INVESTIGATION OF NEUTRON RESONANCES IN Rh^{103}

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Submitted to JETP editor June 1, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 1743-1753 (December, 1963)

Transmission, scattering, and capture measurements for several Rh^{103} samples were carried out with the slow neutron spectrometer of the Neutron Physics Laboratory of the Joint Institute for Nuclear Research. The measurements were performed at resolutions of 0.04, 0.08 and 0.05 μsec/m. The parameters of 17 resonances and the spins of 8 levels were determined. A deviation from the Porter-Thomas law with a single degree of freedom has been found. It can be explained by the fact that from 4 to 5 resonances are due to neutrons with orbital momenta $l = 1$. Force functions for neutrons with $l = 0$ and $l = 1$ were computed under these assumptions.

A study of neutron resonances yields much information on the properties of nuclear levels with excitation energy close to the neutron binding energy. At present there is extensive material on the parameters of the neutron resonances of many nuclides of the periodic system. These data, however, are insufficient for a reliable comparison of experimental and theoretical results. Modern theory is capable of predicting only the statistical laws in the behavior of the parameters (for example, the distribution function of the partial widths for resonances of one nucleus or the general laws of variation of some quantities, averaged over many resonances of one nucleus, with variation of the atomic number, the spin of the resonances, etc.). At the same time, a detailed statistical analysis of the experimental data is practically impossible, owing to the fact that for each individual nucleus, as a rule, we know the parameters of a relatively small number of resonances. Only for several nuclei have several dozen resonances each been investigated, but even in these cases the spins of very many resonances are unknown. In this connection, the acquisition of new data on resonances is a timely problem, with particular interest attached to a determination of the resonance spins, lack of information about which makes it impossible to carry out a complete analysis of even the available material.

In order to investigate systematically the neutron resonances to obtain as complete a set of parameters for each resonance as possible, a neutron spectrometer was developed at the Joint Institute for Nuclear Research, on the basis of the fast pulsed (IBR) reactor [1], using the neutron time of flight method. There were also developed a 1024-channel time analyzer [2], detectors for measurement of the total effective cross sections σ_{tot} for the neutron-nucleus interactions [3], of the effective cross sections σ_γ for radiative capture [3] and of the effective cross sections σ_n for neutron scattering [4]. In addition a program for reducing the experimental data with an electronic computer was worked out.

We report here the results of the first measurements, made with the spectrometer. The resolution of the spectrometer varied in the different measurements and was determined essentially by the duration of the neutron flash of the IBR and the distance between the detector and the reactor. The characteristics of the reactor as a pulsed neutron source are as follows: flash duration 36 μsec, repetition frequency 8.3 pulses/sec, number of neutrons per flash $\sim 5 \times 10^{12}$. The distance from the source to the detector and the corresponding resolution were respectively 1000 meters and 0.036 μsec/m for the measurement of the total effective cross sections, 750 meters and 0.05 μsec/m for the measurement of the effective radiative capture cross sections, and 500 meters and 0.08 μsec/m for the measurement for the effective cross sections (in the last case, the resolution was also affected by the lifetime of the scattered neutrons in the detector).

The first trial measurements were made on Rh^{103}. Having 1/2 spin, Rh^{103} is a convenient object for the determination of the resonance spins with the aid of a combination of data on σ_{tot}, σ_γ, and σ_n. Additional interest in the investigation of this nucleus was due to the fact that the mass of Rh^{103} lies in the region where resonances produced by p neutrons might be discovered. The results of earlier investigations of Rh are found in the report of Hughes and Schwartz [5]. Simultaneously with our work, research on Rh^{103} was carried out with the neutron spectrometer at Saclay [6]. Both in [5] and in [6], only total cross sections were measured, so that the spins of the resonances were not determined.

TRANSMISSION MEASUREMENTS

The resonances in the total cross section of rhodium were investigated in the range from 30 to 1200 eV by measuring the transmission of samples of metallic rhodium 2.805×10^{21}, 1.38×10^{22}, and 5.68×10^{22} nuclei/cm^2 thick. The samples were placed 500 meters away from the reactor. A boron filter 0.21 g/cm^2 thick, which suppresses the recycled neutrons, was placed in front of the samples. The monitors were boron counters located 70 meters from the reactor. Their output was disconnected from the registering circuits before each reactor power pulse and was reconnected approximately 400 microseconds later.

The neutrons were registered with a liquid scintillation detector with methyl borate [3]. The detector had a useful area of 490 cm^2, a depth of 3 cm in the beam direction, and operated with four FÉU-24 photomultipliers. To prevent overloading of the output stages, the photomultipliers were shut off during the reactor pulse.

The detector electronic circuit separated coincident photomultiplier pulses with total amplitude lying in the region of the peak due to registration of α particles from the reaction $B^{10}(n, \alpha) Li^7$ in the scintillator. By thorough adjustment of the electronic circuitry and by selecting the best of a large number of photomultipliers, the detector was very stable and maintained its efficiency constant within 3 per cent in two weeks of operation.

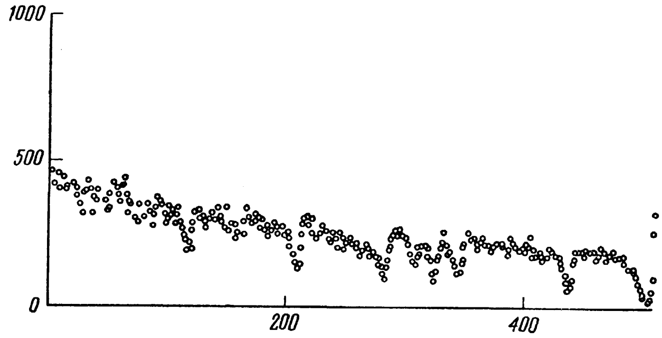

FIG. 1. Section of the experimental spectrum of neutrons passing through an Rh sample 5.68×10^{22} nuclei/cm^2 thick. The ordinates represent the number of counts per hour of measurement.

The neutron registration of efficiency and the time characteristics of the detector are determined by the moderation and capture of the neutrons in the scintillator. Table I lists data for the scintillator employed in this investigation.

The detector was placed inside a lead shield with windows for the entry and exit of the neutron beam. The detector count not connected with the reactor was $(3.5-4.2) \times 10^{-4}$ pulses per cycle per 16 μsec channel.

The background was measured with and without the sample by the resonant filter method, which consists in measuring the spectrum of the neutron detector pulses after placing in the beam additional thin samples which have very strong resonances; the readings in the "dips" of these resonances give directly the value of the background in different portions of the spectrum. In the region below 1.2 keV, where the Rh transmission measurements were made, the absolute value of the background was almost constant, so that the relative contribution of the background dropped from 20 per cent at $E_n \approx 5$ eV to 3 per cent at $E_n \approx 340$ eV, and to an even smaller value at higher energies, owing to the increase in the counting rate of the time channel

Table I. Calculated values of the efficiency ϵ and the average neutron lifetime τ for a detector with methyl borate on a base of natural boron. The data were obtained by the Monte Carlo method [7].

E_n, eV	1	10	100	1000	10000
ε	0,90	0,72	0,51	0,37	0,27
τ, μsec	2.38	1,75	1.60	1,57	1.50

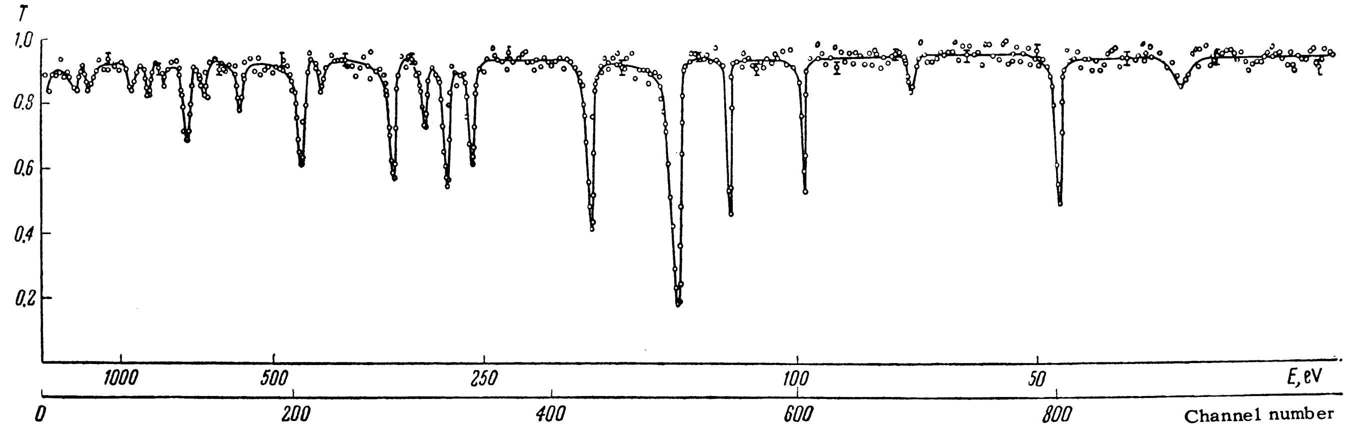

FIG. 2. Transmission curve of Rh^{103} sample 1.38×10^{22} nuclei/cm^2 thick.

with decreasing time of flight. The main fraction of the background is apparently due to delayed neutrons produced and multiplying in the active zone of the reactor during the intervals between power pulses.

The immediate purpose of the measurements was to obtain the time distributions of the neutrons in the open beam and in the beam transmitted through the investigated sample. Hourly runs with and without the sample alternated in the working measurements. Periodically, once every 5—6 hours, the background for both types of runs was measured with the aid of resonant filters of Co and Ag. An example of the experimental spectrum obtained after one hour of measurements with a rhodium sample 5.68×10^{22} nuclei/cm^2 thick is shown in Fig. 1. The transmission was calculated from the experimental spectra with an electronic computer. The computation program included averaging of the analyzer channel readings over many runs of the same type, taking account of corrections for the background, of miscounts in the analyzer, and of the readings of the monitors; also calculation of the transmission for each channel; and calculation of the mean square transmission errors. In averaging over the runs, the readings of the channel in each individual series were compared with the average value for this channel. If a run differed from the average by more than three mean-square errors, it was discarded and the mean recalculated. This procedure excluded the influence of random peaks in the analyzer readings. Figure 2 shows the transmission curve of a rhodium sample 1.38×10^{22} nuclei/cm^2 thick.

Inasmuch as the energy resolution of the apparatus in the investigated energy region exceeded the width of the resonances, the reduction of the transmission curves was by the area method (see, for example,[8]). This method does not call for the knowledge of the resolution function of the apparatus and yields plots of the product $g\Gamma_{ni}$ of the spin factor by the neutron resonance width vs. the total resonance width Γ_i; we start here from the area under the resonance dip $A_{i\alpha}$ in the transmission of the sample (here i—"number" of the resonance and α—"number" of the sample).

Analogous $g\Gamma_{ni} = f_{i\alpha}(\Gamma_i)$ curves were obtained from measurements of the cross sections for the capture and scattering of neutrons, which will be discussed in detail later on. The values of the parameters $g\Gamma_{ni}$ and Γ_i were determined from the coordinates of the effective center of gravity of the region of intersection of the curves, while the errors were determined from the boundaries of this region. In the case of very weak resonances, the value of $g\Gamma_{ni}$ was determined from the area of the resonance dip for the thickest sample, under the assumption that the total width of this resonance is equal to the radiation width averaged over the resonances for which it was reliably determined. A summary of the obtained resonance parameters is listed in Table II.

In measurements of the transmission, we first calculated the areas $A^0_{i\alpha}$ without account of the "wings" of the resonance (this reduces the relative statistical errors of the resonance area). The wings were cut off symmetrically relative to the resonance energy E_{0i} at the points $E_{0i} - \epsilon_i$ and $E_{0i} + \epsilon_i$ where the transmission is close to 0.9 T_c (T_c is the transmission component which does not depend on the energy and is determined by the potential scattering of the neutrons by the sample). The corrections $\Delta_{i\alpha} = n\sigma_0\Gamma_i^2/2\epsilon_i$ for the wings were introduced by the method of successive approximations. In plotting the $g\Gamma_{ni} = f_{i\alpha}(\Gamma_i)$ curves, as in the calculation of the corrections for the resonance wings, theoretical curves were used for the connection between the area of the reso-

Table II. Parameters of Rh^{103} resonances

E_0, eV	$g\Gamma_n$, meV	Γ, meV	J	Γ_γ, meV	$2g\Gamma_n^0$, meV
34.4±0.1	0.011±0,002	—		—	0.0040
46.7±0.1	0.37±0.03	155±16		155±16	0.108
68.3±0.2	0.15±0.01	—		—	0.036
95.5±0.4	1,7±0.1	150±15	0	143±15	0,348
98.4±0.4	0,06±0.02	—		—	0,012
110,7±0.5	0,12±0.02	—		—	0,023
114.0±0.5	0,10±0.02	—		—	0,019
125.3±0.6	6,1±0.4	175±15	1	167±15	1,09
154.5±0.6	46±5	280±30	0	96±36	7,42
178.7±1	0.10±0.03	—		—	0,015
187.0±1	30±2	182±10	1	142±13	4.38
205,0±1.1	0.20±0.05	—		—	0,028
253.7±1.6	20±1.5	190±20	1	163±21	2,52
263.0±1.7	1.5±0.4	—		—	0.185
272.5±1.8	41±3	300±15	0	136±20	4,96
290.2±1.9	11±1	160±40	0	116±40	1.29
320.7±2.3	57±10	380±50	0	152±63	6.38

nance dip and the resonance parameters, the sample thickness, and the Doppler width. These curves were first proposed by Hughes [8]. In the present work we used the curves calculated in [9].

MEASUREMENTS WITH (n, γ)-DETECTOR

The detector [3] used for the registration of the (n, γ) reaction consisted of two identical cylindrical tanks with capacity of approximately 200 liters each, filled with a solution of paraterphenyl (3g/l) and POPOP (0.1 g/l) in toluol. The sample of the substance under investigation was placed on the axis of cylindrical holes of the coaxially arranged tanks. The outside diameter of the tank was 800 mm, the hole opening was 220 mm, and the length 400 mm. Each tank was viewed by four photomultipliers, FEU-49, mounted on the end covers. The pulses from each group of four multipliers were applied to an adder, amplified, and fed to a single-channel pulse-height analyzer. The pulses from the two tanks were further fed to a coincidence circuit. The use of a coincidence circuit greatly reduced the natural detector background, which amounted to 4500 counts/sec at a discrimination level of 0.5 MeV in the case of summation of the pulses from both tanks.

In the coincidence mode, the natural detector background dropped to 15 counts/sec. In addition, the coincidence circuit made it possible to greatly reduce the reactor background, connected with the capture of scattered neutrons by the hydrogen of the scintillator. This background was further decreased by adding boron, in the form of methyl borate $B(OCH_3)_3$, to the scintillator composition, amounting to 1 liter per 20 liters of scintillator.

The detector described above was used to obtain two kinds of information: determination of the parameters $g\Gamma_{ni}$ and Γ_i by the self-indication method (in conjunction with the transmission method), and determination of the level spin.

A detailed discussion of the method for obtaining the resonance parameters by measurements with (n, γ) detectors is given in the paper of Zeliger et al [10]. The self indication method [11] consists of making the measurements both with the sample D, situated inside the detector, and with an additional absorber T made of the same material but placed in the beam under conditions of "good" geometry. Such measurements make it possible to obtain the quantity

$$S = \frac{\Sigma N_i(D, T)}{\Sigma N_i(D)} e^{n_T \sigma_p} = \frac{A_{D+T} - A_T}{A_D}, \qquad (1)$$

where $\Sigma N_i(D, T)$—total count over the resonance region in presence of the samples D and T in the beam; $\Sigma N_i(D)$—total count over the resonance region in the presence of sample D only; n_T—number of nuclei per cm² of sample T; σ_p—potential scattering cross section for the nuclei of sample T; A_{D+T}, A_T, A_D—areas of resonance dips for the samples of the corresponding thickness.

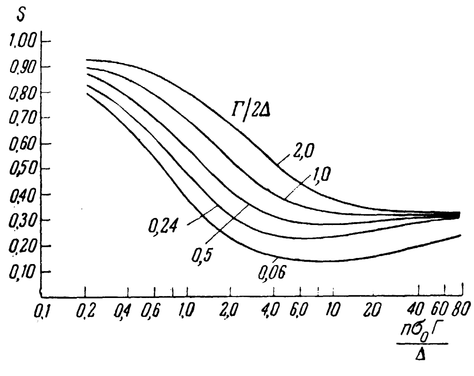

FIG. 3. Family of $S(n\sigma_0\Gamma/\Delta, \Gamma/2\Delta)$ curves for $n_T/n_D = 2$.

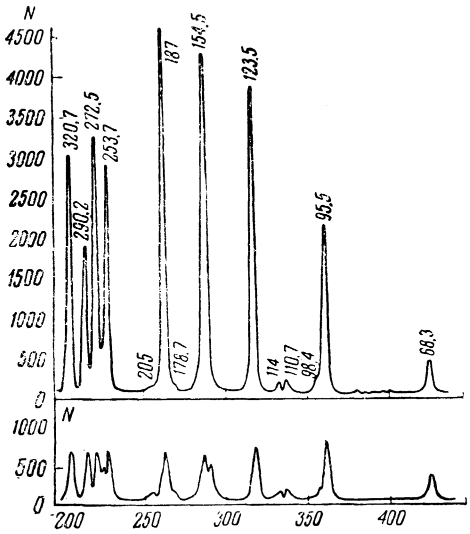

FIG. 4. Section of experimental spectrum obtained by measurements with (n,γ) detector without an absorbing sample (upper plot) and with an absorbing sample (lower plot). Sample thickness $n_D = 7.0 \times 10^{21}$ and $n_T = 14 \times 10^{21}$ nuclei/cm^2.

The values of S as functions of the resonance parameters, Doppler width, and thickness of the samples were calculated on an electronic computer. Figure 3 shows by way of an example several curves for the thickness ratio $n_T/n_D = 2$.

Measurements of radiative capture of neutrons by rhodium nuclei were made with a detector sample D of thickness 7.0×10^{21} nuclei/cm^2 with an irradiated sample area 250 cm^2 and with transmitting samples T of thicknesses 1.4×10^{21}, 7.0×10^{21}, 14×10^{21}, 28×10^{21}, and 56×10^{21} nuclei/cm^2.

Figure 4 shows a section of the time spectrum obtained with measurements without any absorbing sample (upper plot) and with an absorbing sample of thickness 14×10^{21} nuclei/cm^2 (lower plot).

The experimentally obtained values of S have made it possible to obtain the curves of $g\Gamma_{ni}$ vs. Γ_i for different thicknesses n_T. These curves were drawn on a common plot with analogous curves obtained by the transmission method, yielding the values of $g\Gamma_{ni}$ and Γ_i for the investigated resonances.

In measurements with a detector sample we have

$$\sum N_i(D) = \Pi(E_0)\, \varepsilon_\gamma \frac{\Gamma_\gamma}{\Gamma} A_D, \qquad (2)$$

where $\Pi(E_0)$—flux of neutrons of resonance energy over the entire area of the sample per unit energy interval during the measurement time; ϵ_γ—efficiency for the registration of neutron radiative capture.

The product $\Pi(E_0)\epsilon_\gamma$ was obtained in the following manner. For resonances with $\Gamma_n \ll \Gamma_\gamma$, the ratio Γ_γ/Γ is practically independent of the resonance parameters and is close to unity. It then follows from (2) that

$$\Pi(E_0)\, \varepsilon_\gamma = [\Sigma N_i(D)]/A_D. \qquad (3)$$

Substituting the previously obtained value of A_D, we can obtain the desired product at the given energy.

The relative variation of the flux $\Pi(E)$ as a function of neutron energy was obtained by measurements with thin boron counters. The constancy of the efficiency for different resonances was checked by comparing the total count over the resonance region, obtained in the usual operating mode of the detector, with the count obtained when both tanks of the detector were connected not for coincidence but for addition of the pulses. The ratio of the counts over the resonance region in the case of different detector operating modes did not change from resonance to resonance, thus indicating that the spectrum of the γ rays connected with the capture is constant, and consequently also the efficiency ϵ_γ.

The product $\Pi(E)\epsilon_\gamma$ obtained in this manner was used to determine the level spin for which the neutron width is comparable with the radiative width. Re-arranging (2) into

$$\Sigma N_i(D)/\Pi(E_0)\, \varepsilon_\gamma = (1 - \Gamma_n/\Gamma)\, A_D, \qquad (4)$$

we can obtain from (4) two different curves plotted in $g\Gamma_n$ and Γ coordinates, depending on the assumed value of g. The choice of the true value of g, and consequently also of the level spin, was based on which of two curves passed through the point of intersection of the curves obtained by the transmission and self-indication methods.

MEASUREMENTS WITH SCATTERED NEUTRON DETECTOR

The cross section for the scattering of neutrons was investigated with the aid of a scintillation detector[4], in which the scintillator used was ZnS (Ag) + B (compound T-1). To increase detector efficiency and to improve light gathering, the following construction was used. The T-1 powder was deposited in the form of layers 1 mm thick between Plexiglas plates 9 mm thick, so that a block of trapezoidal cross section 50 cm long was obtained, containing five layers of T-1. The detector consisted of 8 blocks, assembled in the form of an octagon, as shown in the section through the detector (Fig. 5).

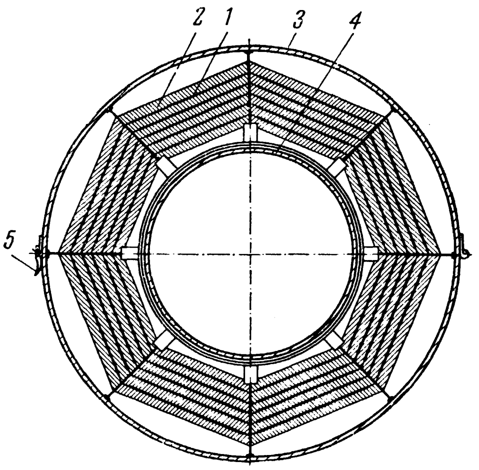

FIG. 5. Section through scattered neutron detector: 1—layer of compound T-1, 2—Plexiglas plate, 3—outer jacket, 4—duraluminum vacuum tube, 5—latch of jacket.

Each block was viewed from both ends by FÉU-24 photomultipliers. Such a detector construction increased the efficiency, owing to the slowing down of the neutrons in the Plexiglass, which simultaneously served as a light pipe.

The detector was placed in a light tight jacket, the inside cylindrical channel of which had a diameter 220 mm. To reduce the scattering of the neutrons by the air, the samples were placed in a vacuum tube installed in the detector channel.

The detector efficiency depended little on the neutron energy and amounted to approximately 15 per cent in the 5—400 eV range. The efficiency to γ rays from Co^{60} was about 0.01 per cent. The lifetimes of the neutrons in the detector were $\sim 15\ \mu$sec, which was acceptable for a reactor flash of 36 μsec.

The measurements of the neutron scattering by rhodium nuclei were made for samples with thicknesses 0.67×10^{21}, 2.82×10^{21}, and 6.73×10^{21} nuclei/cm^2. These measurements alternated with measurements of the background in the absence of the specimen and with measurements with lead, which was used as a standard with a known scattering cross section of 11.3 b. To estimate the contribution to the background of the delayed neutrons scattered by the sample, measurements were made with lead and with a silver filter. In the region of the 5.2 eV resonance, the background from the delayed neutrons did not exceed 5 per cent of the total background, while in the region of higher energies it played an even smaller role.

The determination of the resonance parameters, which is described in greater detail in [10], was carried out in the following manner. The total count over the resonance region, above the level of the potential scattering, is

$$(\Sigma N_i)_{\mathrm{Rh}} = \Pi(E)\, \varepsilon_n A \Gamma_n/\Gamma, \tag{5}$$

in analogy with expression (2) for the (n, γ) reaction.

In measurements with lead, the count in the channel which corresponds to the resonance energy is

$$N_{\mathrm{Pb}} = \Pi(E)\, \varepsilon_n (1 - T_{\mathrm{Pb}})\, \Delta E, \tag{6}$$

where $T_{\mathrm{Pb}} = \exp(-n\sigma)_{\mathrm{Pb}}$ is the transmission of lead n nuclei/cm^2 thick and ΔE is the neutron energy interval determined by the width of the time channel of the analyzer at resonant energy.

The ratio of expressions (5) and (7) contains neither the values of the flux $\Pi(E)$ nor the efficiency ϵ_n:

$$\frac{(\Sigma N_i)_{\mathrm{Rh}}}{N_{\mathrm{Pb}}} = \frac{\Gamma_n}{\Gamma} \frac{A}{(1 - T_{\mathrm{Pb}})\, \Delta E}. \tag{7}$$

Expression (7) does not take into account the correction for neutron capture following the scattering, which is quite appreciable in the case where $\Gamma_\gamma > \Gamma_n$. To take account of this correction on the basis of measurements with samples of different thicknesses the function

$$B(n) = \frac{(\Sigma N_i)_{\mathrm{Rh}}}{N_{\mathrm{Pb}}} (1 - T_{\mathrm{Pb}})\, \Delta E \frac{g\Gamma_n}{A} \tag{8}$$

was extrapolated to zero sample thickness.

The limiting value

$$\lim_{n \to 0} B(n) = g\Gamma_n^2/\Gamma, \tag{9}$$

determined by extrapolation has made it possible to obtain the dependence of $g\Gamma_n$ on Γ for two possible values of the spin factor g. These curves, in conjunction with the total and capture cross sections obtained from the measurements, have made it possible to select one of the two values of g.

The level for potential scattering of neutrons by rhodium nuclei was determined from the sections between resonances and from comparison with the scattering by lead. The cross section of potential scattering for Rh was found to be 5.3 ± 0.3 b.

RESULTS AND DISCUSSION

A summary of the parameters obtained for 17 resonances of rhodium with energy from 34.4 to 320.7 eV is given in Table II. In addition to those listed in the table, resonances were observed also at 365, 407, 436, 447, 556, 648, 701, 780, and 843 eV.

Figure 6 shows a plot of the number of registered resonances as a function of the neutron energy. In the energy region approximately up to 350 eV, the number of resonances increases

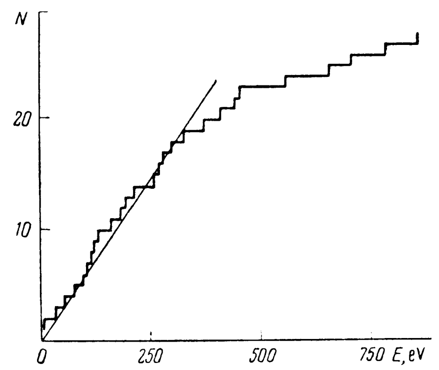

FIG. 6. Dependence of number of registered resonances of Rh^{103} on the neutron energy.

linearly with the energy, thus evidencing that in this region the fraction of unregistered resonances is insignificant. The average distance between levels (without account of the spin), determined from the slope of the line of Fig. 6, turned out to be 17 ± 4 eV. This error was determined from the mean square error of the number of resonances with $E_{0i} \leq 350$ eV under the assumption that the distances between levels have an exponential distribution.

The integral distribution of the reduced neutron widths $2g\Gamma_{ni}^0$ as a function of the quantity $\sqrt{2g\Gamma_n^0}$, plotted from the data of Table II with account of the 1.32 eV level [5], is shown in Fig. 7. In comparing this distribution with the theoretical Porter-Thomas curve with one degree of freedom, an excess of resonances with small neutron widths is observed. A satisfactory agreement between the experimental and theoretical distributions is obtained by excluding from consideration the five weakest resonances. Inasmuch as Rh^{103} is in the region of maximum of the strength function for the p neutrons, it is natural to assume that these resonances are due to an interaction with the neutrons at $l = 1$. If this is so, then the values of the strength functions for s neutrons and for p neutrons turn out to be $S_0 = (0.46 \pm 0.18) \times 10^{-4}$ and $S_1 = (1.8 \pm 1.4) \times 10^{-4}$, respectively, in agreement with [6]. We note that for S_0 it is immaterial what number of weak resonances is ascribed to the p neutrons. The value of S_1, owing to the low statistical accuracy must be regarded only as a rough estimate.

It should be noted that the universally employed method of separating p resonances on the basis of the deviation of the experimental distribution of the values of $2g\Gamma_n^0$ from the Porter-Thomas law which we have employed, is based on the assumption that $2g\Gamma_i^0$ does not depend on the resonance spin. This assumption can be justified on the basis of both the optical and statistical model of the nucleus, but does not have sufficiently weighty experimental evidence. Judging from the fact that in the region of atomic weights far from the maximum of S_1 the experimental distributions of $2g\Gamma_{ni}$ obey the Porter-Thomas law (see, for example, [12]), we can hope that $2g\Gamma_n^0$ is actually independent of the spin. On the other hand, the deductions of Seth [13], who analyzed the behavior of S_0 over a wide range of atomic weights, favor the assumption that $2g\Gamma_{ni}^0$ is proportional to $(2J + 1)^{-1}$. Although the deductions of [13] need confirmation, they serve nevertheless, as an indication that deviations from the Porter-Thomas law may be due not only to p neutrons but also to differences in the values of $2g\Gamma_{ni}^0$ for two systems of s levels with spins $I + 1/2$ and $I - 1/2$ (I is the spin of the target nucleus). The foregoing considerations emphasize once more the need for measuring the resonance spins.

As to our data on the rhodium resonance spins, we can only note the following. The ratio of the number of resonances for which a unity spin has been determined, to the number of resonances for which a zero spin has been determined, is 3/5. According to the predictions of the statistical model of the nucleus this ratio should be 3. The reason for the discrepancy may lie in the fact that the experiments determine the level spins only with sufficiently large values of Γ_{ni}. Since the average value is larger for levels with $J = 0$ than for levels with $J = 1$, there is a greater probability of determining a zero spin. If to all the levels with unknown spin, with the exception of the five levels, is assigned $J \sim 1$, then the experimental ratio becomes equal to 1.4. The remaining discrepancy can be attributed to fluctuations of the number of levels with spin 0 in the investigated energy inter-

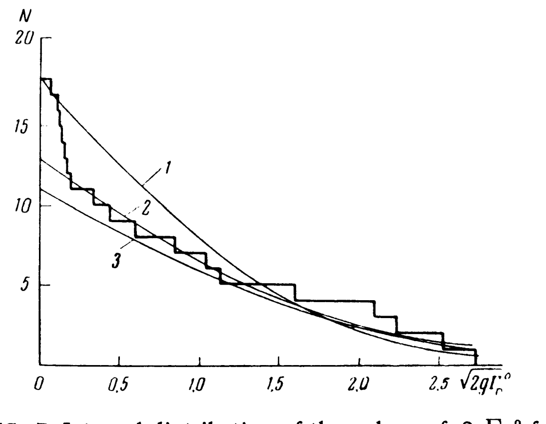

FIG. 7. Integral distribution of the values of $2g\Gamma_n{}^0$ for resonances with energy less than 320.7 eV. 1, 2, 3—theoretical curves, calculated after Porter-Thomas for N = 18, 13, and 11 levels, respectively.

val. To clarify the problem it is necessary to determine the spins of a much larger number of levels.

In conclusion, the authors consider it their pleasant duty to thank I. M. Frank and F. L. Shapiro for interest in the work and for useful discussions.

[1] Blokhin, Blokhintsev, Blyumkina, Bondarenko, Deryagin, Zamoĭskiĭ, Zinov'ev, Kazachkovskiĭ, Kim, Krasnoyarov, Leĭpunskiĭ, Malykh, Nazarov, Nikolaev, Stavisskiĭ, Ukraintsev, Frank, Shapiro, and Yazvitskiĭ, Atomnaya énergiya **10**, 437 (1961).

[2] Matalin, Shimanskiĭ, Chubarov, and Shtranikh, PTÉ no. 3, 54 (1960).

[3] Vizi, Zhukov, Zabiyakin, Karzhavina, Pikel'ner, Popov, Sharapov, and Yazvitskiĭ, Nuclear Electronics **1**, 27 (1962), (IAEA, Vienna); Pikel'ner, Pshitula, Kim, Ch'eng, and Sharapov, PTÉ no. 2, 48 (1963).

[4] Pikel'ner, Pshitula, Kim, Ch'eng, and Sharapov, PTÉ no. 2, 51 (1963).

[5] Neutron Cross Sections, ed. D. J. Hughes and R. B. Schwartz, BNL-325, 1958.

[6] Ribon, Michandon, and Dimitriyvic, Compt. rend. **254**, 2546 (1962).

[7] Kochkin, Shelontsev, and Popov, Preprint, Joint Inst. Nuc. Res.

[8] D. J. Hughes, J. Nucl. Energy **1**, 237 (1955).

[9] V. N. Efimov and I. I. Shelontsev, Preprint, Joint Inst. Nuc. Res. R-641, 1961.

[10] Zeliger, Iliescu, Kim, Longo, Pikel'ner, and Sharapov, JETP **45**, 1294 (1963), Soviet Phys. JETP **18**, 889 (1964).

[11] Rosen, Desjardins, Rainwater, and Havens, Phys. Rev. **118**, 687 (1960).

[12] Desjardins, Rosen, Havens, and Rainwater, Phys. Rev. **120**, 2214 (1960).

[13] K. K. Seth, Nucl. Phys. **24**, 176 (1961).

Translated by J. G. Adashko
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