transparency of the sample with the filter and without it was approximately 0.5%.

### Table 1

Isotope	Energy interval, keV	$\bar{E}$ , keV	$T_2 - T_1$	$Q$	$\frac{\bar{\Gamma}_n^0}{D} \cdot 10^4$	$\frac{\bar{\Gamma}_n^V}{D} \cdot 10^4$ , for $\frac{\Gamma_n^0}{D} \cdot 10^4 = 1.0$	$\frac{\bar{\Gamma}_n^V}{D} \cdot 10^4$ , for $\frac{\Gamma_n^0}{D} \cdot 10^4 = 1.4$
Ni <sup>62</sup>	55-117	92	0.096 ± 0.009	0.31 ± 0.06	1.80 ± 0.37		
Ni <sup>62</sup>	94-165	135*	0.052 ± 0.005	0.31 ± 0.05	1.47 ± 0.14		
Ni <sup>62</sup>	94-165	135	0.080 ± 0.006	0.29 ± 0.04			
Ni <sup>62</sup>	141- 220	181	0.026 ± 0.005	0.15 ± 0.04	0.60 ± 0.14		
Ni <sup>62</sup>	241- 329	286	0.033 ± 0.006	0.37 ± 0.09	1.23 ± 0.30		
Ni <sup>62</sup>	315- 410	362	0.025 ± 0.006	0.48 ± 0.11	1.48 ± 0.38		
Se <sup>80</sup>	55-117	92	0.046 ± 0.009	0.25 ± 0.06	1.42 ± 0.33	1.58 ± 0.63	
Se <sup>80</sup>	141- 220	181	0.050 ± 0.007	0.54 ± 0.11	2.40 ± 0.46	2.23 ± 0.89	1.36 ± 0.54
Se <sup>80</sup>	241- 329	286	0.035 ± 0.006	0.69 ± 0.16	2.65 ± 0.62	1.18 ± 0.47	0.80 ± 0.32
Se <sup>80</sup>	315- 410	362	0.039 ± 0.006	1.29 ± 0.27		1.72 ± 0.69	1.45 ± 0.58
Cd <sup>114</sup>	55-117	92	0.035 ± 0.006	0.16 ± 0.04	0.88 ± 0.19	2.27 ± 0.91	
Cd <sup>114</sup>	94-165	135*	0.030 ± 0.006	0.31 ± 0.07			
Cd <sup>114</sup>	94-165	135	0.057 ± 0.008	0.36 ± 0.06	1.60 ± 0.22	1.52 ± 0.61	
Cd <sup>114</sup>	141- 220	181	0.047 ± 0.005	0.41 ± 0.04	1.73 ± 0.20	1.98 ± 0.79	
Cd <sup>114</sup>	241- 329	286	0.024 ± 0.005	0.38 ± 0.10	1.28 ± 0.35	0.71 ± 0.28	
Cd <sup>114</sup>	315- 410	362	0.030 ± 0.004	0.67 ± 0.11	2.24 ± 0.42	1.06 ± 0.43	
Sn <sup>118</sup>	55-117	92	0.044 ± 0.016	0.19 ± 0.08	1.05 ± 0.50		
Sn <sup>118</sup>	141- 220	181	0.020 ± 0.006	0.14 ± 0.05	0.56 ± 0.19		

Isotope	Energy interval, keV	$\bar{E}$ , keV	$T_2 - T_1$	$Q$	$\frac{\bar{\Gamma}_n^0}{D} \cdot 10^4$	$\frac{\bar{\Gamma}_n^V}{D} \cdot 10^4$ ,	$\frac{\bar{\Gamma}_n^V}{D} \cdot 10^4$ ,
						for $\frac{\Gamma_n^0}{D} \cdot 10^4 = 1.0$	for $\frac{\Gamma_n^0}{D} \cdot 10^4 = 1.4$
Sn <sup>118</sup>	241-	286	0.017 ±	0.19 ±	0.58 ±		
	329		0.006	0.07	0.23		
Sn <sup>118</sup>	315-	362	0.017 ±	0.27 ±	0.78 ±		
	410		0.006	0.10	0.29		
W <sup>183</sup>	55-117	92	0.010 ±				
W <sup>183</sup>	141-	181	0.000 ±				
	220		0.006				
W <sup>183</sup>	241-	286	-0.004 ±				
	329		0.006				
W <sup>183</sup>	315-	362	-0.003 ±				
	410		0.006				
Carbon**	94-165	135	-0.004 ±				
			0.006				
Carbon**	315-	362	0.001 ±				
	410		0.006				
Th <sup>232</sup>	94-165	135	-0.002 ±				
			0.009				
Th <sup>232</sup>	141-	181	0.002 ±				
	220		0.007				
Th <sup>232</sup>	241-	286	0.008 ±				
	329		0.006				
Th <sup>232</sup>	315-	362	-0.002 ±				
	410		0.006				

\* A thin filter was used.

\*\* A natural mixture of isotopes was used.

**Results and discussion.** Table 1 gives the results of the measurements: the energy interval of the spectrum of neutrons incident on the sample; the weighted mean energy  $\bar{E}$  of this interval, the difference  $T_2 - T_1$  of the transparencies of the sample with the filter and without it (with the statistical error); the sticking coefficient  $Q$ , calculated from the difference  $T_2 - T_1$ , under the condition,

that only  $s$ -neutrons interact. The error in the values of  $Q$  also includes the uncertainties in determining the mean energy of the interval, which reached 10-12%.

To check the measurement procedure, a series of control experiments was per-

formed. In the neutron-energy region studied, the total cross section of carbon has no resonances. For thorium, on the contrary, one should expect such a close spacing of levels that, as a result of Doppler broadening, they overlap. Therefore, in both cases no deviation of the transparency from an exponential dependence should be observed. The obtained values of the difference  $T_2 - T_1$  for carbon and thorium over the entire energy region are zero within the measurement errors. At a neutron energy of 135 keV, in experiments with nickel and cadmium samples, in addition to the filters ordinarily used, still thinner filters were used, with transparencies not of 25%, but of  $\sim 45\%$ . As can be seen from Table 1, the values of the sticking coefficient for both filter thicknesses agree within the experimental errors.

An attempt was made to determine  $T_2 - T_1$  for  $^{182}_{74}\text{W}$  (see Table 1). The  $s$ -wave strength function for tungsten <sup>(7)</sup>, measured at small neutron energies, is rather large and amounts to  $(3.0 \pm 1.0) \cdot 10^{-4}$ . Therefore the absence of a noticeable effect can be attributed only to the influence of Doppler broadening of the resonances.

Table 1 gives the values of the  $s$ -wave strength function for the isotopes of nickel, selenium, cadmium, and tin, calculated from the data in the table of values of  $Q$ .

It may be considered that for nickel the main role is played by  $s$ -levels, since the value of the strength function does not change with increasing neutron energy. The low value of the strength function for nickel at an energy of 181 keV is evidently explained by a statistical fluctuation of  $\Gamma_n/D$ , i.e., the selected energy interval (79 keV) contained few levels and sufficient averaging over resonances did not occur.

For selenium and cadmium, an increase of  $\overline{\Gamma}_n^0/D$  is observed with increasing neutron energy. Moreover, the value of  $Q$  for  $\text{Se}^{80}$  at an energy of 362 keV exceeds unity, which contradicts the physical meaning of the sticking coefficient. It is most natural to assume that the increase of  $Q$  is explained by the influence of the  $p$ -wave, which was not taken into account in the calculation. The  $p$ -wave strength functions were calculated from the difference  $T_2 - T_1$  for  $\text{Se}^{80}$  and  $\text{Cd}^{114}$ ; in doing so it was assumed that the  $s$ -wave strength functions for these isotopes are known and constant over the entire neutron-energy region, while the  $p$ -wave strength functions do not depend on the total angular momentum of the compound nucleus. The values of the  $p$ -wave cross sections, as well as the quantity  $R_0 = 1.24A^{1/3} \cdot 10^{-13}$  cm, were taken from the papers of P. E. Nemirovskii on the optical model <sup>(1)\*</sup>. The errors in the values of the  $p$ -wave strength function include both the uncertainties of the experimental data and the additional errors introduced by the calculation of  $\overline{\Gamma}_n^0/D$ .

The value of the strength function for  $\text{Se}^{80}$ , when only  $s$ -interactions are taken into account, for a mean energy of 92 keV is  $(1.42 \pm 0.33) \cdot 10^{-4}$ . Calculations of  $\overline{\Gamma}_n^0/D$  were carried out for two values of  $\overline{\Gamma}_n^0/D$ :  $1.0 \cdot 10^{-4}$  and  $1.4 \cdot 10^{-4}$  (see Table 1). In work <sup>(3)</sup> it is stated that the value of the  $p$ -wave strength function is less

than unity, while the value  $3.04 \cdot 10^{-4}$ , obtained in work <sup>(5)</sup>, is explained by the choice of too small a value  $\overline{\Gamma}_n^0/D = 0.88 \cdot 10^{-4}$ . In work <sup>(8)</sup> the  $s$ -wave strength function for  $\text{Se}^{80}$ , measured in the energy interval 1-15 keV, is  $(2.43_{-0.8}^{+1.2}) \cdot 10^{-4}$ . The latter result apparently indicates that, in calculations of  $\overline{\Gamma}_n^0/D$ , it is better to use  $\overline{\Gamma}_n^0/D = 1.4 \cdot 10^{-4}$ .

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\* The values of the  $p$ -wave cross sections, which are part of the total cross sections, were provided to the authors by P. E. Nemirovskii.

The value of the strength function of the  $s$ -wave of  $\text{Cd}^{114}$  was chosen close to the values  $\overline{\Gamma}_n^0/D$  for neighboring nuclei <sup>(7)</sup> and equal to  $0.5 \cdot 10^{-4}$ . The values of the strength function of the  $p$ -wave obtained in this way are in satisfactory agreement with the experimental data <sup>(9)</sup> for nuclei with similar atomic weights.

Attention is drawn to the fact that the resonance levels of the  $p$ -wave for  $\text{Sn}^{118}$  do not appear; the results given in the table characterize the strength function of the  $s$ -wave. It would be interesting to study the strength functions for the lightest tin isotopes ( $\text{Sn}^{112}$  and  $\text{Sn}^{114}$ ), since these isotopes fall in the region of atomic weights where the influence of the  $p$ -wave is significant.

In conclusion, the authors consider it their pleasant duty to express their gratitude to B. M. Gokhberg and P. E. Nemirovsky for their interest in the work and for their assistance.

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