ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

NEUTRON PHYSICS LABORATORY

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REPORTS SUBMITTED TO THE INTERNATIONAL CONFERENCE ON THE STUDY OF NUCLEAR STRUCTURE WITH NEUTRONS

(Antwerp, Belgium, July 1965)

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СБОРНИК ДОКЛАДОВ, ПРЕДСТАВЛЕННЫХ НА МЕЖДУНАРОДНУЮ КОНФЕРЕНЦИЮ ПО ИССЛЕДОВАНИЮ СТРУКТУРЫ ЯДЕР С ПОМОЩЬЮ НЕЙТРОНОВ

Конференция посвящается изучению структуры ядер с помощью нейтронов. В сборнике докладов описываются работы, выполненные в ЛНФ ОИЯИ на импульсном быстром реакторе.

Препринт Объединенного института ядерных исследований.
Дубна. 1965.

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REPORT SUBMITTED TO "THE INTERNATIONAL CONFERENCE ON THE STUDY OF NUCLEAR STRUCTURE WITH NEUTRONS"

This collection of reports includes the investigations performed at the Neutron Physics Laboratory (Joint Institute for Nuclear Research) on the pulsed fast reactor.

Preprint. Joint Institute for Nuclear Research.
Dubna, 1965.

Contents

Search for the Dependence of the Doppler Broadening of Neutron Resonances on Chemical Binding. Resonance 405 eV for Cl^{35}.

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When the resonance neutrons interact with atomic nuclei one observes the deviation of the resonance shape from the Breit-Wigner curve, which was due to the Doppler-effect caused by the thermal motion of sample atoms. This makes it necessary to introduce corrections for the Doppler-effect in determining resonance parameters. At present there are good methods to take such corrections into account only for two-event cases: for the samples of ideal gases and for those of isotropic Debay crystals consisting of one type of atoms.

In the case of gaseous sample the Doppler-effect is due to the translational motion of atoms in space and is characterized by the Doppler broadening $\Delta = 2\sqrt{\frac{m}{M} kTE_o}$, where E_o is resonance energy /1/.

In the case of bound atoms the nucleus motion is strongly dependent of frequency characteristics of the atomic system, therefore, the Doppler-effect theory on chemical combinations should take into account the structure of these combinations. The problem of neutron interaction with crystal systems has been discussed by Lamb[2]. It has been shown that the case of isotropic crystal consisting of similar atoms and having the Debay frequency spectrum can be reduced to the gas model, if the condition $\Gamma + \Delta \gg 2\theta$ is valid (θ is the Debay temperature) and if the Doppler broadening is defined by the expression $\Delta = 2\sqrt{\frac{m}{M} \kappa T_{eff} E_0}$. In the Lamb approximation the properties of the system which are most important for interaction with neutron are taken into consideration by the parameter

$$T_{eff} = 3\left(\frac{T}{\theta}\right)^3 T \int_0^{\theta/T} \left(\frac{1}{e^t+1} + \frac{1}{2}\right) t^3 \, dt$$

Along with the ideal gas approximation and the Lamb approximation the experimenters have no other ways to determine the Doppler corrections. However, in practice the experimenters have to deal with combinations for which the conditions of applicability of the above approximations are not carried out. The illegality of employing the Lamb approximation for considering the metal resonance shape with the samples of oxides has been shown in refs[3, 4]. A question arises whether the choice of combination form for sample can affect the experimental results in the case when resonance parameters are found from the analysis of resonance areas. Keeping this problem in mind we studied the behaviour of the areas of 405 eV resonance for Cl^{35} for which we might expect that $\frac{\Delta}{\Gamma} > 1$. The interest in this resonance was caused by the absence of data on the values of $g\Gamma_n$ and Γ though in refs[5, 6, 7] the total effective cross sections, radiative capture cross sections and the effective cross sections of the reactions (n, p) for Cl^{35} were measured.

Using a neutron spectrometer of the Laboratory of Neutron Physics[8] the transmission curves were obtained of three combinations of natural chlorine in which Cl atoms are related with atoms strongly differing in weight of other elements: $NaCl$, CCl_4, $PbCl_2$. The thickness of the samples for Cl^{35} $2.075.10^{22}$ $1/cm^2 \pm 0.5\%$ corresponded to the maximum region of the Doppler corrections in the function of the sample thickness/9/. The resonance area was calculated by transmission. Nonresonance transmission in the resonance region was found by extrapolating transmission data for a large number of channels from the left and from the right of the resonance. The values of areas of the resonance for Cl^{35} turned out to be 3.82 ± 0.5 eV, 3.86 ± 0.05 eV; 3.93 ± 0.05 eV for CCl_4, NaCl and $PbCl_2$, respectively.

By using NaCl and CCl_4 the effect of sample temperature on the resonance area was investigated. The transmission curves of the sample NaCl (the thickness $2.13.10^{22}$ for Cl^{35} atoms per cm^2) and CCl_4 (the thickness $1.93.10^{22}$ for Cl^{35} atoms per cm^2) at 300° and 77° were measured. The values of the areas of the 405 eV resonance for Cl^{35} were found to be: NaCl $300^\circ K$ - 3.95 ± 0.07 eV; $77^\circ K$ - 3.56 ± 0.07 eV; CCl_4 $300^\circ K$ - 3.54 ± 0.06 eV; $77^\circ K$ - 3.57 ± 0.6 eV. (The correction for a difference in the sample thickness was not introduced in the above area values). Thus, the results of the measurements are as follows: 1) the difference of the areas of the 405 eV resonance for Cl^{35} in NaCl, CCl_4 and $PbCl_2$ samples does not contradict the accuracy of measurements, 2) when cooling the NaCl sample down to $77^\circ K$ the area of the chlorine resonance was varied by $(10+0.3)\%$ whereas when cooling the CCl_4 sample it remained unchanged.

The equality of the resonance areas for all three samples can be explained in the following way: the Doppler broadening for all these samples differs insignificantly. The value Δ can be estimated by employing to NaCl the Lamb approximation, which appears to be possible since the NaCl crystal is cubic, it consists of atoms close in the atomic weight and has the Debay frequency spectrum. The Debay temperature for NaCl is $\theta = 281^\circ$, the Lamb approximation can be applied to NaCl. For the Doppler width one obtains the value Δ = 1.096 eV. The resonability of using the Lamb approximation can be proved by the fact that it agrees with the values of the area change in cooling the sample down to 77° K. (The calculation variation is about 12%, with Δ (77° K) = 0.694eV)

The constancy of the resonance area of the CCl_4 sample appears to prove the fact that for this combination even at room temperature rather intramolecular motions weakly depending on temperature than the Cl^{35} nuclei displacement together with molecules cause the Doppler effect.

The parameters were calculated by the area method for 10 values of Δ in the range from 0.3 eV to 2.13 eV . Fig.2 shows the dependences of $g\Gamma_n$ and Γ upon the values of Δ . This curve shows how it is important to know Δ to determine accurately Γ . We chose the value Δ = 1.096 eV as a result of the above considerations. Hence, we obtained the following values of the parameters of the 405eV level for Cl^{35}. Γ = 0.823 ± 0.083 eV, $g\Gamma_n$ = 0.037 ± 0.02 eV, which corresponds to σ_o' = 289 + 32 b. Thus, using the data from ref./7/ for $\sigma_o'\Gamma_p$ and $\sigma_o'\Gamma_\gamma$, we obtain Γ_p =55 ± 18 meV and Γ_γ = 420 ± 57 meV. Note that our values for Γ and $g\Gamma_n$ agree best of all with the data of ref./7/, if one takes J = 0, ℓ = 1 and g = 1/8 for Cl^{35} level. This result confirms the hypothesis of ref./7/ on assigning the 405 eV resonance to p -neutrons.

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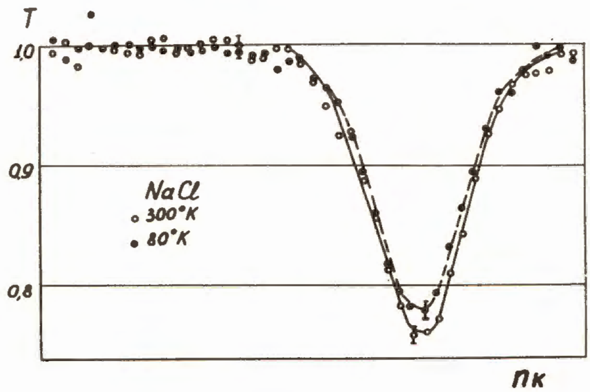

Fig. 1 . The 405 eV resonance for Cl^{35} in NaCl at T = 300°K and T = 80°K. (n_k is the channel number).

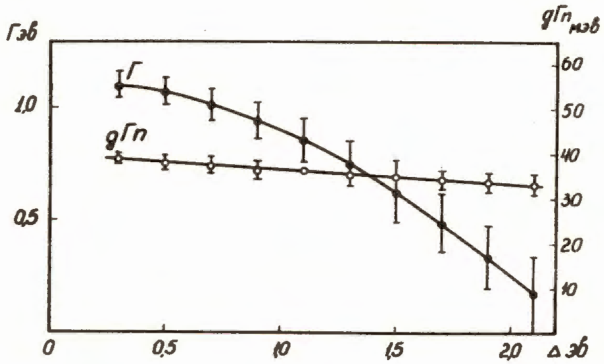

Fig. 2. The dependences $g\Gamma_n$ and Γ of the 405 eV resonance upon the choice of Δ .

Neutron Resonances of Ytterbium Isotopes

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The transmission and yield curves of the capture gamma-rays for some samples of natural ytterbium (Yb_2O_3) and some samples enriched with various isotopes were measured with a neutron spectrometer of the Joint Institute for Nuclear Research/1/. The thickness of samples for which transmission had been measured was $5.93.10^{20}$; $1.13.10^{21}$; $2.12.10^{21}$; $4.81.10^{21}$; $9.91.10^{21}$ and $2.64.10^{22}$ of Yb nuclei per cm^2, respectively. The data on samples for measuring gamma-rays are summarized in Table 1.

The transmission was measured with a liquid neutron detector/2/, the yield curves of gamma-rays were measured with two scintillation detectors having crystals NaI(Tl) 100x100 mm.

In the energy region from 3 to 150 eV some 42 resonances were found. The comparison of resonance strength on the yield curves for capture gamma-radiation for natural Yb and Yb isotopes allowed to identify 40 resonances isotopically and thus determine resonance parameters. Two resonances (for which it was difficult to determine to which isotope they belong) should be assigned either to Yb^{170} or to Yb^{168}. No measurements were performed with these isotopes.

The parameters of resonances clearly seen for natural Yb were determined by using transmission data by the area method. The resonances could be well separated only on isotope samples whereas their parameters were obtained by the yield curves of gamma-rays by calibrating the neutron flux product efficiency obtained from the data on the resonances whose parameters were found by transmission curves. In case of need corrections for capture after scattering were introduced /3/. Data on resonance parameters are summarized in Table 2. As is seen from the Table the overwhelming majority of resonances belongs to Yb^{171} and Yb^{173} isotopes. Figs. 1 and 2 show the distributions of the reduced neutron widths for neutron resonances of Yb^{171} and Yb^{172} found in the same energy region where the number of resonances is increased linearly with increasing energy. The distribution agrees with the Porter-Thomas law on condition that in each isotope 2 or 3 resonances are missing. The values of strength functions S_o were found from the diagrams of $\sum 2g\Gamma_n^o = f(E)$. They turned out to be $(1.1\pm0.4).10^{-4}$ and $(2.4\pm0.9).10^{-4}$ for Yb^{171}; Yb^{173}, respectively. The values $D(Yb^{171}) = 5.5\pm1.5$ eV, $D(Yb^{173}) = 7.3\pm1.5$ eV were found for the average distances between the levels (with the account of corrections for level missings). Since the spin values of Yb^{171} and Yb^{173} are greatly different (½ and 5/2, respectively), the data with D can be used to determine the parameter σ in the Bethe formula for the level density $\rho = \frac{c(2J+1)}{U^2} exp[-\frac{J(J+1)}{2\sigma^2}] exp[2\sqrt{aU}]$

If one takes into consideration the differences in isotope binding energy and assumes that the constants c and a are similar for Yb^{171} and Yb^{173} and the value of a is taken in accordance with ref. /4/, then $\sigma = 2.5$. The change of the parameter by 10% provides that $\sigma = 2.5^{+1.8}_{-1.3}$.

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Table 1.

Data on samples for measuring gamma-ray yield of radiative capture. All the samples are made of Yb_2O_3.

Basic isotope	Sample thickness of isotope nuclei/cm^2	Enrichment (%)
Yb^{171}	$1.21 \cdot 10^{21}$	95%
Yb^{171}	$2.55 \cdot 10^{21}$	90%
Yb^{172}	$3.18 \cdot 10^{21}$	90%
Yb^{173}	$1.97 \cdot 10^{21}$	77.6%
YB^{174}	$3.15 \cdot 10^{21}$	96%
Yb^{176}	$1.76 \cdot 10^{21}$	90%
Natural Yb	$2.38 \cdot 10^{21}$	

Table II

Resonances parameters for Yb isotopes

No	E_0 eV	Isotope	Γ meV	$g\Gamma_n$ meV	$2g\Gamma_n^0$ meV
I.	7.93±0.02	I7I		I.44±0.I7	I.03±0.I2
2.	8.I3±0.02	I7I		0.49±0.06	0.34±0.04
3.	8.85±0.04	I7I		0.025±0.0I0	0.0I7±0.007
4.	I3.I3±0.07	I7I	93±I0	2.5±0.I	I.38±0.06
5.	2I.8±0.I	I7I		0.I9±0.03	0.08I±0.0I3
6.	28.2±0.I	I7I	70±I0	I.8±0.I	0.68±0.04
7.	34.7±0.2	I7I		3.8±0.8	I.3±0.3
8.	4I.5±0.2	I7I	I68±70	7.2±0.7	2.2±0.2
9.	46.5±0.3	I7I		0.90±0.I5	0.26±0.04
I0.	53.2±0.3	I7I		5±I	I.4±0.3
II.	54.4±0.3	I7I		I6±3	4.3±0.8
I2.	60.4±0.4	I7I	I43±36	4.3±0.3	I.I0±0.08
I3.	65.0±0.4	I7I		7±I	I.74±0.25
I4.	77.3±0.6	I7I		II±2	2.5±0.5
I5.	82.6±0.6	I7I		2.4±0.3	0.53±0.07
I6.	84.7±0.7	I7I		2.5±0.4	0.54±0.09
I7.	96.I±0.8	I7I		3.0±0.4	0.6I±0.08
I8.	I08±I	I7I		37±7	7.I±I.4
I9.	II3±I	I7I		I4±3	2.6±0.5
20.	I28±I.2	I7I		20±5	3.5±0.9
2I.	I4I±I.4	I7I		I0±2	I.7±0.3
22.	I47±I.5	I7I		7±2	I.2±0.3
23.	4.53±0.0I	I73		0.082±0.009	0.077±0.008
24.	I7.80±0.07	I73	I00±I0	I4±I	6.6±0.5
25.	3I.6±0.I5	I73	I65±I4	36±3	I2.8±I.I
26.	35.8±0.2	I73		24±4	8.0±I.3
27.	45.5±0.2	I73	I04±I6	I5±I.4	4.4±0.4
28.	53.8±0.3	I73		6.6±I.2	I.8±0.3
29.	59.0±0.4	I73	I4I±65	4.0±0.7	I.0±0.2
30.	66.7±0.5	I73	I43±24	I5.6±I.2	3.8±0.3
3I.	69.I±0.5	I73		5.3±0.7	I.3±0.2
32.	74.8±0.6	I73		4.I±0.7	0.95±0.I2

33.	76.7±0.6	I73		I8±3	4.I±0.7
34.	97.5±0.8	I73		6.4±0.8	I.3±0.2
35.	I06±I	I73		26±5	5±I
36.	II2±I	I73		5.4±0.8	I±0.2
37.	I25±I.2	I73		9.4±I.4	I.7±0.2
38.	I30±I.2	I73		I3.6±I.8	2.4±0.3
39.	40.3±0.2	I70	306±46	I97±I4	3I±2
40.	73.2±0.5	I70		77±I2	9.0±I.4
4I.	22.6±0.I				
42.	I4I±I.5	I72			

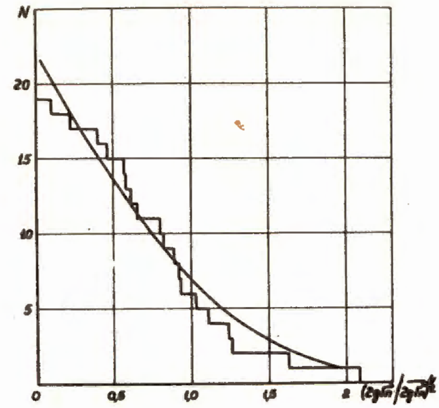

Fig. 1 . The integral distribution of reduced neutron widths for the resonances of Yb^{171}.

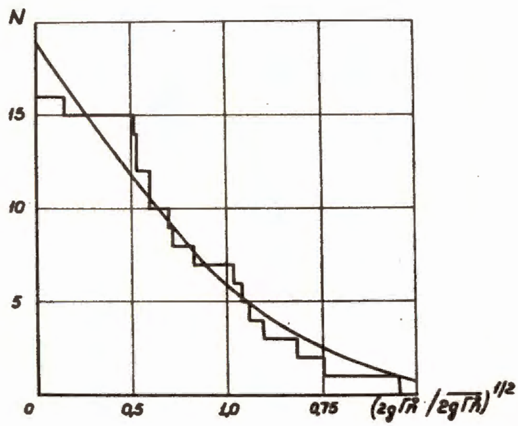

Fig. 2. The integral distribution of reduced neutron widths for the resonances of Yb^{173}.

Radiation Width of Nuclei in the Region of Mass Numbers 60-100

Kim Hi San, L.B. Pikelner, E.I. Sharapov, Kh. Sirazhet

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The investigation of radiation widths (Γ_γ) for a number of nuclei in the region of mass numbers 60-100 has been performed in the Neutron Physics Laboratory of the JINR.

In these experiments performed by the time of flight method using the pulsed fast reactor (IBR) as an neutron source/1/ the measurements of transmission, radiative capture, self-indication and scattering of neutrons were taken. The methods of measurements were generally described in/2,3/. The resolution for all cases was 0.06 - 0.08 μ s/m.

Separated isotopes of Zn and Rb, niobium and natural mixtures of Mo, Ru and Br were used in measurements.

We have used the isotopic identification for Mo from/4/ as for Ru, we have used the isotopic data of Ru^{101} given in paper/5/. For other resonances an indication was used that they do not belong to Ru^{101} and Ru^{100}.

The measurements of amplitude spectra in the resonances by means of a (n, γ)-detector indicated that the resonances observed can-not belong to Ru^{102} and Ru^{104} isotopes with low binding energy. The final conclusion concerning the isotope belonging of the levels was reached on the basis of combined measurements of total and partial cross sections performed similarly to the determination of the spin. For a number of resonances it was impossible to determine whether they belong to Ru^{99} or Ru^{96}. The obtained parameters of the levels of Ru are given in Table I. It is noteworthy that they are in significant disagreement with the data obtained by Bolotin et al.[5]. Radiation widths, if determined, in all cases are not above 200 meV, while in[5] they are about 280 meV. The values of $g\Gamma_n$ are also markedly different.

The data on resonances of other elements are given in[6,7], therefore they are missing in the present paper.

In addition to the measurements of partial cross sections of Br which were taken earlier[2], measurements of transmission were performed which allowed to specify the values of level parameters. The results are given in Table II. The corrected values of average radiation widths for Br^{79} and Br^{81}, equal to 313 meV and 303 meV respectively, are in good agreement with[8,9].

The experimental data obtained permitted to find the dependence of radiation widths upon the number of neutrons (N) in the nucleus for nuclei in the region of mass numbers 60-100. The experimental points obtained by the authors (dark-shaded ones) as well as taken from other papers are shown in Fig.I. It is clear that radiation widths of the magic nucleus of Rb^{87} and of the nuclei closest to that one do not exceed the values of Γ_γ for the neighbouring nuclei.

Some deviation from a smooth dependence of Γ_γ upon N is observed in the region of N=38 - 40. The radiation widths of Ga^{69}, Zn^{68}

and Se^{74} are markedly below those of the neighbouring nuclei. However, it should be noted that we have not enough data on radiation widths in this region. For most nuclei the values of Γ_γ are known only in one or two resonances, therefore these investigations, especially in the region of lighter nuclei, should be continued.

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Table I

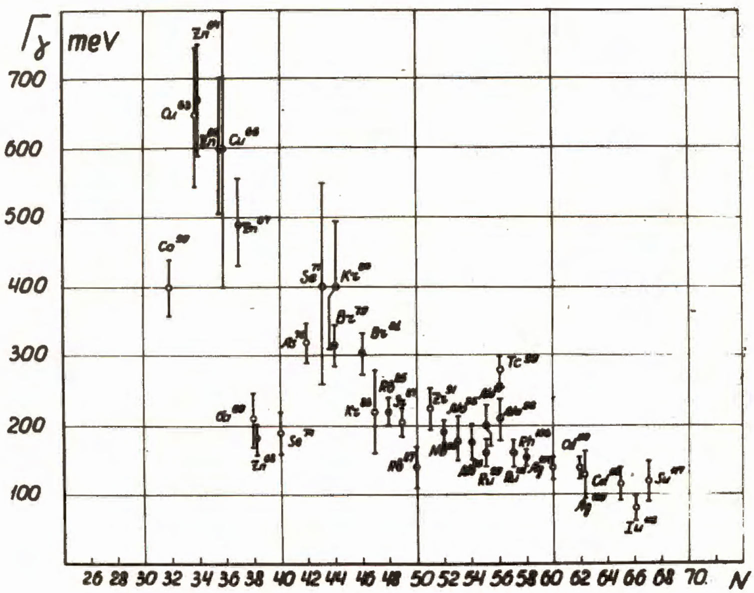
Parameters of Resonances of Ru

EeV	meV $g\Gamma_n$	meV $f g\Gamma_n$	meV Γ	J	meV Γ_γ	Isotope
10.05± 0.03		0.31±0.015	190±20		~180	96.98 or 99
15.8± 0.04	3.0±0.3		180±20		174±20	101
25.3 ± 0.08	6.3±0.7		180±20	3	170±20	99
42.5± 0.2	9.4±0.6		180±20	3	164±20	101
52.3± 0.3	0.95±0.07		190±40		190±40	101
57.3± 0.3		0.84±0.06	175±30		160±30	96 or 99
62.1± 0.4	1.9±0.2					101
67.0± 0.5	18±3					101
82.2± 0.5		0.28±0.02	170±30		~170	
100.5± 0.6	3.2±0.4					101
104.7± 0.6		3.6±0.4	275±35		~200	96 or 99
113± 0.7	3.7±0.4					101
141.6± 0.9		0.37±0.04				

Table 2

Parameter of Resonances of Br

EeV	$g\Gamma_n$ meV	Γ meV	J	Γ_γ meV	Isotope
35.9±0.1	24±1	370±35	2	332±35	79
53.8±0.2	13.5±1	380±40	1	344±40	79
101.3±0.5	94±6	450±30	2	300±30	81
135.9±0.7	155±15	720±50	1	307±50	81
189.8±1.2	31±2	400±40	1	318±40	79
239.4±1.6	350±20	860±40	2	300±40	79
319.6±2.5	350±30	830±50	2	270±50	79



1. Experimental data for radiation widths of nuclei. The black points are those obtained in the work of the authors.

The Characteristics of Neutron Resonances in Barium-135

Kim Hi San, L.B. Pikelner, E.I. Sharapov, Kh.Sirazhet

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The measurements of neutron resonance parameters of Ba^{135} have been performed because of a strong anomaly in the gamma spectra which was recently observed/1/. The intensity of the transition to the ground level for the resonance 24.3 eV was found to be 40 times as large as the average value of the intensity of the other levels. The attempts to explain this phenomenon in usual terms of S-and p-levels meet with a number of contradictions. The unambiguous identification of parity of the anomalous level and the exact values of radiation widths and spins of other levels are required. However, there have been no such data until recently.

The measurements of partial cross sections and of the transmission of a natural mixture of Ba isotopes were performed by the time of flight method using the pulsed fast reactor (IBR) of the JINR as a neutron source. The 750 m flight base ensured the resolution of $0.08 \frac{\mu s}{m}$. The transmissions of six samples of barium oxide, $1.66 \cdot 10^{20} - 5.9 \cdot 10^{21}$ $\frac{Ba^{135} nucl.}{cm^2}$ thick, were measured.

The measurements were performed by means of a lithium glass detector.

Radiative capture and self-indication were measured by means of a liquid scintillation gamma detector described in /2/. The measurements with three barium oxide samples ($8.40 \cdot 10^{19}$; $3.37 \cdot 10^{20}$; $3.55 \cdot 10^{20}$ $\frac{Ba^{135} nucl.}{cm^2}$) inside the detector were performed. Self-indication with four transmitting samples was also measured.

The detector used for the measurement of scattering on a barium fluoride sample, $8.4 \cdot 10^{19}$ $\frac{Ba^{135} nucl}{cm^2}$ thick, is also described in /2/. The methods of measurements of partial cross section are thoroughly described in /3/.

The level parameters were obtained by means of a combined analysis of resonance areas in partial cross sections and the transmission by the methods already described in /3,4/. The obtained resonance parameters of Ba^{135} up to 300 eV are given in table I. The level 106 eV is missing. At our resolution it coincides with the 103 eV level of Ba^{136}. Besides the resonances given in the Table, other resonances at energies of 46.4; 58; 137; 186 and 245 eV were found, however it is unknown to what isotopes they belong.

As is shown, all the investigated levels, except the one at 24.3 eV, have the value of the spin equal to 2. The resonance at 24.3 eV has a different spin. Besides, the value of its radiation width is somewhat larger that the other ones. The value of $g\Gamma_n$ as a function of Γ is shown in Fig.1.

To determine the parity of the excited state in the 24.3 eV resonance measurements with thick barium samples were performed. For example, the transmission curve near the 24.3 eV resonance measured with the sample, $5.46 \cdot 10^{21}$ $\frac{Ba^{135} nucl.}{cm^2}$ thick (corresponding to a $0.827 \cdot 10^{23} \frac{nucl}{cm^2}$ sample of natural mixture) is given in Fig.2. Theoretical curves 1 and 2 are plotted using the Breit-Wigner formula with an interference term and correspond to two values of σ_p, equal to $8 \cdot 10^{-24}$ cm^2 and $4 \cdot 10^{-24}$ cm^2, respectively. Curve 3 [is plotted by the formula without an interference term. Statistical errors of the experimental points are withim 0.5%.

As is shown, the location of the experimental peints corresponds to the presence of interference between resonant and potential scatterings. However, the experimental data are not sufficiently exact to choose unambiguously the value of σ_p for Ba^{135}.

Interference indicates that the 24.3 eV resonance is formed by s-neutrons.

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Table I

Parameters of resonances of Ba^{135}

E_o eV	$g\Gamma_n$ meV	Γ meV	Γ_γ meV	J
24.3 ± 0.I	5.3 ± 0.2	I35 ± I0	I20 ± I0	I
8I.3 ± 0.6	85 ± 5	240 ± 20	I04 ± 20	2
86.8 ± 0.8	36 ± 3	I70 ± 20	II2 ± 20	2
226 ± 3	20 ± 3			
286 ± 4	I75 ± I5	370 ± 35	90 ± 25	2

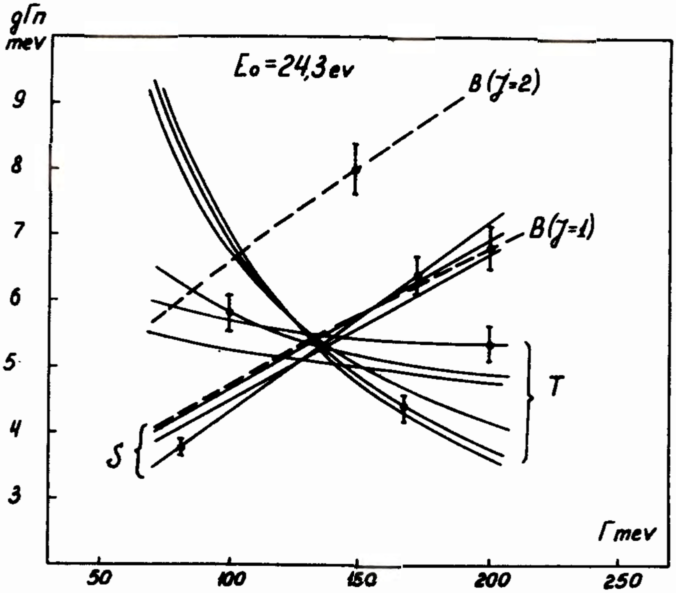

Fig.1. Function of $g\Gamma_n$ versus Γ for the resonance 24.3 eV. Curves T are obtained from transmission measurements , while S and B - from self-indication and neutron scattering ones, respectively.

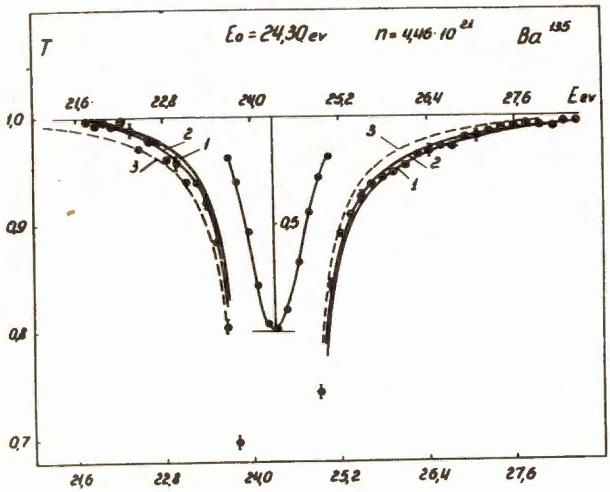

Fig.2. Comparison of the experimental transmission curve (point) with theoretical ones. Curves 1 and 2 are plotted with the account of interference between resonance and potential scattering at σ_p of 8 b and 4 b, respectively. A dotted curve (3) is obtained for the case when there is no interference.

Anomalous Intensities of High Energy γ - Ray Transitions in Resonance Neutron Capture on Ba^{135}

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In our measurements of high energy γ-rays from the capture of resonance neutrons in Ba^{135} with a natural mixture of Ba isotopes we have discovered anomalous high intensities of the ground state transition and of the transition to the first excited state in the 24,5 eV resonance with energies 9,23 MeV and 8,42 MeV respectively.

The results of our first experiments with Ba^{135} were published in a preliminary report[1]. All our measurements were performed on a fast neutron pulse reactor at the JINR in Dubna. The pulse height spectra are recorded with the aid of the multidimensional analyser with a magnetic tape memory. The recording of 128 pulse height channels and 256 time channels is usually used.

The resolution of the time of flight spectrometer was 0,12 $\mu sec/m$ in the single crystal scintilation spectrometer measurements and 0,6 $\mu sec/m$ in all other cases.

In figure 1 the time spectra for different energies of γ - rays taken with a single crystal NaI(Tl) spectrometer are shown. The abnormally hight intensity of the highest energy transitions in 24,5 eV resonance is striking in comparison with the other 10 measured resonances belonging to Ba^{135} isotope. The partial radiation widths for the highest γ - ray transitions were estimated by us for 11 resonances[1]. The difference in pulse height spectra is shown in figure 2.

Since the capture level for the s-wave neutrons has in case of Ba^{135} the spin value either 1 and 2 with positive parity, the above mentioned transitions must be of the M1 type, because spins and parities of the lowest states are 0^+ and 2^+. The partial radiation width of the ground state transition in resonance 24,5 eV was in our experiments determined to have $10{,}5 \pm 2{,}5$ meV and this value is about 40 times higher than the upper limit of the mean value for the other 10 resonances (o,25 meV) . The mean value of the reduced partial radiation width of the ground state transition in the above mentioned 10 resonances is in a good agreement with the expected value for M1 transitions in the mass number region of Ba[2]. The intensity of the ground state transition in 24,5 eV resonance corresponds better with values for the E1 type transitions. The probabilities of s-wave or p-wave neutron capture in this case were discussed in the previous paper[1].

It seems to be possible to use the two 4^+ states is the low level decay scheme of Ba^{136} to decide about the capture state spin value. The transitions from these two states are well known from the nuclear spectroscopy measurements[3] and the low laying level spacing in Ba^{136} is great enough to identify surely the right transitions. These levels may be easily occupied in case of the compound state spin 2^+ by double cascade E1 transitions of the following kind: $2^+ \rightarrow 3^- \rightarrow 4^+$. In a more detailed discussion of possible low number cascades, it may be shown that the occupation of these levels must be stronger for the 2^+ capture levels than for the 1^+ levels.

In order to estimate the occupation of these two 4^+ levels the intensities of 1050 KeV and 1260 KeV transitions in relation to the intensity of the 806 KeV transition were determinated from the low energy spectrum measurement. It is suppósed that the intensity of the 806 keV transition is much less dependent on the capture state spin value. The results of these measurements are presented in table I.

Table I.

Energy of neutron resonance - eV	Relative intensities of γ-ray lines		
	806 keV	1050 keV	1260 keV
24,5	100	9,5±2,5	13±2,5
82	100	24±3	32±3
88	100	23±3	29±3
106	100	19,5±4	29±4
228	100	9±3	12,5±4

It seems to us that this experiment confirms the conclusion, that resonances 82,88,106 eV have the spin value 2 and resonances 24,5 eV and 228 eV have the spin value 1. It was not possible to estimate this ratio for higher neutron resonances by the aid of a scintillation spectrometer as the result of the poor resolution of both spectrometers.

It would be possible to explain the anomaly high intensities of 9,23 and 8.42 MeV transitions in the 24,5eV resonance as a p-wave neutron capture on the 1^- spin level, then the both transitions would be of El type in this case. But this conclusion is in a contradiction with the high value of the neutron width in this resonance and with transmission experiments [4].

To be sure that a chance coincidence of the two levels belonging to the different isotopes with the neutron capture of different waves does not take place in the 24,5 eV resonance, we have measured the low energy spectra from 50 keV to 2 MeV with a germanium lithium drifted detector with a sensitive volume of 3,5 cm^2 x 0,4 cm. There are no lines observed that are characteristic for the other

Ba isotopes in this resonance. In these measurements the precise energy of the transition from the first excited state to the ground state was determinated to have 806 ± 3 keV. Figure 3 shows the spectra in the region of the 806 keV line for the two different types of resonances.

The authors wish to thank Dr. L. F. Shapiro for helpful discussions of the results, Dr. L. B. Pikelner for communication of results prior to publicatinn and J. Hronik for helpful assistance during the measurements.

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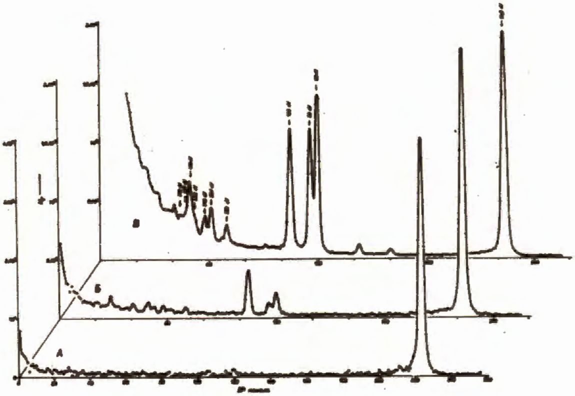

Figure 1. Time spectra of resonance neutron capture on Ba^{135} for the different γ-ray energy ranges.

A. 9,23 MeV, channel width 500 keV

Б. γ-ray energy range 7,3 + 9,23 MeV

B. γ-ray energy range 4 + 9,23 MeV

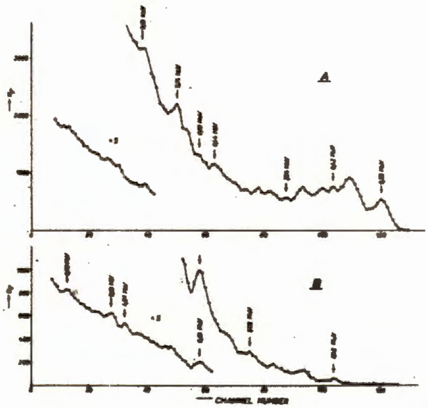

Figure 2. Pulse height spectra for two different neutron resonances
A. 24,5 eV B. 82 eV

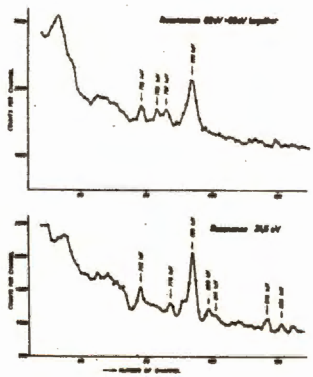

Figure 3 . Low energy spectra taken with the Ge/Li/ spectrometer for two resonances.

The Scattering of Slow Neutrons on the Deuterons

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It has been noted[1] that for the solution of three-nucleon scattering problem the Bubnov- Galerkin method of solving the integral equations[2] can be used. In this paper by means of this method n-d-scattering lengths are calculated for pair and central nucleon-nucleon interactions. In this case the total spin S = ½, 3/2 and the isotopic spin T = ½ are good quantum numbers. Let us consider in some detail the state with S = ½.

The total wave function for S = ½ and T = ½ is[3]:

$$\Psi = \psi^a \zeta^s - \psi^s \zeta^a + \psi' \zeta'' - \psi'' \zeta' \qquad \text{(I)}$$

where ψ are functions of only spatial coordinates and are functions of the spin and isotopic spin ones. The functions ψ^s, ζ^s and ψ^a, ζ^a are symmetric and antisymmetric respectively while pairs of functions (ψ', ψ'') and (ζ', ζ'') are transformed by means of one another in a known manner by the permutations of coordinates. Introduce Jacobi coordinates:

$$\vec{\xi} = \frac{\sqrt{3}}{2}(\vec{r}_3 - \vec{r}_2), \quad \vec{\rho} = -\vec{r}_1 + \frac{1}{2}(\vec{r}_2 + \vec{r}_3)$$

where $\vec{r}_i$ is the radius-vector of the i-th nucleon and an incident neutron has a subscript 1. Write down the Fourier-component of the wave function in the variable $\vec{\rho}$ as:

$$\psi(\vec s,\vec q) = \int d\vec\rho\, \psi(\vec s,\vec\rho)\, e^{-i\vec q\vec\rho}$$

and introduce new functions according to the following expression:

$$\begin{aligned}
&\frac{1}{\sqrt2}(\psi^s-\psi^{\prime\prime}) = (2\pi)^3\,\varphi_d(s)\,\delta(\vec q-\vec q_0) + \Psi_1(\vec s,\vec q),\\
&\frac{1}{\sqrt2}(\psi^s+\psi^{\prime\prime}) = \Psi_2,\quad \frac{1}{\sqrt2}(\psi^a-\psi^{\prime}) = \Psi_3,\quad \frac{1}{\sqrt2}(\psi^a+\psi^{\prime}) = \Psi_4
\end{aligned} \qquad (2)$$

where $\varphi_d(s)$ is the deuteron wave function, $\vec q_0$ is the wave vector of incident neutrons. Then using (I) and (2) the elastic scattering amplitude can be expressed in the following way:

$$f_{1/2}(\theta) = \left\{\frac{q^2-q_0^2}{4\pi}\int d\vec s\,\varphi_d(s)\,\Psi_1(\vec s,\vec q)\right\}_{q\to q_0}$$

and for the functions Ψ_i (i = 1, 2, 3, 4) system of the integral equations can be obtained:

$$\Psi_i(\vec s,\vec q) - \frac{V_i}{(2\pi)^3}\int d\vec k\, d\vec s'\, \frac{e^{i\vec k(\vec s-\vec s')}}{k^2+q^2-\varepsilon-i\eta}\, f_i(s')\,\Psi_i(\vec s',\vec q) =$$

$$= \gamma_i\left[e^{i\vec s\vec p_0} + (-1)^{\delta_i} e^{-i\vec s\vec p_0}\right]\varphi_d(p_{10}) +$$

$$+ \sum_{j=1}^{4}\alpha_{ij}\frac{V_j}{(2\pi)^3}\int d\vec q^{\,\prime} d\vec s'\, \frac{e^{i\vec s\vec p - i\vec s'\vec p_1} + (-1)^{\varepsilon_{ij}} e^{-i\vec s\vec p + i\vec s'\vec p_1}}{q^2+q'^2+\vec q\vec q^{\,\prime} - \frac{3}{4}\varepsilon - i\eta}\, f_j(s')\,\Psi_j(\vec s',\vec q^{\,\prime}) \qquad (3)$$

where $\varepsilon = 4mE/3\hbar^2$, m is the nucleon mass, E – c.m.s. energy, $V_i f_i(s)$ is two nucleon interaction potential with depth V_i. The subscript i indicatws the two-nucleon state: i = 1, i = 2 an even triplet and singlet states respectively, i = 3, i = 4 are odd ones. In the above equations the following symbols have been used:

$$(\gamma_i) = \begin{pmatrix} 2/3\sqrt3 \\ 2/\sqrt3 \\ 2/3 \\ -2/3 \end{pmatrix},\quad (\delta_i) = \begin{pmatrix} 0\\0\\1\\1 \end{pmatrix},\quad (\alpha_{ij}) = \begin{pmatrix} 1/2\sqrt3 & \sqrt3/2 & 1/2 & -1/2 \\ \sqrt3/2 & 1/2\sqrt3 & -1/2 & 1/2 \\ 1/2 & -1/2 & -1/2\sqrt3 & -\sqrt3/2 \\ -1/2 & 1/2 & -\sqrt3/2 & -1/2\sqrt3 \end{pmatrix},\quad (\varepsilon_{ij}) = \begin{pmatrix} 0&0&1&1\\0&0&1&1\\1&1&0&0\\1&1&0&0 \end{pmatrix},$$

$$\vec p = \frac{1}{\sqrt3}\vec q + \frac{2}{\sqrt3}\vec q^{\,\prime},\quad \vec p_0 = \frac{1}{\sqrt3}\vec q + \frac{2}{\sqrt3}\vec q_0,\qquad \vec p_1 = \frac{2}{\sqrt3}\vec q + \frac{1}{\sqrt3}\vec q^{\,\prime},\quad \vec p_{10} = \frac{2}{\sqrt3}\vec q + \frac{1}{\sqrt3}\vec q_0.$$

In accordance with the Bubnov-Galerkin method/2/ expand the wave functions Ψ_i in the total systems of basic functions $\varphi_n^{(i)}(\vec s)$:

$$\Psi_i(\vec s,\vec q) = \sum_n \varphi_n^{(i)}(\vec s)\,\frac{F_n^{(i)}(\vec q)}{q^2-q_0^2-i\eta} \qquad (4)$$

which are orthogonal to the weight coinciding with the potential radial dependence:

$$\int d\vec s\, f_i(s)\,\varphi_n^{(i)}(\vec s)\,\varphi_{n'}^{(i)*}(\vec s) = \delta_{nn'} \qquad (5)$$

Then using (3), (4) and (5) the system of equations for $F_n^{(i)}$ can be obtained:

$$\frac{F_n^{(i)}(\vec{q})}{q^2-q_0^2-i\eta} = \gamma_i\left[C_n^{(i)}(\vec{p}_0,\varepsilon-q^2)+(-1)^{\delta_i}C_n^{(i)}(-\vec{p}_0,\varepsilon-q^2)\right]\varphi_d(p_{10})+$$

$$+\sum_{jn'}\alpha_{ij}\frac{V_j}{(2\pi)^3}\int d\vec{q}\,'\left[\left(q^2+q'^2+\vec{q}\vec{q}\,'-\frac{3}{4}\varepsilon-i\eta\right)\left(q'^2-q_0^2-i\eta\right)\right]^{-1}\times \qquad (6)$$

$$\times\left[C_n^{(i)}(\vec{p},\varepsilon-q^2)M_{n'}^{(j)*}(\vec{p}_1)+(-1)^{\varepsilon_{ij}}C_n^{(i)}(-\vec{p},\varepsilon-q^2)M_{n'}^{(j)*}(-\vec{p}_1)\right]F_{n'}^{(j)}(\vec{q}\,')$$

where

$$M_n^{(i)}(\vec{p})=\int d\vec{s}\,f_i(s)\varphi_n^{(i)*}(\vec{s})\,e^{i\vec{p}\vec{s}}$$

The values $C_n^{(i)}(\vec{p},\varepsilon)$ in(6) satisfy the following system of linear algebraic equations:

$$\sum_{n'}\left[\delta_{nn'}-B_{nn'}^{(i)}(\varepsilon)\right]C_{n'}^{(i)}(\vec{p},\varepsilon)=M_n^{(i)}(\vec{p}),$$

where

$$B_{nn'}^{(i)}(\varepsilon)=\frac{V_i}{(2\pi)^3}\int d\vec{K}\,\frac{M_n^{(i)}(\vec{K})\,M_{n'}^{(i)*}(\vec{K})}{K^2-\varepsilon-i\eta}$$

For the state with the total spin S =3/2 the system of the integral equations has the same form, and only the values of γ_i, δ_i, α_{ij} and ε_{ij} are different.

In the calculation of n-d-scattering lengths the following basic functions have been used

$$\varphi_n(\vec{s})=\varphi_{lm\lambda}(\vec{s})=s^l L_\lambda^{(l)}(s)\,Y_{lm}\left(\frac{\vec{s}}{s}\right) \qquad (7)$$

where $L_\lambda^{(l)}(s)$ are some orthogonal polynomials of the λ-th power. The calculations have been performed with the Yukawa potential for two approximations corresponding to the following choice of the basic functions (7): l=0, λ =0 and l=0, λ =0,1. The following results for the quartet a_4 and doublet a_2 scattering lengths have been obtained : the zero approximation: a_4 = 6.25 f, a_2 -1.78 f ; the first approximation: a_4 = 6.31 f, a_2 =- 1.46 f . This set of calculated scattering lengths is closest to one of the two possible experimental values, namely a_4 = 6.38 ± 0.06 f, a_2 = 0.7 ± 0.3 f, though for

α_2 the agreement is muoh worse.

The author is indebted to V.I. Furman, I.I. Shelontsev and N.N. Vorobyeva for numerical calculations.

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Average Cross Sections of Neutron Interaction
with Oriented Nuclei

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I. The interaction of resonance neutrons was considered in ref./1/. Particularly, it was shown that the cross-sections of unpolarised p-neutron (l=I) interaction with oriented σ_{or} and un-oriented σ_{unor} nuclei are different. The difference depends on the value of orientation f_2, on the angle between the direction of nuclear orientation and beam direction and on F_J coefficients of angular momentum of interacting particles:

$$\sigma_{or} = \sigma_{unor} \left\{ 1 + f_2 F_J P(\cos\theta) \right\} \qquad (I)$$

where P_2 - Legendre polynomial. In obtaining this formula the Breit-Wigner form of S-matrix was taken and the assumption that the neutron width Γ_{nS} does not depend on channel spin S was used (i.e. the average over S width was introduced).

It may be shown that under this assumption formula (I) will be valid taking into account the interference between potential and resonance scattering of neutrons. The orientation of nuclei will not influence the potential cross-section if the potential scattering phase does not depend on the total angular momentum J of the neutron-nucleus system. We consider the IO-IOO kev energy region, where only l=0 and l=I neutrons may be considered and where resonances are separate, but not resolved. Then, if $\frac{\Gamma_n}{\mathcal{D}} = \left(\frac{1}{\varepsilon_I^J}\right)\left(\frac{\Gamma_{nJ}}{\mathcal{D}_J}\right)$ does not depend on J (or it is necessary to take an average over J value as $\Gamma_n/\mathcal{D}$ /2/) the differences $\Delta\sigma = \sigma_{unor} - \sigma_{or}$ for average cross sections are the following:

reaction
$$\Delta\sigma_r = -P_2(\cos\theta) f_2 \frac{2\pi^2\lambda^2}{2(2I+1)} \sum_J \overline{\frac{\Gamma_{nJ}\Gamma_r}{\mathcal{D}_J\Gamma}} (2J+1)\varepsilon_I^J \cdot F_J \qquad (2a)$$

scattering
$$\Delta\sigma_s = -P_2(\cos\theta) f_2 \frac{2\pi^2\lambda^2}{2(2I+1)} \left\{ \sum_J \overline{\frac{(\Gamma_{nJ})^2}{\mathcal{D}_J\Gamma}} (2J+1)\varepsilon_I^J F_J + 2\frac{\Gamma_n}{\mathcal{D}} Q \cdot \sin^2\xi \right\} \qquad (2b).$$

total cross section
$$\Delta\sigma_t = P_2(\cos\theta) f_2 \frac{2\pi^2\lambda^2}{2(2I+1)} \cdot \frac{\Gamma_n}{\mathcal{D}} Q \cos 2\xi \qquad (2c)$$

Here $Q = -\sum_J (2J+1)\varepsilon_I^J F_J = \frac{6\sqrt{2}(2I)^{1/2}(2I-1)^{1/2}}{(2I+1)(2I+3)^{1/2}(2I+2)^{1/2}} \left[(2I-1)^{1/2}(2I+2)^{1/2} - (2I)^{1/2}(2I+3)^{1/2}\right]$

The Q-values of different nuclear spins I are shown in the table.

Q	1,05	1,03	0,96	0,87	0,79	0,75	0,67	0,63
I	1	3/2	2	5/2	3	7/2	4	9/2

$\mathcal{D}_J$ – level spacing, ε_I^J – the quantity of combinations from 1=I, I and ½ for J ; Γ_n – the reaction width and Γ the total width; – λ neutron wave length ; ξ – the phase of p-neutron potential scattering. The line on the top means the average over resonance width distribution

Formula (2c) is more interesting because the p-neutrons strength function results immediately. From the transmission experiments with oriented and unoriented (or at θ = 60°) nuclei we directly recieve the optical model value $T = 2\pi\frac{\Gamma_n}{\mathcal{D}}$ at different energies, what is interesting in relation with the problem of two-particle one-hole interaction /3/. This interaction may modulate the energy behaviour of T. As for $\Delta\sigma_t/\sigma_t$, the evaluation by optical model /5/ in the region of A = 40 ÷ 240 gives the value rising a little quicker than $E^{1/2}$, and at E = I0 kev $\Delta\sigma_t/\sigma_t \leq 2\%$ for f_2 = I being maximum at A ~ I00 The effect may be increased by I,5 taking the difference of cross-sections at two directions of orientation where P_2 (cos θ) = -½ and I. The measuring of fission and total cross sections oriented and unoriented U^{235} could be an attractive application of formula (2a). For p-neutron $\Gamma_n \ll \Gamma_f$, then

$$\Delta\sigma_f = P_2(\cos\theta) f_2 \frac{2\pi^2\lambda^2}{2(2I+1)} \frac{\Gamma_n}{D} Q \overline{\left\langle \frac{\Gamma_f}{\Gamma_\gamma+\Gamma_f} \right\rangle},$$

where Γ_f - fission and Γ_γ - radiative capture widths, $\langle\,\rangle$ means average over J . It is clear from (2c) that $\Delta\sigma_f = \Delta\sigma_t$ if $\Gamma_\gamma \ll \Gamma_f$ (cos $2\gamma \approx 1$ up to 0.5 MeV). Comparing $\Delta\sigma_f$ and $\Delta\sigma_t$ we compare Γ_γ and Γ_f for p-neutrons. But the effect for U^{235} is small because of large I and $\Delta\sigma_f/\sigma_f \sim 1\%$ for E ~ 20 kev f_2=I. The evaluation is made by the values of strength-functions (at Iev) $\Gamma_n^{(0)}/D$ = (0.9I$\pm$ 0.0I).10^{-4} and $\Gamma_n^{(1)}/D$ =(2.5$\pm$0.2).10^{-4} They were obtained from an analysis of the energy dependence of the fission cross-section U^{235} up to E ~ 30 kev/4/.

Now we will consider two additional effects. The first one is the d-neutron effect. For them the formulas (2) are the same, but it is necessary to take d-parameters and coefficients $\tilde{F}_J$ and $\tilde{Q}$ for l=2 $\tilde{Q}$ being $\leq$ I.5. We used/5/. The ratio of d-to p-parts $\frac{\Delta\sigma_{f_2}}{\Delta\sigma_f} < \frac{\Delta\sigma_{t_2}}{\Delta\sigma_t} \leq$ $\leq$ 0.3 at E $\leq$ I00 kev over the whole A region. More difficulties are with the d-contribution in a reaction cross-section. We may neglect this contribution only in the region of A ~ 80 ÷ I20, where by the same evaluation $\Gamma_n \gg \Gamma_\gamma$ and $\Delta\sigma_{t_2}/\Delta\sigma_t \leq 0.2\, \Gamma_\gamma/\Gamma_n$ In other cases the estimation by concrete parameters is needed.

The second is the contribution of potential scattering σ_{pot} . The optical model interactions $(\vec{I}\vec{\sigma})$ and $(\vec{\ell}\vec{\sigma})$ ($\vec{\sigma}$ -spin of neutron) separately do not give the dependence of potential scattering from J. In that case the σ_{pot} contribution is zero. But if this dependence exists (e.g. the sum of $(\vec{I}\vec{\sigma})$ and $(\vec{\ell}\vec{\sigma})$ interactions) then it is better to get the evaluation. By the maximum value, when the contribution in potential scattering is of order of σ_{pot} , the evaluation of $\frac{\sigma_{pot}}{\Delta\sigma_t}$ was considered for the wide region of nuclei at E=I0 kev and I00 kev. This ratio rises as E^3 and may give visible contribution only at E $\gtrsim$ I00 kev for heavy nuclei (for U^{235} this ratio $\leq$ I). If this ratio is large it would be interesting to measure it, then we may either conclude about spin interactions or neglect this contribution. This experiment may be performed between resonances of light nuclei at $E \sim I$ Mev where ξ is rather big. $_7N^{14}$ is such a nucleus. It has I=1, the quadrupole moment +0.02 barn and the p-potential cross-section ~ 10% from the total $\sigma_{pot} \sim 2$ barn in the space between two S-resonances at E ~ 0.8 Mev.

We have considered the case of $f_2 \neq 0$ $f_1 = 0$. If the method of orientation is such that $f_1 \neq 0$ also, then the unpolarised beam may become polarised while penetrating into the sample and may scatter by the second interaction. This gives the difference between transmission of an unpolarised beam through a polarised and unpolarised sample by a coefficient $ch(n\sigma_0 f_1 \delta)$ depending on the value, but not on the direction of polarisation. Here n-sample thickness, σ_0 - total S-neutron cross-section, $\delta = \frac{I}{(I+1)}$ for $J = I + \frac{1}{2}$ and -1 for $J = I - \frac{1}{2}$. It is necessary to be cautious in that case, and this problem may be considered especially. However, for the ratio of transmissions for different orientation directions at the same experimental geometry and constant f_1 this coefficient is excluded. In this case, the formulas (2) have the same value.

The author thanks F. Shapiro and V. Efimov for their initiation and constant interest in this problem.

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Radiative Capture of Neutrons by Ho and Lu

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In the present paper the cross sections for radiative capture of neutrons with energy up to 50 keV have been obtained. The measurements were performed with the lead neutron slowing down time spectrometer of the Physical Institute, USSR Academy of Sciences/1/, by means of direct detection of prompt gammas produced in the neutron capture/2/. The results are shown in Figs. 1 . and 2. In the keV energy range our results for Ho are 30% lower that the data of Block et al./3/ and Gibbons et al./4/ and for Lu are 20% lower than the data of/3/ and more than by a factor of two lower than those of/4/. It is noteworthy that for Ho^{165} and Lu our measurements with proportional and scintillation gamma detectors coincide. The reason of disagreement between our results in the keV energy range and those of/3/ and/4/ is not clear. There are no experimental data on the value of the total resonance absorption integral for Ho. The value of the resonanse absorption integral, which has been measured for neutrons with energies above 130 eV, where the parameters of separate resonances are unknown, is equal to 64 $\pm$ 6 b.

With a view of determining average interaction parameters of s- and p-neutrons with Ho^{165} and Lu nuclei an analysis of averaged cross sections for radiative capture in the keV energy range has been performed according to the programme described in/5/. The results are given in Table I. The calculated curve for Ho^{165} in the keV energy range according to the parameters of Table I is shown in Fig. I. The dashed curves indicate the contributions of s- and p-neutrons to the cross section for radiative capture.

In the region of mass numbers A=140-200 a contribution of d-neutrons to the cross section for radiative capture can be essential, the strength function of these neutrons has a maximum at $A\sim150$. The estimate of the d-neutron contribution to the cross section for the radiative capture by the sticking coefficients/6/ shows that for the investigated nuclei it is not above 5% at $E_n = 30$ keV, and therefore it is neglected in our calculations. In paper/4/ the averaged cross sections for radiative capture are analysed in the 7-200 keV energy range. However, near the lower boundary of this energy range the capture cross section is weakly sensitive to the strength function of s-neutrons, and at high energies such analysis can be not exact because of a contribution of d-neutrons. Besides, a usual linear ratio between the partial cross section for the formation of a compound nucleus and the strength function ($\sigma_c^{\ell} \sim S_{\ell}$) is violated at energies $E_n > 30$ keV near the maxima of giant s-resonances/7/.

The values of strength functions of p-neutrons (S_1) obtained from the analysis in the 50 keV energy range where the effect of the contribution of d-neutrons and non-linearity/7/ is much smaller are overlapped, within experimental error, with the results of/4/. The obtained values of $S_\gamma = \bar{\Gamma}_\gamma / D_0$ are smaller than those of/4/ approximately by a factor of two, although both of them are largely above the values of S_γ calculated from measurements of separate resonance parameters/8/. This can be due to inaccuracies in the values of $\bar{\Gamma}_\gamma$ and to omission of weak resonances in measurements of total cross sections/8/.

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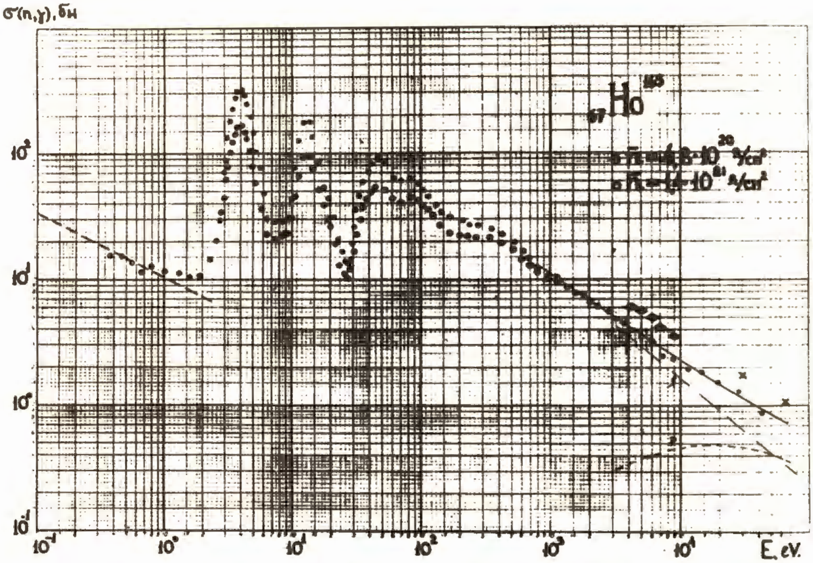
Table I

The Results of the Analysis of the Averaged Capture Cross Sections x)

Element, isotope	I	Other auters S_0	Other auters $S_\gamma = \bar{\Gamma}_\gamma / D_0$	Other auters S_1	S_0	S_{γ_0}	S_{γ_1}	S_1	$\bar{S}_1$
					2,5	11,2±0,4		1,7±0,3	
${}_{67}Ho^{165}$	7/2	2,5±0,4 /8/	6,9 /8/		1,9±0,4	14,1±3,2		1,1±0,5	1,5±0,9
			31 /4/	0,4±0,4 /4/	2,5	11,1±0,5	10±4	1,8±0,5	
					1,7	15,3±0,3		0,76±0,10	
${}_{71}Lu$	7/2	1,7±0,2 /8/	10,7 /8/		1,33±0,05	23,4±1,7		0,18±0,08	0,5±0,4
			50 /4/	0,1±0,1 /4/					

x) All parameters in the Table are in 10^{-4} units, the designations are given in /5/.



.g.1. The dependence of the effective cross section for radiative capture upon the neutron energy for Ho samples.
ñ – the thicknesses of the samples,
◇ – the results of [3], x – the results of [4].

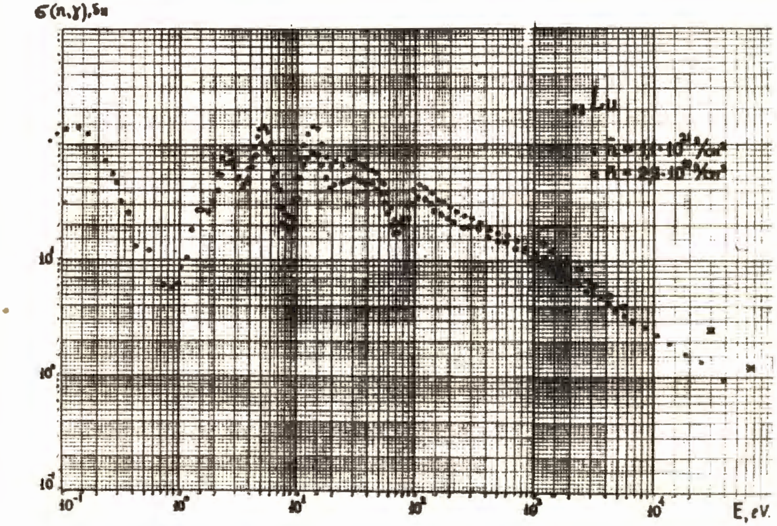


Fig.2. The dependence of the effective cross section for radiative capture upon the neutron energy for Lu samples. (The designations are the same as in Fig.1.)

Strength Functions of U-235 for Neutrons with ℓ = 0 and 1

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The cross sections of fission and radiative capture for U-238 in the neutron energy range from 0.3 to 30 keV[1] were measured by the time-of-flight method on the fast pulsed reactor at Dubna.

The results of the measurements permit to analyze the average summed cross section of fission and radiative capture of neutrons (the reaction cross section $\overline{\sigma_r}$). The experiment is considerably simplified due ta the fact that for U-235 in the energy region up to 100 keV the condition $\Gamma_f + \Gamma_\gamma \gg \Gamma_n$ (1) is valid, where Γ_f is fission level width, Γ_γ is the total radiative level width and Γ_n is a neutron level width. Performing the conventional averaging over energy of the Breit-Wigner formula for an isolated level in the energy range where resonances are not overlapped but are already prohibited by the spectrometer and where the main contribution to the cross section goes from neutrons with orbital momenta ℓ =0 and 1, we obtain with the account of (1):

$$\overline{\sigma_r} = \overline{\sigma_r^0} + \overline{\sigma_r^1} = 2\pi^2 \lambda\!\!\!^{-2} \left\{ \overline{\left(\Gamma_n/D\right)_0} + 3\left(\Gamma_n/D\right)_1 \right\} \quad , (2)$$

where $\lambda\!\!\!^-$ is the wave length of the neutron of energy E, D is the distance between the levels of the compound nucleus with the momentum

J and the parity π . A dash above means averaging, use is made of the conventional[2] assumption on the independence of the neutron sticking coefficient $T_\ell = 2\pi(\Gamma_n/D)_\ell$ from J. This assumption is confirmed experimentally for neutrons with ℓ =0 for the majority of nuclei. Targets-nuclei As, Au and some others with spin 3/2[3] appear to be an exception. At energies below 100 keV for U-235 in the optical model $(\Gamma_n/D)_0 = S_0\sqrt{E}$ and $(\Gamma_n/D)_1 = \left[(R/\lambda)^2/1+(R/\lambda)^2\right] S_1\sqrt{E}$, where S_0 and S_1 are strength functions of neutrons with $\ell = 0$ and 1 reduced to 1 eV, R is the nucleus radius. By using different energy dependences $(\Gamma_n/D)_0$ and $(\Gamma_n/D)_1$, one can separate the contributions of these terms to expression (2) and obtain independent parameters S_0 and S_1. The following values of the strength functions $S_0 = (0.91 \pm 0.03)\cdot 10^{-4}$ and $S_1 = (2.8 \pm 0.4)\cdot 10^{-4}$ were obtained by the least squares method. An electronic computer was used. The value of S_0 is in good agreement with the value $(0.92 \pm 0.17).10^{-4}$ obtained from the analysis of separate levels in the energy range up to 50 eV[1]. The calculated values:

$$T_1 = 2\pi\sqrt{E}\,\frac{(R/\lambda)^2}{1+(R/\lambda)^2}\cdot S_1\,, \quad (R = r_0 A^{1/3},\ r_0 = 1.35\ \text{ф},\ A = 235)$$

agree with those for the optical potential. S_0 and S_1 are close to the values $(1.02 \pm 0.03).10^{-4}$ and $(2.0 \pm 0.3).10^{-4}$ obtained by Uttley[4] from the analysis of experimental data on neutron transmission. For neutrons with ℓ =0 with energies up to 30 keV $\overline{\Gamma_n}$ is $\leq$ 20% from the average total width $\overline{\Gamma}$ Considering; $\overline{\Gamma_\gamma}$ to be constant in the energy interval under study and knowing the energy dependence $\alpha = \overline{\sigma_\gamma}/\overline{\sigma_f}$ one can estimate the correction value $\overline{\sigma_{nn}}$ which is smaller than $(10 \pm 3)\%$ from $\overline{\sigma_\tau}$ in this case. The results given in this paper have been obtained from the analysis without any correction. The experimental errors $\Delta\overline{\sigma_\tau}$ include the errors resulting from the fluctuation of the level number in the interval of averaging Δ E. These uncertainties were considered to be $\frac{1}{\sqrt{n}}\overline{\sigma_\tau}$, where n is the level number in the given energy range of averaging.

Fig. 1 shows the experimental values $\overline{\sigma_{\gamma}}(E)$ with the correction $\overline{\sigma}_{nn}(E)$ and the calculated curve obtained with the above values of S_0 and S_1. The contributions from neutrons with $\ell = 0$ (the dashed curve) and $\ell = 1$ the dot-and-dash curve) are shown separately. The contribution of neutrons with $\ell = 2$ is negligibly small and in accordance with the optical model is not larger than 0.5% in the energy region up to 100 keV. The account of the interference terms in the average cross section gives the relative correction proportional to $(\Gamma/D)^2$. This is smaller than (2-3)% from $\overline{\sigma_{\gamma}}$ (E) in the energy range under consideration.

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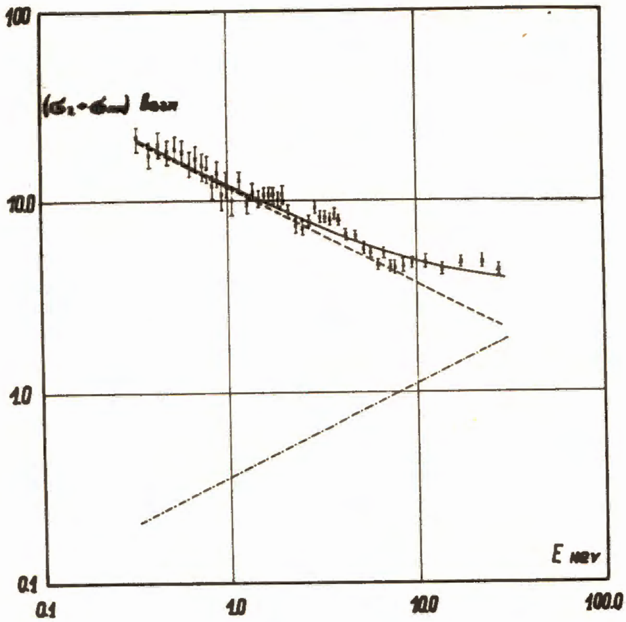

Fig.1. The cross section $\overline{\sigma_z} + \overline{\sigma_{nn}}$ in the energy range (0.3–30) keV. The solid curve is the calculated cross section. The dashed curve is the contribution of neutrons with ℓ =0. The dot-and-dash curve is the contribution of neutrons with ℓ =1.