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# NUCLEAR PHYSICS RESEARCH IN THE USSR

(Collected Abstracts)

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INSTITUTE OF PHYSICS AND POWER ENGINEERING

# FISSION CROSS-SECTION OF $^{249}Cf$ FOR THERMAL AND FAST NEUTRONS

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(Submitted to Atomnaja Energija)

The authors describe the results of measurements of the fission cross-section and angular anisotropy of fission fragments of $^{249}Cf$ for thermal and fast neutrons. The measurements involving thermal neutrons were carried out in the thermal column of the BR-5 reactor. The fast neutron source was an electrostatic generator. The measurements were performed for neutron energies of 500, 750, 850, 1450, 4000, 4500 and 5020 keV. Results are shown in Table 1.

Table 1

| | En MeV | ΔEn MeV | $\frac{\sigma_f(Cf^{249})}{\sigma_f(Pu^{239})}$ | $\Delta\left(\frac{\sigma_f(Cf^{249})}{\sigma_f(Pu^{239})}\right)$ | * $\sigma_f(Pu^{239})$ barn | $\sigma_f(Cf^{249})$ barn | $\Delta\sigma_f(Cf^{249})$ barn | $\frac{\sigma_f(0^\circ)}{\sigma_f(90^\circ)}$ | $\Delta\left(\frac{\sigma_f(0^\circ)}{\sigma_f(90^\circ)}\right)$ |
|---|---|---|---|---|---|---|---|---|---|
| I. | | - | 2,I50 | ±0,050 | 790 | I700 | ± 40 | - | - |
| 2. | 0,500 | ±0,090 | 0,997 | ±0,030 | I,59 | I,58 | ± 0,05 | 0,I02 | ± 0,050 |
| 3. | 0,750 | ±0,080 | 0,876 | ±0,027 | I,64 | I,44 | ± 0,05 | 0,030 | ± 0,080 |
| 4. | 0,850 | ±0,075 | 0,810 | ±0,025 | I,68 | I,36 | ± 0,06 | 0,I33 | ± 0,060 |
| 5. | I,450 | ±0,070 | 0,866 | ±0,030 | I,93 | I,67 | ± 0,06 | 0,I37 | ± 0,060 |
| 6. | 4,000 | ±0,I00 | I,072 | ±0,042 | I,82 | I,95 | ± 0,08 | 0,I34 | ± 0,080 |
| 7. | 4,500 | ±0,I00 | I,I20 | ±0,039 | I,78 | I,99 | ± 0,07 | 0,209 | ± 0,060 |
| 8. | 5,020 | ±0,I00 | I,I35 | ±0,034 | I,76 | 2,00 | ± 0,06 | 0,I58 | ± 0,050 |

* Reference values for $^{239}$Pu fission cross-sections were taken from Ref. [3] for thermal neutrons and from Ref. [4] for fast neutrons.

# RATIO OF NEUTRON RADIATIVE CAPTURE AND FISSION CROSS-SECTIONS FOR PLUTONIUM-239 IN THE ENERGY RANGE BELOW ~50 keV

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A.E. Samsonov, V.A. Tolstikov, A.N. Medvedev

The authors present the results of measurements of the parameter $\alpha(E)$ (the ratio of neutron radiative capture and fission cross-sections) for plutonium-239 which were performed on a spectrometer using the slowing-down time in lead.

The main feature of the method is that the sample and the detector are located in an isotropic neutron field, which does not vary due to neutron scattering by nuclei of the sample and the material of the detector. The low gamma background level of the spectrometer makes it possible to record the prompt gamma rays from radiative capture and fission with a gas proportional counter, on which the gamma ray recording efficiency is proportional to their energy. Measurements of the fission effect were performed with an ionization fission chamber.

The relative energy dependence of the cross-sections was normalized using a well-thermalized neutron spectrum obtained in a graphite prism placed close to the main prism of the lead moderator.

The results of the measurements, averaged over the ranges corresponding to the energy resolution of the spectrometer, are given in Table 1.

Table 1

Averaged values for neutron fission and radiative-capture cross-sections and for the parameter $\alpha(E)$ for plutonium-239

| Energy range, eV | $\langle \sigma_f(E) \rangle$ barn | $\langle \alpha(E) \rangle$ | $\langle \sigma_c(E) \rangle$, barn |
|---|---|---|---|
| 60000 - 20000 | I,43 ± 0,II | 0,39 ± 0,I4 | 0,56 ± 0,20 |
| 20000 - 9000 | I,6I ± 0,II | 0,70 ± 0,I5 | I,I2 ± 0,25 |
| 9000 - 4000 | 2,02 ± 0,II | 0,89 ± 0,I6 | I,80 ± 0,34 |
| 4000 - 2000 | 2,66 ± 0,I4 | 0,99 ± 0,I6 | 2,63 ± 0,45 |
| 2000 - I000 | 4,06 ± 0,22 | I,I2 ± 0,I6 | 4,6 ± 0,7 |
| I000 - 700 | 5,80 ± 0,30 | I,06 ± 0,I5 | 6,I ± 0,9 |
| 700 - 400 | 8,2I ± 0,45 | 0,95 ± 0,I4 | 7,8 ± I,2 |
| 400 - 200 | I2,8 ± 0,7 | 0,89 ± 0,I3 | II,4 ± I,8 |
| 200 - I00 | I8,5 ± 0,8 | 0,7I ± 0,I2 | I3,I ± 2,5 |

## METHOD OF MEASURING THE RADIATIVE CAPTURE TO FISSION CROSS-SECTION RATIO

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E.A. Plaksin, V.M. Furmanov

A method is described for measuring the radiative capture to fission cross-section ratio α, based on the use of a single-crystal scintillation spectrometer with separate channels for recording neutrons and gamma rays. The authors discuss the correction factors involved and the accuracy of measuring α by this method. The value of alpha was measured for uranium-235 and plutonium-239 in the "scandium" and "iron" beams of the reactor at Obninsk Nuclear Power Station. Table 1 shows the results of the measurements for neutrons with energies of 2 ± 0.35 and 24.5 ± 1.0 keV (the results for $E_o$ = 24.5 keV are provisional).

Table 1

| $E_o$, keV | α ($E_o$) for $^{235}$U | α ($E_o$) for $^{239}$Pu |
|---|---|---|
| 2 ± 0.35 | 0.49 ± 0.04 | 1.35 ± 0.09 |
| 24.5 ± 1.0 | 0.43 ± 0.14 | 0.30 ± 0.09 |

## ABSOLUTE MEASUREMENTS OF α FOR $^{235}$U AND $^{239}$Pu IN THE 10 keV-1 MeV NEUTRON ENERGY REGION

V.N. Kononov, E.D. Poletaev, Yu.S. Prokopets,
A.A. Metlev, Yu.Ya. Stavissky

The radiative capture to fission cross-section ratios for $^{235}$U and $^{239}$Pu were measured on a pulsed Van de Graaff accelerator using the time-of-flight method for the 10 keV-1 MeV neutron energy range. The capture and fission events were recorded with a liquid scintillation detector having a volume of 400 l. The capture and fission events were identified from the recording of the fission neutrons after they had been slowed down and absorbed in cadmium. In the 10-80 keV neutron energy range the experiment was performed on a continuous neutron spectrum from the reaction $^7$Li(p,n)$^7$Be and the neutron energy was measured by the time-of-flight method. At higher energies the experiment was performed with monoenergetic neutrons. An absolute method of measuring α was used.

The basic α values obtained for $^{235}U$ and $^{239}Pu$ are shown in Tables 1 and 2. The tables also show the root-mean-square error of the energy dependence of α (including only the statistical error) and the total root-mean-square error in the value of α. The samples used for the experiments were metallic $^{239}Pu$ with a thickness of 2.9 x $10^{-21}$ nuclei/$cm^2$ and $^{235}U_3O_8$ with a thickness of 4.1 x $10^{-21}$ $^{235}U$ nuclei/$cm^2$.

Table 1

Value of $\alpha$ for $^{235}U$, obtained in the present study

| $E_n$ , keV | $\alpha$ | $\sigma\alpha$ rel. to trend | $\sigma\alpha$ total error |
|---|---|---|---|
| I2,4 ± 0,7 | 0,549 | 0,043 | 0,057 |
| I3,4 ± 0,8 | 0,476 | 0,06I | 0,069 |
| I4,3 ± 0,8 | 0,457 | 0,040 | 0,05I |
| I5,4 ± 0,9 | 0,53I | 0,032 | 0,048 |
| I5,9 ± I,0 | 0,452 | 0,030 | 0,043 |
| I6,4 ± I,0 | 0,424 | 0,03I | 0,042 |
| I6,9 ± I,I | 0,365 | 0,032 | 0,04I |
| I7,4 ± I,I | 0,350 | 0,026 | 0,036 |
| I7,9 ± I,2 | 0,394 | 0,033 | 0,043 |
| I8,5 ± I,2 | 0,398 | 0,024 | 0,036 |
| I9,I ± I,3 | 0,370 | 0,020 | 0,033 |
| I9,8 ± I,4 | 0,338 | 0,029 | 0,038 |
| 20,4 ± I,4 | 0,3I7 | 0,024 | 0,033 |
| 2I,I ± I,5 | 0,307 | 0,020 | 0,030 |
| 2I,9 ± I,6 | 0,337 | 0,034 | 0,042 |
| 22,7 ± I,7 | 0,339 | 0,02I | 0,03I |
| 23,5 ± I,8 | 0,344 | 0,02I | 0,032 |
| 24,3 ± I,9 | 0,336 | 0,0I3 | 0,030 |
| 25,3 ± 2,0 | 0,283 | 0,0I7 | 0,026 |
| 26,2 ± 2,0 | 0,268 | 0,0I9 | 0,027 |
| 27,3 ± 2,2 | 0,292 | 0,0I4 | 0,025 |
| 28,4 ± 2,4 | 0,3I2 | 0,0I6 | 0,027 |
| 29,5 ± 2,5 | 0,333 | 0,0I7 | 0,029 |
| 30,7 ± 2,7 | 0,346 | 0,0I9 | 0,03I |
| 32,I ± 2,8 | 0,350 | 0,0I9 | 0,03I |
| 33,4 ± 3,0 | 0,342 | 0,0I8 | 0,030 |
| 34,9 ± 3,2 | 0,350 | 0,0I7 | 0,030 |
| 36,5 ± 3,4 | 0,340 | 0,020 | 0,03I |
| 38,2 ± 3,7 | 0,346 | 0,0I9 | 0,03I |
| 40,0 ± 3,9 | 0,332 | 0,0I9 | 0,030 |
| 42,0 ± 4,2 | 0,335 | 0,0I9 | 0,030 |
| 44,I ± 4,6 | 0,308 | 0,0II | 0,025 |
| 46,3 ± 4,9 | 0,307 | 0,0I6 | 0,027 |

Table 1 (continued)

| $E_n$ , keV | $\alpha$ | $\sigma_\alpha$ rel. to trend | $\sigma_\alpha$ total error |
|---|---|---|---|
| 48,8 ± 5,3 | 0,300 | 0,017 | 0,027 |
| 51,4 ± 5,7 | 0,285 | 0,016 | 0,026 |
| 54,3 ± 6,2 | 0,288 | 0,018 | 0,027 |
| 57,4 ± 6,8 | 0,277 | 0,015 | 0,025 |
| 60,8 ± 7,4 | 0,292 | 0,013 | 0,025 |
| 90 ± 15 | 0,307 | 0,020 | 0,030 |
| 135 ± 25 | 0,247 | 0,015 | 0,024 |
| 185 ± 15 | 0,218 | 0,010 | 0,019 |
| 300 ± 10 | 0,181 | 0,011 | 0,018 |
| 400 ± 10 | 0,183 | 0,010 | 0,018 |
| 500 ± 10 | 0,150 | 0,006 | 0,014 |
| 750 ± 30 | 0,127 | 0,011 | 0,012 |
| 900 ± 30 | 0,101 | 0,010 | 0,014 |
| 1100 ± 30 | 0,077 | 0,009 | 0,013 |

Table 2

Value of $\alpha$ for $^{239}Pu$, obtained in the present study

| $E_n$ , keV | $\alpha$ | $\sigma_\alpha$ rel. to trend | $\sigma_\alpha$ total error |
|---|---|---|---|
| 9,4 ± 0,5 | 0,502 | 0,079 | 0,085 |
| 10,4 ± 0,5 | 0,508 | 0,058 | 0,067 |
| 11,3 ± 0,6 | 0,572 | 0,041 | 0,055 |
| 12,2 ± 0,7 | 0,517 | 0,068 | 0,076 |
| 13,1 ± 0,7 | 0,538 | 0,077 | 0,084 |
| 14,2 ± 0,8 | 0,478 | 0,037 | 0,048 |
| 15,2 ± 0,9 | 0,418 | 0,054 | 0,061 |
| 15,9 ± 1,0 | 0,366 | 0,038 | 0,045 |
| 16,4 ± 1,0 | 0,342 | 0,042 | 0,049 |
| 16,8 ± 1,1 | 0,331 | 0,032 | 0,040 |
| 17,3 ± 1,1 | 0,325 | 0,028 | 0,037 |
| 17,9 ± 1,2 | 0,329 | 0,030 | 0,038 |
| 18,4 ± 1,2 | 0,316 | 0,026 | 0,035 |
| 19,2 ± 1,3 | 0,328 | 0,031 | 0,039 |

Table 2 (continued)

| $E_n$ , keV | $\alpha$ | σα rel. to trend | σα total error |
|---|---|---|---|
| I9,6 ± I,4 | 0,340 | 0,025 | 0,034 |
| 20,3 ± I,4 | 0,352 | 0,032 | 0,040 |
| 20,9 ± I,5 | 0,346 | 0,02I | 0,032 |
| 2I,6 ± I,6 | 0,369 | 0,0I8 | 0,030 |
| 22,4 ± I,7 | 0,348 | 0,0I5 | 0,029 |
| 23,2 ± I,7 | 0,346 | 0,022 | 0,033 |
| 24,0 ± I,8 | 0,320 | 0,0I8 | 0,029 |
| 24,8 ± I,9 | 0,3I6 | 0,0I5 | 0,027 |
| 25,8 ± 2,0 | 0,330 | 0,022 | 0,032 |
| 26,7 ± 2,2 | 0,302 | 0,0I7 | 0,027 |
| 27,8 ± 2,3 | 0,293 | 0,0I5 | 0,026 |
| 28,8 ± 2,4 | 0,282 | 0,02I | 0,030 |
| 30,0 ± 2,6 | 0,247 | 0,0II | 0,022 |
| 3I,2 ± 2,7 | 0,258 | 0,0II | 0,022 |
| 32,5 ± 2,9 | 0,272 | 0,0I2 | 0,024 |
| 33,9 ± 3,I | 0,286 | 0,0I6 | 0,026 |
| 35,3 ± 3,3 | 0,260 | 0,0I5 | 0,025 |
| 36,9 ± 3,5 | 0,260 | 0,009 | 0,022 |
| 38,6 ± 3,4 | 0,243 | 0,0II | 0,022 |
| 40,4 ± 4,0 | 0,247 | 0,0I4 | 0,024 |
| 42,3 ± 4,3 | 0,240 | 0,0I0 | 0,02I |
| 44,3 ± 4,6 | 0,225 | 0,007 | 0,020 |
| 46,5 ± 4,9 | 0,2I3 | 0,006 | 0,0I9 |
| 48,9 ± 5,3 | 0,207 | 0,009 | 0,020 |
| 5I,4 ± 5,7 | 0,I93 | 0,007 | 0,0I8 |
| 54,2 ± 6,2 | 0,I76 | 0,008 | 0,0I8 |
| 57,2 ± 6,7 | 0,I74 | 0,007 | 0,0I8 |
| 60,4 ± 7,3 | 0,I70 | 0,005 | 0,0I7 |
| 64 ± 8,0 | 0,I72 | 0,006 | 0,0I7 |
| II0 ± 20 | 0,I49 | 0,007 | 0,0I5 |
| I50 ± 25 | 0,II5 | 0,0I0 | 0,0I6 |
| I85 ± I5 | 0,090 | 0,009 | 0,0I5 |
| 300 ± I0 | 0,I03 | 0,0I2 | 0,0I8 |
| 400 ± I0 | 0,075 | 0,009 | 0,0I5 |
| 500 ± I0 | 0,082 | 0,0I0 | 0,0I5 |
| 750 ± 30 | 0,07I | 0,009 | 0,0I5 |
| 900 ± 30 | 0,032 | 0,006 | 0,0I2 |
| I00 ± 30 | 0,008 | 0,0I3 | 0,0I7 |

## NEUTRON YIELD AND KINETIC ENERGY OF FRAGMENTS IN THERMAL FISSION OF $^{249}$Cf

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(Submitted to Jadernaja Fizika)

Measurements were made of the mean number of prompt neutrons ($\bar{\nu}$ = 4.06 $\pm$ 0.04) and the mean kinetic energy of the fragments ($\bar{E}_k$ = 187.3 $\pm$ 1.5 MeV) for thermal neutron fission of $^{249}$Cf. The dependence of $\bar{\nu}$ and $\bar{E}_k$ on the nucleonic composition of the fissioning nucleus is discussed.

## THE GENETIC CONNECTION BETWEEN DELAYED NEUTRON RADIATION AND THE FISSION PROCESS

B.P. Maksyutenko

The genetic connection between delayed neutron radiation and the fission process is considered. A method is developed, by which it is possible, on the basis of data for the relative delayed neutron yield from the thermal fission of $^{235}$U, to calculate quite accurately the number of prompt fission neutrons and the dispersion of the distribution of the number of prompt fission neutrons. It is shown that this method can be employed for calculating the same values for fast fission.

After analysing the relationships of the fission product charge and the cumulative yields, the author examines the correlation between the number of prompt fission neutrons emitted and fragment mass. The width of the excitation energy distribution during fission is found. The following results are obtained:

$\bar{\nu}$ = 2.55 (mean number of prompt fission neutrons produced in thermal fission of $^{235}$U);

Dispersion: $\sigma_\nu$ = 1.30.

# CROSS-SECTIONS FOR THE FORMATION OF GAMMA RAYS DURING INELASTIC SCATTERING OF NEUTRONS IN THE SPECTRUM OF A URANIUM-WATER REACTOR

A.T. Bakov, V.G. Dvukhsherstnov, Yu.A. Kazansky

The mean gamma ray yield cross-sections (separate lines or groups of unresolved lines) were measured in the neutron spectrum of a uranium-water reactor $\varphi(E_n)$ for Na, Al, Ti, V, Mn, Fe, Ni, Cu, Zn, Zr, W, Pl, Bi and $^{238}U$, using a single-crystal scintillation gamma ray spectrometer with neutron discrimination according to de-excitation time. Since the cross-sections $\langle\sigma_{\gamma i}\rangle$ depend essentially on the type of neutron spectrum, the authors propose a more conservative system for calculating the quantity of gamma rays from inelastic scattering in a neutron spectrum different from that used in this experiment, i.e. a system involving a quantity which is less dependent on the shape of the neutron spectrum:

$$\langle \xi_{\gamma i} \rangle = \frac{\int_{lim}^{\infty} \varphi(E_n)\, \sigma_{\gamma i}(E_n) dE_n}{\int^{\infty} \varphi(E_n)\, \sigma_{in}(E_n) dE_n}$$

where $E_{lim}$ is the neutron energy, at which the emission of gamma rays of energy $E_\gamma$ is possible in inelastic scattering of neutrons of energy $E_n \geqslant E_{lim}$.

## CORRECTION FOR MULTIPLE NEUTRON SCATTERING IN "THIN" SPECIMENS

V.S. Shorin

(Preprint, Institute of Physics and Power Engineering)

The effects of multiple neutron scattering are considered on the basis of a one-velocity approximation of "initial collisions". The analysis concerns cylindrical samples with a thickness of $\Sigma t \leqslant 0.25$ subjected to wide plane-parallel neutron flux.

## ELECTRONIC EQUIPMENT FOR AN EXPERIMENT TO MEASURE THE RADIATIVE CAPTURE TO FISSION CROSS-SECTION RATIO IN THE FAST NEUTRON REGION

E.D. Poletaev, V.N. Kononov, M.V. Bokhovko

The authors describe the electronic equipment used in an experiment to make absolute measurements of the radiative capture to fission cross-section ratios for $^{239}Pu$ and $^{235}U$ in the 10 keV-1 MeV energy region on a pulsed Van de Graaff accelerator. The equipment provides a means of identifying capture and fission events and measuring neutron energy from the time-of-flight.

I.V. KURCHATOV ATOMIC ENERGY INSTITUTE

# THE ENERGY DEPENDENCE OF $\bar{\nu}$ FOR THE FISSION OF $^{238}U$ BY FAST NEUTRONS

(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

M.V. Savin, Yu.A. Khokhlov, I.N. Paramonova, V.A. Chirkin

The results are given of measurements of $\bar{\nu}$ in fission of $^{238}U$ by neutrons with energies of 1.3-7 MeV. The measurements were performed in a linear electron accelerator by the time-of-flight method (resolution 1 nsec/m), use having been made of a liquid scintillation detector. The energy dependence of $\bar{\nu}(E)_n$ measured in the experiment is described by a broken line with two gradients of $\frac{d\bar{\nu}}{dE_n} = 0.10$ for $E_n < 3$ MeV and $\frac{d\bar{\nu}}{dE_n} = 0.18$ for $E_n > 3$ MeV. The accuracy of determining absolute values of $\bar{\nu}$ is 1.5-3% in this particular energy range.

Table 1

The average number of prompt neutrons in fission of $^{238}U$

| $E_n$ /MeV/ | $\bar{\nu}$ | $E_n$ /MeV/ | $\bar{\nu}$ | $E_n$ /MeV/ | $\bar{\nu}$ |
|---|---|---|---|---|---|
| I,27 | 2,503 ± 0,055 | 2,I8 | 2,6I0 ± 0,039 | 3,80 | 2,680 ± 0,057 |
| I,30 | 2,498 ± 0,052 | 2,24 | 2,6I8 ± 0,042 | 3,94 | 2,886 ± 0,058 |
| I,33 | 2,544 ± 0,05I | 2,3I | 2,653 ± 0,042 | 4,09 | 2,9II ± 0,06I |
| I,35 | 2,575 ± 0,049 | 2,37 | 2,679 ± 0,043 | 4,24 | 2,876 ± 0,058 |
| I,42 | 2,59I ± 0,046 | 2,44 | 2,708 ± 0,043 | 4,50 | 2,98I ± 0,057 |
| I,45 | 2,59I ± 0,046 | 2,5I | 2,652 ± 0,042 | 4,86 | 3,023 ± 0,057 |
| I,48 | 2,5I8 ± 0,045 | 2,59 | 2,609 ± 0,044 | 5,39 | 3,095 ± 0,080 |
| I,5I | 2,470 ± 0,044 | 2,66 | 2,630 ± 0,045 | 5,62 | 3,I86 ± 0,092 |
| I,55 | 2,467 ± 0,042 | 2,74 | 2,6I3 ± 0,044 | 5,87 | 3,I84 ± 0,092 |
| I,58 | 2,576 ± 0,044 | 2,83 | 2,66I ± 0,045 | | |
| I,62 | 2,577 ± 0,04I | 2,92 | 2,644 ± 0,047 | | |
| I,70 | 2,639 ± 0,042 | 3,II | 2,689 ± 0,048 | | |

Table 1 (continued)

| En /MeV/ | $\bar{\nu}$ | En /MeV/ | $\bar{\nu}$ | En /MeV/ | $\bar{\nu}$ |
|---|---|---|---|---|---|
| I,78 | 2,552 ± 0,04I | 3,2I | 2,72I ± 0,049 | | |
| I,82 | 2,589 ± 0,04I | 3,32 | 2,72I ± 0,049 | | |
| I,87 | 2,586 ± 0,04I | 3,43 | 2,8I2 ± 0,053 | | |
| I,92 | 2,543 ± 0,04I | 3,55 | 2,778 ± 0,053 | | |
| I,97 | 2,62I ± 0,039 | 3,68 | 2,8I9 ± 0,056 | | |
| 2,02 | 2,59I ± 0,039 | | | | |
| 2,07 | 2,587 ± 0,04I | | | | |
| 2,I3 | 2,6I2 ± 0,039 | | | | |

## MEASUREMENT OF THE CAPTURE TO FISSION CROSS-SECTION RATIO FOR $^{235}U$

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Yu.D. Molchanov, G.B. Yankov

The development of fast reactors has made it necessary to provide more accurate values of $\alpha = \sigma_{ne}/\sigma_{nf}$, especially in the neutron energy range from a few keV to 100 keV. It was desirable to use a different measuring technique from that used earlier by other authors [1-6], in order to avoid the systematic errors produced.

In our work the α-values for $^{235}U$ were measured by a direct method in the 5-50 keV and 130 keV neutron energy ranges.

### Experimental method

The measurements were performed in an electrostatic accelerator under pulsed operating conditions [7].

A sample of 90% enriched $^{235}U$ with a thickness of 0.0089 atoms per barn was irradiated with neutrons from the $^{7}Li(p,n)$ reaction. The neutron energy was determined by the time-of-flight method over 37 cm with a resolving time of 8 nsec.

The energy dependence of the coefficient α was determined from the relative yield of capture gamma rays and fission neutrons. The fast neutrons and gamma rays were recorded by three 5 x 5 cm stilbene detectors. To reduce background, the sample and the crystals were placed inside a shield containing lead, lithium-6 and paraffin. The signals corresponding to the neutrons and the gamma rays were distinguished by the pulse shape [8]. Transmission of gamma pulses to the neutron channel did not exceed 0.01% at a pulse rate of $10^3$ pulses per second.

Under these conditions the number of gamma rays $N_\gamma$ and neutrons $N_n$ recorded over a given time interval is expressed by:

$$N_\gamma = \varepsilon_{\gamma c} n_e + \varepsilon_{\gamma f} n_f ; \quad N_n = \varepsilon_n n_f$$

where $n_e$ and $n_t$ are the number of capture and fission events, $\varepsilon_{\gamma c}$ is the efficiency of recording a capture event, and $\varepsilon_{\gamma f}$ and $\varepsilon_n$ are the efficiency of recording a fission event for gamma rays and neutrons respectively. Then

$$\alpha = \frac{n_e}{n_f} = \left(\frac{N_\gamma}{N_n} - \frac{\varepsilon_{\gamma f}}{\varepsilon_n}\right) \bigg/ \frac{\varepsilon_{\gamma c}}{\varepsilon_n}$$

is determined, if $\frac{\varepsilon_{\gamma c}}{\varepsilon_n}$ and $\frac{\varepsilon_{\gamma f}}{\varepsilon_n}$ are known. For measuring $\frac{\varepsilon_{\gamma f}}{\varepsilon_n}$ the authors used the coincidences between fission fragments and fission gamma rays and between fragments and fission neutrons. For this purpose the uranium sample was placed throughout the experiment between two thin uranium layers ($2 \times 10^{-6}$ at/b) inside the gas scintillation chamber recording the fission fragments. The value of $\frac{\varepsilon_{\gamma c}}{\varepsilon_n}$ was obtained by normalization, using the value $\alpha = 0.375 \pm 0.032$ [6] for the neutron energy range 29-34 keV.

Pulses corresponding to fission neutrons in the energy range 0.5-8 MeV were recorded in one group of channels of an AI-4096 analyser and pulses from gamma rays in the range 0.5-3 MeV in another group. The gamma rays were detected in two ways: either by recording individual gamma rays (summation of signals from separate counters) or by recording coincidences of signals in any two out of three counters.

## Measurements and results

The background was measured from the counting level in channels outside the neutron spectrum employed and was also checked by replacing the uranium sample in the chamber with a lead one. During the measurements the background was stable. In the neutron group it was 60%, 20% and 2% for neutron energies of 5, 10 and 40 keV respectively. The gamma ray background during recording of coincidences was 75, 40 and 5% for the same neutron energy values. During recording based on the summation technique the background was 20% at 40 keV increasing with decrease in neutron energy to a level of 80% at 8 keV. Therefore, when the summation method was being used, α was not determined below neutron energies of 8 keV.

Table 1 shows the values of α obtained as well as the associated errors, which include both statistical and systematic errors with the exception of the inaccuracy in the value used at 30 keV. The data obtained using the coincidence system are in the second and third columns, whilst the summation data are in the fourth and fifth columns. The values for α in the range 5-50 keV were obtained on a continuous neutron spectrum but in the measurements at 130 keV monoenergetic neutrons were used.

The measured values of alpha were corrected for the effect of gamma ray absorption by the sample (< 3%), and also for $^{238}U$ content in the sample (< 1%). In the experiment it was assumed that the efficiency of recording gamma rays is independent of the incident neutron energy. This is in accord with the fact that the summation data agree with the coincidence data.

The results obtained here for the range 10-50 keV and 130 keV agree with the data in Refs [1, 3, 6, 10] but in the range below 10 keV the values given here are 15-25% higher than those in Refs [10, 11].

In conclusion, the authors wish to thank G.A. Otroshchenko for his assistance in the work.

Table 1

Alpha values for $^{235}U$

| Averaging interval keV | Coincidence method | | Summation method | |
|---|---|---|---|---|
| | | | | |
| 5,0 - 6,0 | 0,38 | 0,II | | |
| 6,0 - 7,0 | 0,44 | 0,I0 | | |
| 7,0 - 8,0 | 0,46 | 0,09 | | |
| 8,0 - 9,0 | 0.42 | 0,07 | 0,38 | 0,05 |
| 9,0 - I0,0 | 0,40 | 0,07 | 0,35 | 0,05 |
| I0,0 - II,0 | 0,38 | 0,06 | 0,35 | 0,04 |
| II,0 - I2,0 | 0,44 | 0,05 | 0,45 | 0,04 |
| I2,0 - I3,3 | 0,38 | 0,05 | 0,38 | 0,03 |
| I3,3 - I4,8 | 0,35 | 0,04 | 0,36 | 0,02 |
| I4,8 - I6,7 | 0,40 | 0,03 | 0,37 | 0,02 |
| I6,7 - I8,8 | 0,39 | 0,03 | 0,38 | 0,02 |
| I8,8- 2I,5 | 0,36 | 0,03 | 0,38 | 0,0I |
| 2I,5 - 24,7 | 0,37 | 0,03 | 0,38 | 0,0I |
| 24,7 - 28,7 | 0,34 | 0,02 | 0,37 | 0,0I |
| 28,7 - 33,8 | 0,375 | 0,02 | 0,375 | 0,0I |
| 33,8 - 40,3 | 0,37 | 0,02 | 0,38 | 0,0I |
| 40,3 - 49,0 | 0,38 | 0,02 | 0,38 | 0,02 |
| I30 ± I0 | 0,28 | 0,06 | 0,3I | 0,02 |

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# ANGULAR DISTRIBUTION OF FRAGMENTS AND THE CROSS-SECTION FOR NEUTRON-INDUCED FISSION OF $^{238}U$ CLOSE TO THE THRESHOLD

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The angular distribution of fragments and the cross-section for neutron-induced fission of $^{238}U$ were measured in the energy range $E_n$ = 0.55–1.45 MeV. The energy resolution was 20 keV and the angular resolution 12°. The measurements were performed in an electrostatic accelerator, the neutron source being a solid tritium target. The fragments were detected by glasses placed at angles of 0, 30, 60 and 90° relative to the incident neutron beam. The neutron flux was recorded with a boron counter having uniform sensitivity to the neutrons used in the measurements. The $^{238}U$ sample had an impurity content of ≈ 0.01% $^{235}U$ and a deduction was made in the calculations for the effect of fission of $^{235}U$. The results are shown in the tables.

Table 1

Cross-section for neutron-induced fission of $^{238}U$

The relative measuring error is shown here; the absolute value of the cross-section for $E_n$ = 1.0 MeV is taken from "Neutron Cross-Sections" by D.J. Hughes (BNL-325).

| $E_n$ | $\sigma_f$ | $\Delta\sigma_f$ | $E_n$ | $\sigma_f$ | $\Delta\sigma_f$ |
|---|---|---|---|---|---|
| MeV | mb | mb | MeV | mb | mb |
| 0,55 | 0,I8 | 0,09 | I,05 | I8,7 | I,I |
| 0,60 | 0,65 | 0,07 | I,I0 | 24,8 | I,5 |
| 0,65 | 0,87 | 0,08 | I,I5 | 3I,3 | 2,0 |
| 0,72 | 2,I0 | 0,I5 | I,20 | 39,7 | 2,0 |
| 0,76 | 2,7 | 0,2 | I,25 | 43,5 | 2 |
| 0,80 | 4,3 | 0,3 | I,30 | 6I | 3 |
| 0,85 | 7,9 | 0,5 | I,35 | 97 | 6 |
| 0,90 | I3,2 | 0,8 | I,40 | I70 | I0 |
| 0,95 | I8,I | I,0 | I,45 | 237 | I4 |
| I,00 | I7,8 | I,0 | | | |

Table 2

Angular distribution of fragments from neutron-induced fission of $^{238}U$

The subscript on W denotes the mean square angle of recording of the fragments. The values given in the table are ratios of the counts of a detector set at 90°. The error for each ratio is indicated.

| $E_n$ | $W_{14°}$ | $W_{34°}$ | $W_{60°}$ | $\Delta W$ |
|---|---|---|---|---|
| MeV | rel. units | | | % |
| 0,60 | I,II | 0,97 | I,I0 | I5 |
| 0,65 | I,29 | I,30 | I,I6 | I2 |
| 0,72 | I,50 | I,26 | I,03 | I5 |
| 0,76 | I,28 | I,28 | 0,96 | I2 |
| 0,80 | I,32 | I,04 | I,03 | 8 |
| 0,85 | I,I8 | I,27 | I,I6 | 6 |
| 0,90 | I,44 | I,32 | I,00 | 6 |
| 0,95 | I,52 | I,29 | I,I9 | 6 |
| I,00 | I,4I | I,57 | I,I9 | 6 |
| I,05 | I,2I | I,I8 | I,I6 | 6 |
| I,I0 | I,04 | I,00 | 0,96 | 6 |
| I,I5 | I,50 | I,36 | I,I5 | 5 |
| I,20 | I,67 | I,3I | I,I7 | 5 |
| I,25 | I,40 | I,29 | I,I3 | 5 |
| I,30 | I,32 | I,26 | I,I0 | 5 |
| I,35 | I,32 | I,I6 | I,03 | 5 |
| I,40 | I,39 | I,2I | I,0I | 4 |
| I,45 | I,50 | I,33 | I,I0 | 5 |

# NEUTRON RESONANCES OF $^{112}$Cd

Yu.G. Shchepkin, G.V. Muradyan, Yu.V. Adamchuk

Measurements have been performed to identify the S and P levels [1,2] and to establish the total cross-section, the radiative capture cross-section and the self-indication of the isotope $^{112}$Cd [3, 4]. The authors have determined the orbital angular momenta for levels in the range up to 3 keV and the values of $E_0$, $g\Gamma_n$ and $\Gamma_\gamma$ up to 4 keV. (See Table 1).

A specific orbital angular momentum has been assigned to 23 of the 29 levels observed. The values of the strength functions $S_0$ and $S_1$ have been determined with allowance for the probability of identification and take the form:

$$S_0 = (0.72 ^{+0.40}_{-0.23}) \times 10^{-4};$$

$$S_1 = (3.9 ^{+1.9}_{-1.3}) \times 10^{-4}$$

The values of the radiation widths $\Gamma_\gamma$ are found with an accuracy of ~ 15% for 12 energy levels. The mean value $\Gamma_\gamma$ = 80 ± 4 MeV is comparable with the results of calculations based on different models.

Table 1

Neutron resonance parameters of $^{112}$Cd

| № | $E_0$ eV | $g\Gamma_n^0$ meV | $\Delta(g\Gamma_n^0)$ % | $\Gamma_\gamma$ meV | $\Delta\Gamma_\gamma$ % | $\varphi_s$ % | $K$ % |
|---|---|---|---|---|---|---|---|
| I | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| I. | 66,9I | I,I6 | 5 | 52 | I5 | I00 | I7,4 |
| 2. | 82,43 | 0,00485 | I0 | | | 50*) | |
| 3. | 83,27 | 0,0503 | 8 | | | I7 | I,64 |
| 4. | I54,4 | 0,00379 | 20 | | | 50*) | |
| 5. | 227,I | I,424 | 7 | 94 | 25 | I00 | 28 |
| 6. | 284,5 | 0,0089 | 25 | | | 50*) | |
| 7. | 444,7 | 2,89 | 8 | 9I | 22 | I00 | 39,3 |
| 8. | 455,5 | 0,I82 | I0 | | | 25 | 3,4 |

* Level parity not identified.

Table 1 (continued)

| I | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 9. | 570,7 | 0,II7 | 20 | | | 70 | I,9 |
| I0. | 743,3 | II,I6 | 5 | 77 | I3 | I00 | 40 |
| II. | 902,4 | 0,I67 | 20 | | | 60 | 2,2 |
| I2. | 9I7,9 | I0,22 | 6 | 79 | I2 | I00 | 45 |
| I3. | I064 | 0,3I8 | I2 | | | I5 | 4,I |
| I4. | II25 | 22,6 | 6 | 86 | I4 | I00 | 30 |
| I5. | I224 | 0,743 | I5 | | | I0 | 9,2 |
| I6. | I355 | 0,925 | I5 | | | 0 | II |
| I7. | I443 | 22,6 | 7 | 88 | I4 | I00 | 33 |
| I8. | I662 | 0,54 | 23 | | | 88 | 5,5 |
| I9. | I727 | I0,I | 5 | 88 | I5 | I00 | 5I |
| 20. | I84I | 0,745 | I8 | | | 75 | 7,3 |
| 2I. | I983 | I,35 | 20 | | | 0 | I3,2 |
| 22. | 2068 | 37,4 | 9 | 94 | I6 | I00 | 25 |
| 23. | 2268 | 0,84 | 35 | | | 52 | 7,4 |
| 24. | 2384 | 2I,5 | I0 | 95 | I6 | I00 | 4I |
| 25. | 2498 | 0,8 | 35 | | | 60 | 6,6 |
| 26. | 2620 | 32,2 | 9 | 92 | I6 | I00 | 3I |
| 27. | 275I | 40,0 | 7 | II2 | I6 | I00 | 27 |
| 28. | 2878 | I,49 | 25 | | | 0 | I2 |
| 29. | 30I3 | 8,72 | 27 | | | 0 | 49 |
| 30. | 3I75 | 8,9 | 30 | | | | |
| 3I. | 3243 | I,58 | 50 | | | | |
| 32. | 33I5 | I,04 | 35 | | | | |
| 33. | 3387 | 8,93 | 25 | | | | |
| 34. | 350I | I,I8 | 30 | | | | |
| 35. | 358I | 4,I9 | I5 | | | | |
| 36. | 379I | 2,II | 30 | | | | |
| 37. | 388I | 3,2I | 30 | | | | |
| 38. | 3975 | 4,I2 | 23 | | | | |

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# INVESTIGATION OF THE NEUTRON WIDTHS AND THE NEUTRON ORBITAL ANGULAR MOMENTUM FOR LEVELS OF $^{121}Sb$ AND $^{123}Sb$

Yu.V. Adamchuk, G.V. Muradyan, Yu.G. Shchepkin

The authors have obtained values for the neutron strength functions $S_0$ and $S_1$. To this end measurements were performed, to determine the orbital angular momentum of the interaction of a bombarding neutron with a nucleus, using the moving sample method, and measurements were also made of the total cross-section and the neutron capture cross-section in order to determine the neutron widths.

All the measurements were performed over a 37 metre flight path [1] in the linear electron accelerator at the Atomic Energy Institute: the mean neutron yield is ~ 2 x $10^{12}$ n/sec and the pulse length 0.2 μsec. The resolution of the spectrometer is 11 nsec/m.

The spectrometer detector consists of two 200 x 100 mm NaI(Tl) crystals, which are shielded on the side facing the sample by a layer of boron-10 with a thickness of ~ 4.5 g/$cm^2$.

The measurements to identify the levels in terms of the orbital angular momentum were performed using the moving sample method [2]. The velocity V = 140 m/sec. The thickness of the samples used for transmission was $n_T$ = 0.0455 at/b ($^{121}Sb$) and $n_T$ = 0.0358 at/b ($^{123}Sb$), and of the samples in the detector $n_D$ = 0.0075 at/b ($^{121}Sb$) and $n_D$ = 0.0067 at/b ($^{123}Sb$) with ~ 98.5% enrichment. The measurements on each isotope lasted approximately 300 hours.

The results of the measurements were recorded in the form of a dependence of the number of counts of neutron capture events in the detector sample after transmission of the neutron beam through the moving sample.

Fig. 1 shows an example of the measurements of $^{123}Sb$ with curves A and B representing the movement of the sample in and against the direction of the neutron beam respectively.

When the moving sample was outside the neutron beam, measurements were made of the capture cross-section (curves C and D in Fig. 1), the latter measurements being used, firstly, for determining the level parameters, secondly for normalizing the series of measurements, which correspond to movement of the sample with and against the beam, to a single flux and, thirdly, for finding the value of the asymmetry $\Delta A_{\gamma}^{theor}$, assuming an S-interaction, which is to be expected in measurements of neutron capture after passage through the moving sample. By comparing the difference in areas $\Delta A_{\gamma}^{exp}$ under the resonances on the two lower curves with the expected value of $\Delta A_{\gamma}^{theor}$ and zero, one can assign levels to S or P interactions.

The asymmetry coefficient $K = \frac{2(A_{\gamma}^{(+)theor} - A_{\gamma}^{(-)theor})}{A_{\gamma}^{(+)theor} + A_{\gamma}^{(-)theor}}$ and the ratio

$\frac{2 \cdot A_{\gamma}^{(o)theor}}{A_{\gamma}^{(+)theor} + A_{\gamma}^{(-)theor}}$ used for determining $\Delta A_{\gamma}^{theor}$ were calculated for each level by computer. The areas under the resonances $A^{(+)theor}$, $A_{\gamma}^{(-)theor}$ and $A_{\gamma}^{(o)theor}$ ($A_{\gamma}^{(o)theor}$ is the area under the resonance in the capture cross-section) were calculated in the range $\Delta E = 600 . \Gamma . \delta x$ ($\delta x$ is the integration step) on the basis of measured values of $\Gamma_n$. The radiation width ($\Gamma_{\gamma}$) and the potential cross-section ($\sigma p$) were assumed to be 100 meV and 4.3 b respectively. Tables 1 and 2 show the results of identification of levels with respect to $\ell$ in the form of the probability $\varphi_s$ that the level is due to an S-interaction. As can be seen from the tables, $\ell$ was determined in the majority of cases.

Neutron width determinations and isotopic identification have been performed in Ref. [3]. In our measurements we have defined more precisely the values of $2g\Gamma_n$, for which purpose we carried out transmission measurements on the same spectrometer as our measurements to identify the levels with respect to $\ell$, using the same samples and covering the additional range of 6–240 eV.

The detector used in the level identification measurements has a background approximately 3–6 times lower than that in Refs [1, 3]. Thanks to this and the accumulation of measuring statistics on capture cross-sections (curves C and D in Fig. 1) about 20 levels were identified for $^{121}Sb$ and $^{123}Sb$.

On the basis of the level identification, the isotopic identification and the neutron width measurements, the authors calculated the neutron strength functions $S_o$ and $S_1$.

$$S_o = \begin{cases} (0.20 \pm^{0.03}_{0.02}) \cdot 10^{-4} & \text{for } Sb^{121} \\ (0.24 \pm^{0.06}_{0.05}) \cdot 10^{-4} & \text{for } Sb^{123} \end{cases}$$

$$S_1 = \begin{cases} (10.1 \pm^{3.7}_{2.6}) \cdot 10^{-4} & \text{for } Sb^{121} \\ (4.0 \pm^{2.5}_{1.3}) \ 10^{-4} & \text{for } Sb^{123} \end{cases}$$

In determining $S_1$ account was taken of the non-identified levels with small $\Gamma_n$ by using the Porter-Thomas distribution. The error calculations allow for both statistical errors and possible errors associated with identification.

Comparison of the values obtained for $S_0$ and $S_1$ with corresponding values calculated using the optical model shows that the experimental values of $S_0$ are in satisfactory agreement with the calculations of Ref. [4], in which absorption is removed ~ 0.5 fermi outside the nucleus. Compared with calculations for surface absorption in Ref. [5], the $S_0$ values obtained here are lower by a factor of six.

The S values for $^{123}$Sb agree within the error limits with calculations corresponding to the two potentials - with remote and surface absorption [4, 5]. For $^{121}$Sb the experimental value of $S_1$ is several times in excess of the theoretical value.

The value of the parameter $\nu$ of the Porter-Thomas distribution for the system of levels with $\ell = 0$ was determined:

$\nu = 1.35 \pm 0.21$ for $^{121}$Sb ($n = 93$) and $\nu = 1.07 \pm 0.29$ for $^{123}$Sb ($n = 43$) (n is the number of levels, $\Delta\nu = 2/\sqrt{n}$). It was assumed that the mean values of $2g\Gamma_n^{(o)}$ are uniform for the two spin systems.

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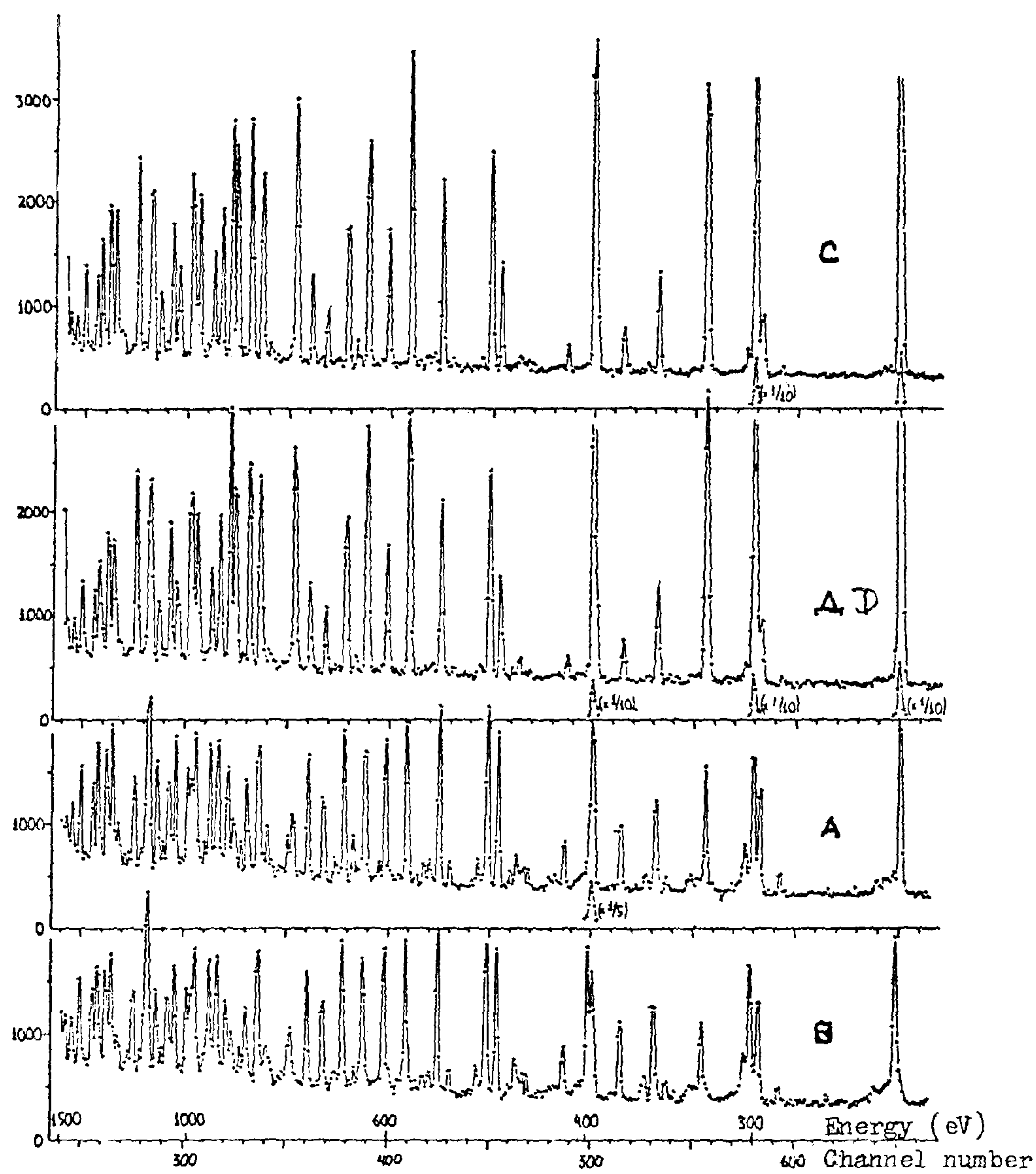


Fig. 1 Identification of $^{123}Sb$ levels for the orbital angular momentum of an incident neutron in the 220–1500 eV region.

Table 1

Results of measurements of $^{121}Sb$

| No. | $E_o$ eV | $2g\Gamma_n^{(o)}$ meV | $\Delta(2g\Gamma_n^{(o)})$ % | $\varphi_s$ % | $K$ % |
|---|---|---|---|---|---|
| I | 2 | 3 | 4 | 5 | 6 |
| I. | 6,24 | 0,8 | 5 | I00 | |
| 2. | I5,40 | I,76 | 6 | I00 | |
| 3. | 29,55 | I,2 | 20 | I00 | 7,2 |
| 4. | 37,77 | 0,002I | 30 | 50*/ | - |
| 5. | 47,I3 | 0,0I | 20 | 50*/ | - |
| 6. | 53,50 | 0,275 | 4 | I00 | 6,3 |
| 7. | 55,0I | 0,0067 | 20 | 50*/ | - |
| 8. | 64,40 | 0,084 | 4 | 98 | 2,5 |
| 9. | 73,73 | 0,82 | 6 | I00 | II,5 |
| I0. | 89,63 | I,0 | 25 | 50*/ | - |
| II. | 90,II | 0,58 | 25 | 50*/ | - |
| I2. | III,4 | 0,275 | 5 | I00 | 6,4 |
| I3. | I26,6 | 2,4 | I5 | I00 | I8,6 |
| I4. | I3I,9 | 0,92 | 7 | I00 | I4,4 |
| I5. | I44,4 | I,I5 | I5 | I00 | I6,2 |
| I6. | I49,8 | 2,42 | 4 | I00 | 20,4 |
| I7. | I58,8 | 0,0087 | 30 | 50*/ | - |
| I8. | I60,7 | 0,I25 | 7 | 90 | 2,6 |
| I9. | I67,0 | I,43 | I0 | I00 | I8,4 |
| 20. | I77,7 | 0,006 | 25 | 50*/ | - |
| 2I. | I85,0 | 0,0I4 | 20 | 50*/ | - |
| 22. | I92,3 | 0,I2 | 20 | 50*/ | - |
| 23. | 200,5 | 0,00035 | 30 | 50*/ | - |
| 24. | 2I4,2 | 0,086 | I0 | 55 | I,4 |
| 25. | 222,7 | 0,35 | I0 | I00 | 6,5 |
| 26. | 228,7 | 0,006 | 30 | 50*/ | - |
| 27. | 230,7 | 0,064 | I0 | 65 | I,I |
| 28. | 236,4 | 0,003 | 40 | 50*/ | - |
| 29. | 246,6 | 0,020 | 30 | 50*/ | - |

Table 1 (continued)

| I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 30. | 249,6 | 0,020 | 30 | 50*/ | - |
| 3I. | 262,3 | 0,0I2 | 30 | 50*/ | - |
| 32. | 266,4 | 0,0I4 | 30 | 50*/ | - |
| 33. | 270,5 | 0,0I6 | 25 | 50*/ | - |
| 34. | 274,8 | 0,0I7 | 20 | 50*/ | - |
| 35. | 282,7**/ | 0,007 | 50 | 50*/ | - |
| 36. | 287,2 | 0,83 | I0 | I00 | I3,6 |
| 37. | 293,7 | 0,006 | 30 | 50*/ | - |
| 38. | 307,0 | 0,0I5 | 30 | 50*/ | - |
| 39. | 3I0,2 | 0,I95 | I0 | 92 | 3,0 |
| 40. | 32I,2 | 0,032 | 25 | 50*/ | - |
| 4I. | 332,I | 0,I4I | 5 | 63 | 2,0 |
| 42. | 338,0**/ | 0,I8 | 40 | 50*/ | - |
| 43. | 339,5 | 0,52 | I0 | 50*/ | - |
| 44. | 348,I | 0,009 | 20 | 50*/ | - |
| 45. | 356,3 | 0,0I3 | 25 | 50*/ | - |
| 46. | 363,8 | 0,0I9 | 25 | 50*/ | - |
| 47. | 393,9 | I,3 | I0 | I00 | I8,0 |
| 48. | 407,I | 0,07 | I5 | 50*/ | - |
| 49. | 4I6,I | 0,038 | 20 | 50*/ | - |
| 50. | 422,2 | 0,54 | 8 | I00 | 7,7 |
| 5I. | 432,6 | 0,0096 | 50 | 50*/ | - |
| 52. | 444,9 | 2,I | 25 | 50*/ | - |
| 53. | 448,8 | I,68 | I5 | 50*/ | - |
| 54. | 45I,8 | 2,I | I5 | 50*/ | - |
| 55. | 455,5 | 7,0 | I5 | 50*/ | - |
| 56. | 463,6 | 0,084 | 30 | 50*/ | - |
| 57. | 47I,3 | 0,53 | I5 | I00 | 7,I |
| 58. | 476,6 | 0,028 | 30 | 50*/ | - |
| 59. | 483,3 | 0,068 | 30 | 50*/ | - |
| 60. | 499,2 | 0,38 | I5 | 80 | 4,9 |
| 6I. | 502,I | 0,058 | 30 | 50*/ | - |
| 62. | 5I0,8 | 0,03I | 30 | 50*/ | - |
| 63. | 535,9 | 0,38 | I0 | I00 | 4,I |
| 64. | 544,7 | 4,6 | 8 | I00 | 32,0 |

Table 1 (continued)

| I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 65. | 55I,2 | 0,034 | 40 | 50*/ | - |
| 66. | 560,4 | I,0 | 20 | I00 | I2,7 |
| 67. | 565,4 | 0,07 | 20 | 50*/ | - |
| 68. | 582,I | 0,04 | 30 | 50*/ | - |
| 69. | 589,I | 0,024 | 30 | 50*/ | - |
| 70. | 60I,3 | 0,I9 | I5 | 50*/ | - |
| 7I. | 607,5 | 2,5 | 6 | I00 | 29 |
| 72. | 6I5,2 | 0,52 | 5 | 35 | 6,2 |
| 73. | 632,5 | I,4 | I5 | I00 | I7,7 |
| 74. | 647,9 | 0,03 | 30 | 50*/ | - |
| 75. | 662,9 | I,08 | 7 | I00 | I2,8 |
| 76. | 672,8 | I,42 | I0 | 95 | I7,0 |
| 77. | 678,3 | 0,76 | I5 | 70 | 8,5 |
| 78. | 700,0 | 0,03 | 80 | 50*/ | - |
| 79. | 7I2,I | 0,7 | I0 | 55 | 7,2 |
| 80. | 7I5,8 | 0,09 | 30 | 50*/ | - |
| 8I. | 720,7 | I,2 | I5 | 95 | I4 |
| 82. | 73I,9 | 0,0I8 | 40 | 50*/ | - |
| 83. | 737,6 | 0,I6 | I5 | 50*/ | - |
| 84. | 754,0 | 0,0I | 50 | 50*/ | - |
| 85. | 763,0 | 0,02 | 50 | 50*/ | - |
| 86. | 774,7 | 2,8 | I0 | 0 | 27 |
| 87. | 792,0 | 0,86 | 20 | 50*/ | - |
| 88. | 797,7 | I,9 | 20 | 50*/ | - |
| 89. | 803,5 | 3,3 | 20 | 50*/ | - |
| 90. | 805,0 | 2,5 | 30 | 50*/ | - |
| 9I. | 84I,0 | 0,83 | I0 | I00 | 8 |
| 92. | 86I,5 | 0,52 | I5 | 95 | 5 |
| 93. | 857,0 | 0,02 | 40 | 50*/ | - |
| 94. | 892,I | 0,25 | 20 | 28 | 2,4 |
| 95. | 9I3,7 | 0,5 | 30 | 50*/ | - |
| 96. | 9I9,0 | 4,2 | 20 | I00 | 32 |
| 97. | 938,8 | 0,I3 | 25 | 50*/ | - |
| 98. | 949,8 | I,4 | I0 | I00 | I4 |
| 99. | 964,9 | I,35 | I0 | I00 | I3 |

Table 1 (continued)

| I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| I00. | 996,2 | 4,2 | I0 | 0 | 32 |
| I0I. | I0I6 | I,0 | I5 | 80 | 9,5 |
| I02. | I040 | 0,2 | 25 | 50*/ | - |
| I03. | I048 | 0,3 | 20 | 50*/ | - |
| I04. | I088 | 0,88 | I0 | 98 | 7,9 |
| I05. | III3 | 3,6 | I0 | I00 | 29 |
| I06. | II25 | 0,2 | 30 | 50*/ | - |
| I07. | II47 | 0,45 | 25 | 60 | 3,8 |
| I08. | II80 | 2,8 | 40 | 0 **/ I00 | 24 |
| I09. | II83 | 2,8 | 40 | I00 **/ 0 | 24 |
| II0. | I205 | I,9 | I5 | I00 | I6 |
| III. | I222 | 0,95 | 20 | 6 | 8,I |
| II2. | I255 | 2,8 | 30 | 25 | 2I |
| II3. | I262 | 0,35 | 20 | 50*/ | - |
| II4. | I3II | 2,98 | I0 | I00 | 23 |

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*/ Level parity not identified.

**/ Parameters taken from Ref. [4].

## Table 2

Results of measurements of $^{123}Sb$

| No. | $E_o$ eV | $2g\Gamma_n^{(o)}$ meV | $\Delta(2g\Gamma_n^{(o)})$ % | $\varphi_s$ % | $\varkappa$ % |
|---|---|---|---|---|---|
| I | 2 | 3 | 4 | 5 | 6 |
| I. | 2I,4 | 6,35 | 8 | I00 | - |
| 2. | 50,5 | 0,39 | 6 | I00 | 6,6 |
| 3. | 67 | 0,003 | I00 | 50*/ | - |
| 4. | 76,7 | 0,68 | I0 | I00 | I0,2 |
| 5. | I04,9 | 4,I5 | 5 | I00 | I5,4 |
| 6. | I3I,0 | 0,I04 | I0 | 70 | I,6 |
| 7. | I76,3 | 0,02I | 20 | 50*/ | - |
| 8. | I86,5 | 0,023 | 20 | 50*/ | - |
| 9. | I9I,8 | I,42 | I0 | I00 | I6,5 |
| I0. | I98,0 | 0,34 | 30 | 50*/ | - |
| II. | 2I9,0 | 0,30 | I0 | 60 | 4,3 |
| I2. | 225,8 | 0,02I | 25 | 50*/ | - |
| I3. | 236,4 | 0,02 | 25 | 50*/ | - |
| I4. | 24I,0 | I,3 | 8 | 98 | I7,7 |
| I5. | 296,7 | 0,087 | 20 | 65 | I |
| I6. | 300,0 | I,39 | 6 | I00 | I6,8 |
| I7. | 3I7 | 0,03 | 60 | 50*/ | - |
| I8. | 324,4 | I,87 | 5 | I00 | I9,8 |
| I9. | 332,I | 0,062 | 25 | 50*/ | - |
| 20. | 34I,5 | 0,034 | 30 | 50*/ | - |
| 2I. | 35I,5 | 0,332 | 6 | 88 | 3,93 |
| 22. | 374,2 | 0,I05 | 20 | 60 | I,I |
| 23. | 392,9 | 0,II6 | 20 | 56 | I,2 |
| 24. | 395,9 | I,9 | I5 | 94 | 2I,5 |
| 25. | 4I5,4 | 0,070 | 30 | 50*/ | - |
| 26. | 427,6 | 0,0I5 | 80 | 50*/ | - |
| 27. | 472,6 | 0,I94 | 6 | 70 | I,98 |
| 28. | 483,3 | 0,56 | I0 | I00 | 5,9 |
| 29. | 492,9 | 0,043 | 25 | 50*/ | - |
| 30. | 522,6 | 0,043 | 30 | 50*/ | - |

Table 2 (continued)

| I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 3I. | 533,5 | 0,556 | 7 | I00 | 5,62 |
| 32. | 55I,9 | 0,03 | 40 | 50*/ | - |
| 33. | 572,4 | I,67 | 20 | I00 | I7,I |
| 34. | 600,9 | 0,39 | 20 | 85 | 3,5 |
| 35. | 629,4 | I,3 | 20 | I00 | I2,6 |
| 36. | 645,8 | 0,054 | 30 | 50*/ | - |
| 37. | 660,7 | 0,75 | I0 | 94 | 6,9 |
| 38. | 698,2 | 0,I5 | 20 | 65 | I,2 |
| 39. | 702,6 | 0,034 | 50 | 50*/ | - |
| 40. | 7I9,4 | 0,2I | 25 | 68 | I,7 |
| 4I. | 749,8 | 7,I | I0 | I00 | 34 |
| 42. | 8I8,2 | I,55 | I0 | 72 | I2,6 |
| 43. | 842,6 | 3,4 | I0 | 97 | 26,3 |
| 44. | 874,6 | 7,8 | I0 | I00 | 32,8 |
| 45. | 887,9 | 2,9 | 5 | I00 | 22,2 |
| 46. | 896,3 | 0,097 | 25 | 50*/ | - |
| 47. | 9II,9 | 0,9 | 20 | 96 | 6,87 |
| 48. | 938,3 | 0,58 | I0 | I3 | 4,42 |
| 49. | 970,7 | I,I2 | 8 | I00 | 8,7I |
| 50. | 980,4 | 0,I6 | 30 | 50*/ | - |
| 5I. | 990,2 | 2,64 | I0 | I00 | I9,9 |
| 52. | I03I | 0,44 | 25 | 88 | 3,08 |
| 53. | I050 | I,79 | I0 | 25 | I3,6 |
| 54. | I086 | 0,36 | 20 | 50*/ | - |
| 55. | I094 | 0,I8 | 30 | 50*/ | - |
| 56. | III3 | 0,72 | 25 | 50*/ | - |
| 57. | II20 | 2,36 | I0 | 20 | I7 |
| 58. | II68 | 2,33 | 6 | 69 | I8 |
| 59. | I228 | 0,I7 | 35 | 50*/ | - |
| 60. | I239 | 0,I4 | 35 | 50*/ | - |
| 6I. | I253 | I,03 | I5 | 97 | 8,9 |
| 62. | I276 | I,3 | I0 | 99 | 8,65 |
| 63. | I3II | 0,78 | I5 | 32 | 4,95 |
| 64. | I333 | 0,52 | 30 | 43 | 3,23 |
| 65. | I387 | 0,49 | 20 | 80 | 2,93 |

*/ Level parity not identified.

# ELASTIC SCATTERING OF NEUTRONS BY $^{208}Pb$ AND THE OPTICAL NUCLEAR MODEL

V.M. Morozov, Yu.G. Zubov, N.S. Lebedeva

Measurements were made of the differential elastic scattering cross-sections of neutrons of energy 1.8 ± 0.2 MeV by a $^{208}Pb$ nucleus in the scattering angle range 12-168°. The cross-section $\sigma(\vartheta)$ was obtained in a beam of neutrons emitted by the reaction D-$^{12}C$ at an angle $\alpha_{rad} = 37°$ with a mean accelerated deuteron energy of 2.2 MeV. The cross-section $\sigma^{\varphi}(\vartheta)$ was measured in a neutron beam obtained from the first beam by passing it through a $^{208}Pb$ filter 124 mm thick (transparency 0.122) and differing from the first beam in that it was depleted by one or more orders of magnitude in neutrons corresponding to the resonances in the total cross-section for the interaction of neutrons with a $^{208}Pb$ nucleus.

The differential cross-section has a diffraction character and has no symmetry relative to 90°. Due to this some doubt is cast on the applicability of the theory concerning the existence of the two non-interfering processes of elastic scattering - potential scattering and scattering by the compound nucleus - at any rate in the range of isolated resonances of the nucleus. Attention is given to the relative displacement of the minima and maxima in the angular distributions of $\sigma(\vartheta)$, $\sigma^{\varphi}(\vartheta)$ and $\sigma(\vartheta) - \sigma^{\varphi}(\vartheta)$. The values for $\sigma(\vartheta)$, $\sigma^{\varphi}(\vartheta)$ and $\sigma(\vartheta) - \sigma^{\varphi}(\vartheta)$ are given in Table 1.

Table 1

| | | | |
|---|---|---|---|
| I2° | 2,I8 | I,84 | 0,34 ± 0,06 |
| 20° | I,84 | I,53 | 0,3I ± 0,05 |
| 30° | I,26 | I,06 | 0,20 ± 0,04 |
| 40° | 0,72 | 0,635 | 0,08 ± 0,02 |
| 50° | 0,346 | 0,3I5 | 0,03I ± 0,0I |
| 60° | 0,I47 | 0,I44 | 0,003 ± 0,004 |
| 70° | 0,095 | 0,086 | 0,009 ± 0,003 |
| 80° | 0,I35 | 0,I25 | 0,0I0 ± 0,004 |
| 90° | 0,225 | 0,I95 | 0,030 ± 0,006 |

Table 1 (continued)

| | | | |
|---|---|---|---|
| I00° | 0,320 | 0,298 | 0,022 ± 0,009 |
| II0° | 0,338 | 0,326 | 0,0I2 ± 0,009 |
| I20° | 0,3I9 | 0,309 | 0,0I0 ± 0,009 |
| I30° | 0,236 | 0,244 | 0,008 ± 0,007 |
| I40° | 0,I84 | 0,I67 | 0,0I7 ± 0,005 |
| I50° | 0,I86 | 0,I46 | 0,040 ± 0,005 |
| I60° | 0,247 | 0,I80 | 0,067 ± 0,006 |
| I68° | 0,3I4 | 0,223 | 0,09I ± 0,008 |

The statistical accuracy of measuring the cross-sections is ~ 2%. The absolute values of the cross-sections $\sigma(\vartheta)$ and $\sigma^{\varphi}(\vartheta)$ are determined relative to each other with an accuracy of ~ 4%. The accuracy of determining the absolute values of cross-sections is 7%.

## THE SENSITIVITY OF THE THERMAL UTILIZATION FACTOR TO VARIATIONS IN MACROSCOPIC CROSS-SECTIONS

N.I. Laletin

Estimates are made of the effect (influence factor) of different macroscopic cross-sections on the thermal utilization factor. This is determined as $K(\vartheta;\Sigma_i) = \frac{\delta\vartheta}{\vartheta}/\frac{\delta\Sigma_i}{\Sigma i}$. A one-velocity approximation is used. Simple formulae are obtained which provide a means of performing quantitative evaluations for a wide range of nuclei. The basic formulae are:

$$K(\theta;\Sigma_{af} \cong -\frac{1-\theta}{d}, \qquad (I)$$

$$K(\theta;\Sigma_{am}) \cong (1-\theta), \qquad (2)$$

$$K(\theta;\Sigma_{s,f}) \approx 0,4(1-\theta)\frac{Q-1}{d}\cdot\frac{\Sigma_{sf}}{\Sigma_f}, \qquad (3)$$

$$K(\theta;\Sigma_{sm}) \lessapprox 0.5\,\frac{\bar{\Phi}_m-\Phi_{bo}}{\bar{\Phi}_m}\,(1-\theta), \qquad (4)$$

$$K(\theta;\Sigma_{sm}^{(1)}) \lessapprox (1-\theta)\bar{\mu}\,\frac{\bar{\Phi}_m-\Phi_{bo}}{\bar{\Phi}_m}\,0.5, \qquad (5)$$

$$K(\theta;\Sigma_{sm}^{(n)}) \lessapprox 0.05\bar{\mu}(1-\theta) \qquad (6)$$

The following notation is employed:

$\vartheta$ is the thermal utilization factor;

$d = \frac{\bar{\Phi}_m}{\bar{\Phi}_f}$ is the ratio of the mean flux in the moderator $\bar{\varphi}_m$ to the mean flux in the fuel $\bar{\varphi}_f$ (disadvantage factor);

$\Sigma_{af}$ is the fuel absorption cross-section;

$\Sigma_{am}$ is the moderator absorption cross-section;

$Q = \frac{\varphi_{bo}}{\varphi_f}$ is the shielding constant of the fuel element;

$\varphi_{bo}$ is the neutron flux at the fuel element boundary;

$\Sigma_{sf}$ $\Sigma_f$ are the scattering cross-section and the total cross-section for neutron interaction in the fuel; $\Sigma_{sm}$ and $\Sigma_m$ are similar values for the moderator; $\Sigma_{sm}^{(n)}$ is the $n^{th}$ angular momentum of the scattering cross-section in the fuel and $\bar{\mu}$ is the mean cosine of the scattering angle in the fuel.

## THE EFFECT OF VARIATION IN MICROSCOPIC CROSS-SECTIONS FOR NEUTRON INTERACTION ON THE INTEGRAL CHARACTERISTICS OF A THERMAL NEUTRON SPECTRUM

G.Ya. Trukhanov

To formulate accuracy requirements for nuclear data in reactor construction, it is necessary to have an idea of the sensitivity of the integral characteristics of neutron distribution (used directly in the design of nuclear reactors) to variations in the microscopic cross-sections for neutron interaction with a substance. The solution of this problem as a whole for reactor construction must be preceded by work to assess the sensitivity of the integral parameters to errors in nuclear data for various types of reactor systems.

In this paper the author studies the effect of variations in the microscopic cross-sections for neutron interaction with a substance on the integral characteristics of a thermal neutron spectrum in the case of a plane uranium-water-graphite cell (thickness of the graphite 15 cm, of the water 0.5 cm and of the uranium slug 1.5 cm), which is characterized by the temperature non-uniformities ($T_c = 893^\circ K$; $T_{H_2O} = 353^\circ K$). The nuclear constants were taken from Hughes' Atlas [1]. A quantitative evaluation of the sensitivity of the integral parameters to variations in microscopic cross-section was performed by applying an influence factor, introduced via the relation:

$$\frac{\delta X}{X} = K(X, \beta)\ \frac{\delta \beta}{\beta}$$

where $\delta\beta$ and $\delta\chi$ are variations of the constant $\beta$ and the corresponding variations of $\chi$. Calculation of the space-energy distribution of thermal neutrons in the cell and calculation on this basis of the integral values for given microscopic interaction cross-sections was performed on the basis of the "DEMETRA" thermalization programme [2, 3].

The results of the analysis are given in Table 1.

Table 1

The effect of variations in nuclear data on the thermal utilization factor $\theta$ in a uranium-water-graphite cell

| Variable parameters | $\frac{\delta\beta}{\beta}$, % | $K(\theta,\beta)$ P$_I$ - approximation | $K(\theta,\beta)$ Quasi-diffusion solution | Variable parameters | $\frac{\delta\beta}{\beta}$, % | $K(\theta,\beta)$ P$_I$ - approximation | $K(\theta,\beta)$ Quasi-diffusion solution |
|---|---|---|---|---|---|---|---|
| I | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $\gamma_C$ | -I5,4 | +0,022 | +0,023 | $\gamma_{U^{238}}$ | -4,4 | -0,009 | -0,009 |
| | -9,4 | +0,022 | +0,020 | | -I,46 | -0,009 | -0,009 |
| | +9,6 | -0,022 | -0,02I | | +I,46 | +0,009 | +0,009 |
| | +I5,5 | -0,022 | -0,023 | | +4,4 | +0,009 | +0,009 |
| $\gamma_H$ | -0,6I | +0,035 | +0,039 | $\sigma_s^C$ | -8,4 | +0,0I3 | +0,0I2 |
| | +0,6I | -0,035 | -0,039 | | +8,4 | -0,0I3 | -0,0I2 |
| | +I,5 | -0,035 | -0,039 | | | | |
| $\gamma_{U^{235}}$ | -I,00 | -0,0I6 | -0,0I7 | $\sigma_s^H$ | -I9 | +0,009 | +0,0095 |
| | -0,32 | -0,0I6 | -0,0I8 | | +I9 | -0,009 | -0,0095 |
| | +0,32 | +0,0I6 | +0,0I8 | | | | |
| | +I,00 | +0,0I6 | +0,0I7 | | | | |

Note 1. $\gamma = \sigma_a(v_T) \cdot v_T$ [barn $\cdot$ eV$^{1/2}$], where $\sigma_a(v_T)$ is the microscopic absorption cross-section in barns, $v_T$ is the thermal neutron velocity in eV$^{\frac{1}{2}}$.

2. $\sigma_s$ is the microscopic scattering cross-section.

From the results in Table 1 the following conclusions can be drawn:

1. The sensitivity of $\vartheta$ to variations in the microscopic cross-sections for neutron interaction with a substance is very low for systems of the type considered;

2. The influence factors are constant over a wide range of nuclear data values, which extends well beyond the limits of experimental error;

3. The $P_I$-approximation gives qualitatively and quantitatively correct values of the influence factors.

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## NEUTRON FLUX RELAXATION LENGTHS AND RETHERMALIZATION LENGTHS IN GRAPHITE AND WATER

G.Ya. Trukhanov, Yu.A. Safin

The authors present the results of an analysis of experiments on neutron thermalization in a graphite-water system having a temperature jump over a wide range of graphite temperatures from 133 to 823°K, which were performed in the I.V. Kurchatov Atomic Energy Institute over a number of years [1, 2]. The method of measurement and the processing of experimental data are described in detail in Ref. [1]. The method of deriving the first relaxation length and the rethermalization length from the experimental data is explained in Ref. [3].

Table 1 shows the relaxation lengths of neutrons in water. The values obtained for the first relaxation length $L_1$ are considerably less than the maximum possible value for water $\frac{1}{x^*}$ = 0.74 cm. On the one hand, this can mean that in water there is only a fundamental relaxation length, and the values of $L_1$ obtained are the result of an attempt to describe a continuous spectrum of eigenvalues with one discrete eigenvalue. On the other hand, the fact that they all come within a specific range (0.27–0.37 cm) may indicate that a quasi-discrete relaxation length exists in the region of the continuous spectrum for water in the same way as quasi-discrete damping constants can exist in the non-stationary thermalization problem [4].

Table 2 shows neutron rethermalization lengths in graphite. It can be seen that the rethermalization length in graphite strongly depends on graphite temperature which is a reflection of the effect of chemical bonds in the graphite. The neutron rethermalization lengths in water are given in Table 3. No specific dependence on the temperature of the neighbouring zone is to be observed. In addition, the rethermalization properties of water were calculated. The differential scattering cross-sections were calculated in accordance with the Nelkin model [5]. The results of the calculation are given in Table 4. The neutron rethermalization lengths in water, obtained on the basis of the Nelkin model, do in fact depend, if only very slightly, on the temperature of the neighbouring zone.

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Table 1

Relaxation lengths in water

| No. of exp. | I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $T_c$, °K | I33 | I33 | 443 | 594 | 725 | 823 |
| $T_{H_2O}$, °K / L, cm | 297 | 343 | 298 | 302 | 305 | 305 |
| $L_\tau$ | 0,29±0,03 | 0,30±0,03 | 0,37±0,04 | 0,43±0,04 | 0,36±0,04 | 0,40±0,04 |
| $L_1$ | 0,27±0,03 | 0,27±0,03 | 0,33±0,03 | 0,37±0,04 | 0,32±0,04 | 0,35±0,03 |

Table 2

Rethermalization lengths in graphite

| | I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $T_C$, °K | I33 | I33 | 443 | 594 | 725 | 823 |
| $T_{H_2O}$, °K | 297 | 343 | 298 | 302 | 305 | 305 |
| $T_I$, °K | I55 | I55 | 454 | 596 | 726 | 830 |
| $L_\tau$, cm | I8 ± 3 | I5,6±3,2 | 7,4±0,7 | 6,3±0,6 | 5,I±0,5 | 4,9±0,5 |
| $L_{\tau t}$, cm | I0 ± I | 9,2±I,I | 5,5±0,6 | 4,9±0,5 | 4,I±0,4 | 4,0±0,4 |

## Table 3

Rethermalization lengths in water

| | I | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $T_C$, °K | I33 | I33 | 443 | 594 | 725 | 823 |
| $T_{H_2O}$, °K | 297 | 343 | 298 | 302 | 305 | 305 |
| $T_2$, °K | 307 | 356 | 303 | 3I0 | 3I0 | 3I5 |
| $L_r$ , cm | 0,30 ± 0,03 | 0,47 ± 0,05 | 0,52 ± 0,05 | 0,44±0,04 | 0,45±0,04 | 0,48±0,05 |
| $L_{rt}$ , cm | 0,26 ± 0,03 | 0,4I ± 0,04 | 0,44 ± 0,04 | 0,38±0,04 | 0,39±0,04 | 0,4I±0,04 |

## Table 4

Rethermalization characteristics of water
(Nelkin model)

| $T_I$, °K | $T_2$, °K | $T_{H_2O}$, °K | $L_{D1}$ , cm | $D_1$ , cm | $\Sigma_{s1}$ , $cm^{-I}$ | $\Sigma_R^{1\to2}$ , $cm^{-I}$ | $L_{rt}$ , cm |
|---|---|---|---|---|---|---|---|
| I55 | 307 | 297 | 3,00 | 0,I23 | 3,73 | 0,735 | 0,339 |
| I55 | 356 | 343 | 3,I2 | 0,II9 | 3,74 | 0,82I | 0,374 |
| 380 | 3I0 | 304 | 2,99 | 0,I87 | 2,82 | 0,689 | 0,5I4 |
| 453 | 305 | 300 | 2,83 | 0,I89 | 2,72 | 0,765 | 0,49I |
| 596 | 3I0 | 300 | 2,85 | 0,20I | 2,54 | 0,748 | 0,5I4 |
| 725 | 3I0 | 300 | 2,85 | 0,2II | 2,4I | 0,724 | 0,534 |
| 833 | 3I0 | 300 | 2,85 | 0,2I7 | 2,35 | 0,7I0 | 0,547 |

JOINT INSTITUTE OF NUCLEAR RESEARCH

## EXTRACTION OF ULTRA-COLD NEUTRONS FROM A REACTOR

V.V. Golikov, V.I. Lushchikov, F.L. Shapiro

The authors calculate the yield of ultra-cold neutrons from different sources (converters) of temperature $T_K$ irradiated with an isotropic thermal neutron flux having a Maxwellian spectrum of temperature $T_n$. The results of the calculations of the dependence of the ultra-cold neutron flux on the temperature of a number of converters, $T_K$, for a fixed neutron spectrum temperature ($T_n = 300^{\circ}K$) are given in Fig. 1.

For polyethylene, beryllium and zirconium hydride (curves 1, 2 and 3 respectively), the ultra-cold neutron yield increases noticeably with cooling of the converter. The ultra-cold neutron yield from magnesium (curve 4), however, depends only slightly on the converter temperature. The results of the calculations are comparable with those of experiments performed on the ultra-cold neutron channel of the IBR-30 pulsed reactor. Cooling of the polyethylene converter from room temperature ($T = 300^{\circ}K$) to $T_K = 130^{\circ}K$ and $T_K = 90^{\circ}K$ caused the ultra-cold neutron flux to increase by factors of $2.2 \pm 0.2$ and $4 \pm 0.2$ respectively, which is slightly less than the theoretical values of 3 and 5.5.

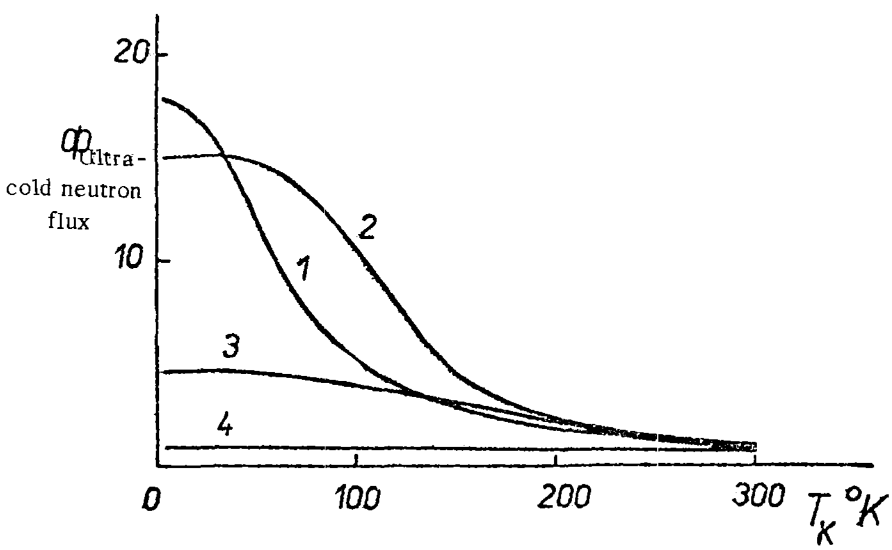


Fig. 1.

## EXPERIMENTS WITH ULTRA-COLD NEUTRONS

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(JINR Preprint, RZ-5392, 1970; Physics Lett. 34B, 4 (1971) 293)

It is shown how ultra-cold neutrons can be extracted from a stationary reactor through curved reflecting neutron tubes.

The ultra-cold neutron flux at the end of the tube was several neutrons per second, which corresponds to the theoretically predicted value. The background from residual neutrons at the point of installation of the ultra-cold neutron detector was 10% of the total count.

In the neutron tube, made of electropolished copper tubes 10 cm in diameter, the diffusion length was measured as $4.7 \pm 0.1$ M, which corresponds to the probability of diffuse and mirror reflection of neutrons on the wall of the neutron tube being in the ratio 1:9. The method of raising the neutron tube in the field of gravity was used to measure the ultra-cold neutron spectra at the tube outlet. By measuring the ultra-cold neutron counting rate as a function of the helium pressure in the neutron tube it was possible to estimate the mean source-to-detector time ($\sim$ 5 sec for a length of 6 m).

Direct measurements were made of the confinement time in closed volumes of the order of 30 litres with walls made of beryllium, pyrographite, copper, stainless steel etc. According to preliminary data the confinement time in these volumes does not exceed 30 sec in the range of wall temperature variation from $-190^{\circ}C$ to $+400^{\circ}C$.

## NEUTRON RESONANCES OF THE ISOTOPES SAMARIUM-147 AND 149

E.N. Karzhavina, A.B. Popov

The LNF neutron spectrometer of the Joint Institute of Nuclear Research, which has a resolution of 6 nsec/m, was used to measure the transmission and yield of gamma rays from neutron capture on samples of samarium with different isotopic composition. Isotopic identification was performed and the resonance parameters of $^{147}Sm$ and $^{149}Sm$ were determined in the ranges up to 400 eV and 250 eV respectively.

Values for D - the mean distances between resonances for $^{147}Sm$ and $^{149}Sm$ - were obtained as $(7.2 \pm 0.9)$ eV; $(2.3 \pm 0.3)$ eV and for $S_o$ - the strength functions - as $(3.7 \pm 0.8) \times 10^{-4}$ and $(5.1 \pm 0.9) \times 10^{-4}$.

Table 1

Neutron resonance parameters of $^{147}Sm$

| $E_0$, eV | $\Gamma$ meV | $2g\Gamma_n$, meV | $\Gamma_\gamma$, meV | $2g\Gamma_n^0$ |
|---|---|---|---|---|
| I8,3±0,J | | 62 ± 7 | | I4,5 ± I,6 |
| 27,I | | 4,2±0,2 | | 0,8I± 0,08 |
| 29,7 | 75±I6 | I4 ± 2 | 6I ± I6 | 2,6 ± 0,4 |
| 32,I | II3±25 | 35 ± 7 | 78 ± 26 | 6,2 ± I,2 |
| 39,7 | | 80 ± II | | I2;7 ± I,7 |
| 40,6±0,I | | (2,4) | | (0,38) |
| 49,3±0,2 | 66±I7 | I7 ± 3 | 49 ± I7 | 2,4 ± 0,4 |
| 57,9± | 85±7 | 44 ± 5 | 4I ± 9 | 5,8 ± 0,7 |
| 64,9 | | I4 ± 2 | | I,7 ± 0,3 |
| 76,0 | 62±9 | 23 ± 4 | 39 ± I0 | 2,6 ± 0,5 |
| 79,8 | | 2,8 ± 0,3 | | 0,3I ± 0,03 |
| 83,4±0,2 | 95±7 | 60 ± 6 | 35 ± 9 | 6,6 ± 0,7 |
| 94,9±0,3 | | I7 ± 4 | | I,7 ± 0,4 |
| 99,5 | | 290 ± 44 | | 29 ± 5 |
| I02,6 | | I45 ± 20 | | I4 ± 2 |
| I06,8 | | 3I ± 6 | | 3,0± 0,6 |
| I08,4 | | (0,8) | | (0,08) |
| I23,4±0,3 | I74±9 | I36 ± I0 | | I2,2± 0,9 |
| I40,0±0,4 | | 77 ± 8 | | 6,5 ± 0,7 |
| I43,3 | | 2,0 ± 0,2 | | 0,I7 ± 0,02 |
| I5I,3±0,4 | | I34 ± I4 | | II ± I |
| I60,8±0,5 | | 90 ± I0 | | 7,I ± 0,8 |
| I63,6 | | 88 ± I0 | | 6,9 ± 0,8 |
| I7I,7 | | I2 ± 2 | | 0,92 ± 0,I5 |
| I79,7 | | 3,0 ± 0,3 | | 0,22 ± 0,02 |
| I83,7 | | 420 ± 40 | | 3I ± 3 |
| I90,8 | | 9,4± I,4 | | 0,68 ± 0,I0 |
| I93,5 | | 2,6± 0,6 | | 0,I9 ± 0,04 |
| I98,0 ±0,5 | | 8,4± 0,9 | | 0,60 ± 0,06 |
| 205,8 ± 0,6 | | I84± 22 | | I2,8 ± I,5 |
| 22I,6 | | II0± I6 | | 7,4 ± I,I |
| 225,3 | | I40± I6 | | 9,3 ± I,I |
| 228,6 | | 2,5± 0,4 | | 0,I7 ± 0,03 |
| 240,6 ± 0,6 | | I3± 2 | | 0,84 ± 0,I3 |
| 247,7 ± 0,7 | | I20± I4 | | 7,6 ± 0,9 |
| 256,5 ± 0,7 | | I35± I6 | | 8,4 ± I,0 |
| 263,5 ± 0,8 | | (55) | | (3,4) |
| 265,8 | | (II2) | | (6,9) |
| 27I,0 | | (36) | | (2,2) |
| 274,4 | | 9± 3 | | 0,54 ± 0,I8 |
| 283,3 ± 0,8 | | 28± 5 | | I,7 ± 0,3 |
| 289;4 ± 0,9 | | (25) | | (I,5) |
| 290,5 | | (25) | | (I,5) |
| 308,0 | | 5,0± I,2 | | 0,28 ± 0,07 |
| 3I2,0 ± 0,9 | | I2± 4 | | 0,7 ± 0,2 |
| 32I ± I | | 7± 2 | | 0,4 ± 0,I |

Table 1 (continued)

| $E_0$, eV | Γ meV | 2gΓn meV | Γγ meV | $2g\Gamma_n^0$ |
|---|---|---|---|---|
| 330 } 332 } | | I60± 25 | | 8,8 ± I,4 |
| 340 | | 76± I2 | | 4,I ± 0,6 |
| 350 | | 57± 8 | | 3,0 ± 0,4 |
| 359 ± I } | | 270± 30 | | I4,2 ± I,6 |
| 379 ± I,2 | | 350± 80 | | I8 ± 4 |
| 382 ± I,2 | | (I2) | | (0,6I) |
| 39I ± I,3 | | I02± 22 | | 5,3 ± I,I |
| 398 } 399 ± I,3 } | | (II0) | | (5,5) |
| 406 ± I,4 | | I7 ± 6 | | 0,84 ± 0,30 |
| 4I2 ± I,4 | | 44 ± 8 | | 2,2 ± 0,4 |
| 4I9 ± I,5 | | 94 ± 30 | | 4,6 ± I,5 |
| 423 ± I,5 | | 29 ± 9 | | I,4 ± 0,4 |

Table 2

Neutron resonance parameters of $^{149}Sm$

| $E_0$, eV | 2gΓn meV | $2g\Gamma_n^0$ meV |
|---|---|---|
| I5,8 ± 0,I | 0,32 ± 0,04 | 0,08 ± 0,0I |
| I7,I | 2,8 ± 0,4 | 0,68 ± 0,I0 |
| 23,2 | I,2 ± 0,2 | 0,25 ± 0,04 |
| 24,6 | (0,36) | (0,07) |
| 25,2 | 24 ± 7 | 4,8 ± I,4 |
| 26,I | 5,0 ± 0,7 | 0,98 ± 0,I4 |
| 27,9 | 0,30 ± 0,06 | 0,06 ± 0,0I |
| 29,9 | 4,7 ± I,6 | 0,86 ± 0,29 |
| 30,7 | I7 ± 4 | 3,I ± 0,7 |
| 33,9 | I0 ± 2 | I,7 ± 0,3 |
| 40,I | 28,± 5 | 4,4 ± 0,8 |
| 4I,3 | 38 ± 7 | 5,9 ± I,I |
| 44,3 | 90 ± 27 | I3,5 ± 4,I |
| 45,I ± 0,I | 23 ± 6 | 3,4 ± 0,9 |
| 49,5 ± 0,2 | I6 ± 3 | 2,3 ± 0,4 |
| 50,5 | 2,2 ± 0,4 | 0,3I ± 0,06 |
| 5I,6 | 5I ± 20 | 7,I ± 2,8 |
| 57,4 | 30 ± 9 | 4,0 ± I,2 |
| 59,7 | 90 ± 20 | II,6 ± 3 |
| 60,9 | 2,3 ± 0,6 | 0,30 ± 0,08 |
| 62,I | 6I ± II | 7,7 ± I,4 |
| 64,7 | 98 ± 33 | I2,2 ± 4,I |
| 68,3 | 27 ± 7 | 3,3 ± 0,8 |
| 70,8 | 96 ± 40 | II,4 ± 4,7 |
| 72,2 | | |
| 73,I | (I30) | (I5) |
| 74,6 | 29 ± 6 | 3,4 ± 0,7 |

Table 2 (continued)

| $E_0$ , eV | $2g\Gamma_n$ meV | $2g\Gamma_n^0$ meV |
|---|---|---|
| 75,3 | 30 ± 6 | 3,5 ± 0,7 |
| 76,9 ± 0,2 | 4,5 ± 0,8 | 0,5I ± 0,09 |
| 83,8 ± 0,2 | 20 ± 5 | 2,2 ± 0,5 |
| 87,7 ± 0,3 | 22 ± 4 | 2,3 ± 0,4 |
| 90,6 | 64 ± 36 | 6,7 ± 3,8 |
| 92,I | 57 ± I7 | 5,9 ± I,8 |
| 95,6 } | (I30) | (I3) |
| 96,3 } | | |
| 98,I | (22) | (2,2) |
| 99,5 | (I2) | (I,2) |
| I0I,6 | 2,8 ± 0,5 | 0,28 ± 0,05 |
| I04,7 | 20 ± 4 | 2,0 ± 0,4 |
| I07,0 | I2 ± 2 | I,2 ± 0,2 |
| I09,0 | I6 ± 3 | I,5 ± 0,3 |
| III,2 | I3 ± 2 | I,2 ± 0,2 |
| II5,I | I0 ± 2 | 0,93 ± 0,20 |
| II7,0 | 3,2 ± I,2 | 0,29 ± 0,II |
| II9,4 | I9 ± 4 | I,7 ± 0,4 |
| I2I,7 | I,7 ± 0,8 | 0,I5 ± 0,07 |
| I25,2 | 33 ± 8 | 2,9 ± 0,7 |
| I27,I | 2,6 ± 0,4 | 0,23 ± 0,04 |
| I30,3 ± 0,3 | 4,7 ± 0,6 | 0,42 ± 0,05 |
| I34,I ± 0,4 | I80 ± 60 | I5 ± 5 |
| I38,6 | 0,8 ± 0,2 | 0,07 ± 0,02 |
| I4I,0 | I,7 ± 0,3 | 0,I4 ± 0,03 |
| I44,2 | 3I ± 6 | 2,6 ± 0,5 |
| I45,7 } | (I60) | (I3) |
| I46,9 } | | |
| I49,5 | 7,6 ± I,4 | 0,62 ± 0,I2 |
| I54,7 | 54 ± I6 | 4,3 ± I,3 |
| I57,5 | I9 ± 4 | I,5 ± 0,3 |
| I58,7 ± 0,4 | 4,0 ± 0,5 | 3,2 ± 0,4 |
| I68,3 ± 0,5 | 20 ± 4 | I,5 ± 0,3 |
| I73,5 | (3,6) | (0,27) |
| I74,7 | (3,6) | (0,27) |
| I77,8 | (70) | (5,3) |
| I79,9 | (70) | (5,3) |
| I85,4 | 52 ± 48 | 3,8 ± 3,5 |

Table 2 (continued)

| $E_0$, eV | $2g\Gamma_n$ meV | $2g\Gamma_n^0$ meV |
|---|---|---|
| I88,0 | 44 ± 26 | 3,2 ± I,9 |
| I92,9 | I2 ± 3 | 0,87 ± 0,22 |
| I95,0 | 2,2 ± 0,4 | 0,I6 ± 0,03 |
| I97,4 ± 0,5 | 20 ± 6 | I,4 ± 0,4 |
| 20I,I± 0,6 | (8,0) | (0,56) |
| 203,7 | 44 ± 26 | 3,I ± I,8 |
| 2I0,9 | I0 ± 2 | 0,69 ± 0,I4 |
| 2I4,7 | I7 ± 5 | I,2 ± 0,3 |
| 2I8,2 | 9 ± 2 | 0,6I ± 0,I4 |
| 225,6 | 3I ± I0 | 2,I ± 0,7 |
| 228.2 | 25 ± 8 | I,6 ± 0,5 |
| 230,I | 52 ± 30 | 3,4 ± 2,0 |
| 234,0 | 8 ± 3 | 0,5 ± 0,2 |
| 238,4 ± 0,6 | (8,0) | (0,52) |
| 240,I ± 0,7 | I4 ± 3 | 0,9 ± 0,2 |
| 244,3 | 30 ± II | I,9 ± 0,7 |
| 248,7 | I8 ± 5 | I,I ± 0,3 |

## TOTAL ALPHA WIDTHS OF NEUTRON RESONANCES

Yu.P. Popov, M. Pshitula, R.F. Rumi, V.G. Semenov,
M. Stempinsky, M. Florek, V.I. Furman

Results are given of an investigation of the (n,α) reaction for target nuclei of $^{64}$Zn, $^{67}$Zn and $^{177}$Hf. Alpha decay was observed from resonance states arising after capture of a neutron of energy 2637 eV by a $^{64}$Zn nucleus ($\Gamma_\alpha \sim 4 \times 10^{-4}$ eV), of energy 1548 eV by a $^{67}$Zn nucleus ($\Gamma_\alpha \sim 12 \times 10^{-4}$ eV) and of energies 1.09, 2.38, 5.89, 6.57 and 8.87 eV by a $^{177}$Hf nucleus ($\Gamma_\alpha$ in the range from $1.10^{-9}$ to $5 \times 10^{-9}$ eV). These data and the previously measured values of the alpha widths $\langle\Gamma_\alpha\rangle$ (or the upper estimates) for ten isotopes in the mass number range $95 \leq A \leq 189$ are comparable with the results of calculations based on an optical nuclear model. The fluctuations of the total alpha widths are analysed and it is shown how the resonance spins can be determined from the total alpha widths. The authors supply the distribution of the $\Gamma_\alpha$ - widths and the results of spin identification of resonances for a $^{147}$Sm nucleus based on recent measurements with a neutron energy resolution of 40 nsec/m. $\ell = 3$ is assigned to the following resonances: 3.4, 27.1, 29.7, 40.6, 83.4, 102.6, 123.4, 160.8, 183.7, 190.8 and 198.0 eV.

## DISTRIBUTION OF PARTIAL ALPHA WIDTHS OF NEUTRON RESONANCES

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The paper presents the results of an analysis of distributions of experimentally determined partial alpha widths for neutron resonances of $^{147}$Sm and $^{143}$Nd. Assuming that partial alpha widths are subject to a chi-square distribution, the authors obtained from experimental data the number of degrees of freedom for the distribution of alpha widths in the transition to the ground state of a daughter nucleus: $\nu_{ex} = 0.62 \pm 0.15$ for eight resonances of $^{147}$Sm and $\nu_{ex} = 1.3 \pm 0.4$ for five resonances of $^{143}$Nd. For the distribution of partial alpha widths in the transition to the first excited state in the case of $^{147}$Sm resonances a value of $\nu_{ex} = 4.9 \pm 2.1$ was obtained, which indicates that the fluctuations of the reduced alpha widths are independent of the various orbital angular momenta $\ell$, participating in the transition. The theoretical value of $\nu$ in the first two cases above is unity and in the other case 1.9.

## OPTICAL MODEL ANALYSIS OF THE $(n,\alpha)$ REACTION

V.I. Furman, Yu.P. Popov

The $(n,\alpha)$ reaction, studied in terms of resonance neutrons, is the only source of information on mean alpha particle widths for nuclei with mass numbers of $A > 50$ [1]. Since the mean alpha widths are considerably smaller than the mean neutron and radiation widths (1) we can write with good accuracy

$$(T^J_{\alpha f\ell})_{OM} = 1 - |U^J_{\alpha f\ell}|^2 = 2\pi \frac{\langle \Gamma^J_{\alpha f\ell}\rangle}{D^J} \qquad (1)$$

where $(T^J_{\alpha f\ell})_{OM}$ is the transmission coefficient of the optical model (OM), $\ell$ is the orbital angular momentum of the alpha particles, $U^J_{\alpha f\ell}$ is the scattering matrix, $\langle \Gamma^J_{\alpha f\ell}\rangle$ is the mean experimental alpha width for the levels of a compound nucleus with spin J, $D^J$ is the distance between these levels, and f numbers the excitation levels of the daughter nucleus. In the case of s-neutrons there are two compound nucleus spins, and the total width is obtained from (1) as:

$$\langle\Gamma_\alpha\rangle = \frac{1}{N}\sum_{\lambda=1}^{N}\sum_f \Gamma_{\lambda\alpha f} = \langle\Gamma_\alpha\rangle_{OM} = \frac{D_H}{2\pi}\sum_f\left\{\sum_\ell^{J^+} T^{J^+}_{\alpha f\ell} + \sum_\ell^{J^-} T^{J^-}_{\alpha f\ell}\right\} \qquad (2)$$

Here N is the total number of levels and $D_H$ is the mean distance between them. In view of the strong energy dependence of the alpha widths it is convenient to introduce the strength function:

$$S^J_{\alpha\ell} = \frac{\sum_\ell \langle \Gamma^J_{\alpha\ell} \rangle}{2D^0 \sum_\ell P_{\alpha\ell\ell}} = \left(S^J_{\alpha\ell}\right)_{OM} = \frac{\sum_\ell T^J_{\alpha\ell\ell}}{4\pi \sum_\ell P_{\alpha\ell\ell}} \tag{3}$$

where $P_{\alpha fl}$ is the penetration factor with allowance for the nuclear potential. For calculating $\langle \Gamma_\alpha \rangle_{OM}$ and $(S^J_{\alpha\ell})_{OM}$ it is necessary to use the optical potential (OP) with smooth dependence of the parameters on A, which enables the results for different nuclei to be compared. We use the theoretical alpha-particle OP [2], since no "unique" phenomenological potential exists. In this case the OP for alpha particles is obtained by averaging the single-nucleon phenomenological OP over the nucleon distribution density in an alpha particle. The real part of the potential obtained in this way is approximated by the Woods-Saxon potential with variable diffusity a(R). For A > 40

$$a(R) = 0{,}69 + 0{,}24 \exp\{-[(R - R_{ov})/4{,}75]^2\}; \quad R_{ov} = r_{ov} A^{1/3} \tag{4}$$

The corresponding depth is obtained automatically as $V_{o\alpha} = K_v(A) \sum_{i=1}^{4} V_{oi}$ ; here $K_v(A)$ is the renormalization coefficient from Ref. [2], and $V_{oi}$ are the depths of the single-nucleon OP. Taking the parameters of the single-nucleon potentials from Ref. [3], we arrive at the alpha-particle potential, the parameters of which are given in Table 1 for the relevant nuclei.

The imaginary part of the OP for alpha particles must be selected on the basis of the best agreement with absolute values of $\langle \Gamma_\alpha \rangle_{ex}$. Table 3 shows the results of such calculations with $W_o$ = 2 MeV, $R_{ow} = 1.215\ A^{1/3}$ f and $a_w$ = 1.5 f (the absorption has a Gaussian shape). The penetration factors necessary for obtaining the strength functions and for considering the statistical properties of the α-particle widths [1] were calculated using the method proposed in Ref. [4], taking as channel radius the position of the peak of the irregular scattering function $g_\ell$ in the real part of the alpha potential closest to the internal reversal point. Table 2 shows the strength functions in relation to A and $E_\alpha$, the energy of the alpha transitions calculated from the optical model and obtained by experiment.

In accordance with the hypothesis as to the possible existence of giant resonances in the interaction of alpha particles with a nuclear substance, it should be assumed that all the measured nuclei reach a minimum between single-particle resonances.

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Table 1

| Target nucleus | Product nucleus | $r_{0v}$ $\times 10^{-13}$ cm | $V_\alpha$ MeV | Target nucleus | Product nucleus | $r_{0v}$ $\times 10^{-13}$ cm | $V_\alpha$ MeV |
|---|---|---|---|---|---|---|---|
| $Zn^{64}$ | $Ni^{61}$ | I.20I0 | 20I | $Sm^{147}$ | $Nd^{144}$ | I.22I5 | 205 |
| $Zn^{67}$ | $Ni^{64}$ | I.20I8 | 20I | $Sm^{149}$ | $Nd^{146}$ | I.2220 | 205 |
| $Mo^{95}$ | $Zr^{92}$ | I.2075 | 203 | $Eu^{151}$ | $Pm^{148}$ | I.2223 | 205 |
| $Pd^{105}$ | $Ru^{102}$ | I.2I05 | 204 | $Gd^{155}$ | $Sm^{152}$ | I.2227 | 205 |
| $Te^{123}$ | $Sn^{120}$ | I.2I75 | 204.5 | $Hf^{177}$ | $Yb^{174}$ | I.2254 | 206 |
| $Nd^{143}$ | $Ce^{140}$ | I.22I0 | 205 | $Os^{187}$ | $W^{184}$ | I.2264 | 206,5 |
| $Nd^{145}$ | $Ce^{142}$ | I.22I2 | 205 | $Os^{189}$ | $W^{186}$ | I.2267 | 206,5 |

Table 2

| Target nucleus | $S_{\alpha\ell}^{J}$ | Permissible $\ell_\alpha$ | $N_\alpha^{J\pi} / N^{J\pi}$ | $(S_{\alpha\ell}^{J\pi})_{exp.}$ $\times 10^2$ | $(S_{\alpha\ell}^{J\pi})_{OM}$ $\times 10^3$ |
|---|---|---|---|---|---|
| $Mo^{95}$ | $S_{\alpha0}^{2+}$ | 2 | 3/3 | 0,I2±0,I | 0,33±0,08 |
| $Te^{123}$ | $S_{\alpha0}^{0+}$ | 0 | 3/4 | 0,38±0,I3 | 0,37±0,09 |
| $Nd^{143}$ | $S_{\alpha0}^{3-}$ | 3 | 4/7 | 0,43±0,I5 | 0,45±0,08 |
| $Nd^{145}$ | $S_{\alpha0}^{3-}$ | 3 | 3/3 | ≤0,72±0,I3 | 0,35±0,06 |
| | $S_{\alpha0}^{3-}$ | 3 | 7/7 | 0,43±0,II | 0,56±0,I8 |
| $Sm^{147}$ | $S_{\alpha1}^{3-}$ | I,3, 5 | 6/7 | 0,23±0,I5 | 0,45±0,I5 |
| | $S_{\alpha1}^{4-}$ | 3, 5 | 4/4 | 0,27±0,I2 | 0,45±0,I5 |
| $Sm^{149}$ | $S_{\alpha0}^{3-}$ | 3 | 6/7 | <0,3 ±0,I | 0,7 ±0,2 |

Table 3

| Target nucleus | No. of widths N | $\langle D_H \rangle$ (eV) | $\langle \Gamma_\alpha \rangle_{exp}$ μeV | $\langle \Gamma_\alpha \rangle_{OM}$ μeV | $\frac{\langle \Gamma_\alpha \rangle_{exp.}}{\langle \Gamma_\alpha \rangle_{OM}}$ |
|---|---|---|---|---|---|
| $Zn^{64}$ | 2/2 | 4300±800 | $(2,4^{+2}_{-I,5}).I0^{2}$ | $(0,84 \pm 0,I7).I0^{2}$ | $2,8^{+2,5}_{-2,0}$ |
| $Zn^{67}$ | I/2 | 700±250 | $(8^{+8}_{-5}).I0^{2}$ | $(57 \pm 20).I0^{2}$ | $0,I4^{+0,I4}_{-0,I}$ |
| $Mo^{95}$ | 6/6 | 80±20 | II ± 7 | 25 ± 6 | 0,44 ± 0,3 |
| $Pd^{105*}$ | 3/3 | I3±3 | ≤ I,3 | I,05 ± 0,24 | ≤ I,25 |
| $Te^{123}$ | 6/6 | 30±7 | 2 ± I,3 | 0,7 ± 0,I7 | 2,85 ± 2 |
| $Nd^{143}$ | 8/I3 | 38±6 | 8 ± 3 | 6 ± I | I,3 ± 0,6 |
| $Nd^{145*}$ | 3/3 | 20±3 | 2,6± 0,7 | I,65± 0,3 | I,6 ± 0,7 |
| $Sm^{147}$ | I9/I9 | 6,8 ± I,6 | 2,3± 0,7 | 4,0± I | 0,58 ± 0,25 |
| $Sm^{149}$ | I5/I7 | 2,7 ± 0,5 | 0,I9± 0,04 | 0,37± 0,I | 0,52 ± 0,2 |
| $Eu^{151*}$ | IT/I | 0,85± 0,I4 | $\geq 0,85.I0^{-4}$ | $(I,3 \pm 0,25).I0^{-4}$ | ≥ 0,65 |
| $Gd^{155*}$ | IT/I | 2,0± 0,4 | $\geq I,47.I0^{-4}$ | $(9,2 \pm 2).I0^{-4}$ | ≥ 0,I6 |
| $Hf^{177}$ | 5/5 | 2,3± 0,5 | $(3 \pm 2).I0^{-3}$ | $(I4 \pm 3).I0^{-3}$ | 0,22 ± 0,I6 |
| $Os^{187}$ | 2/2 | I0,4± 2 | ≤ I,2 | 0,2± 0,04 | ≤ 6 |
| $Os^{189}$ | 6/6 | 5,I± I | ≤ 0,23 | 0,I8±0,03 | ≤ I,25 |

Remark: In the case of nuclei marked *, all the resonances studied have the same spin.

## APPARATUS FOR INVESTIGATING THE (n,α) REACTION

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Using powerful neutron beams from pulsed sources, the authors consider various aspects of the recording and spectrometry of alpha particles and describe the characteristics of alpha-particle detectors, which have been developed by the group: a gas scintillation detector with electrical field, a multilayer ionization chamber with central collector, a multisection proportional chamber, and also alpha-ray spectrometers based on a multilayer ionization chamber and an ionization chamber with inclined target. The main characteristics of these detectors are indicated in the table.

Table 1

| Type of detector | Target area [$cm^2$] | Efficiency with respect to alpha particles from the (n, α) reaction, [%] | Natural background of the detector (pulses/h.$cm^2$) in the energy range (MeV) | Detector resolution for 4.5 MeV alpha-particle energy (keV) | | The detectors and spectrometer are capable of operating with a neutron source pulse power of 60 MW without variation in the main characteristics, starting (μsec) after a burst over the flight length (m) | |
|---|---|---|---|---|---|---|---|
| | | | | Outside neutron beam | In neutron beam | [μsec] | [m] |
| Gas scintillation detector | 7000 | 30-40 | 0.012 (1.5-7) | - | - | 300 | 100 |
| Ionization chamber with central collector | 4000 | 30-40 | 0.012 (7-12) | 300 | 600 | 600 | 100 |
| Multisection proportional chamber | 13000 | 40 | 0.006 (1-10) | - | - | 200 | 30 |
| Double ionization chamber with slit collimator | 1600 | 100 | 0.013 (5-10) | 100 | 200-400 | 400 | 100 |
| Large ionization chamber | 9000 | 100 | 0.013 (5-10) | 100 | 200-400 | 1200 | 100 |

# INVESTIGATION OF NEUTRON RADIATIVE CAPTURE REACTIONS LEADING TO SPONTANEOUSLY FISSIONABLE ISOMERS

Yu.P. Gangrsky, B.N. Markov, T. Nad,
I.F. Kharisov

The authors measured the cross-sections for the formation of the spontaneously fissionable isomers $^{236}$U, $^{242}$Am, $^{244}$Am in the radiative capture of neutrons with energies of 1-3 MeV and of thermal neutrons. In the case of the isomers $^{242}$Am and $^{244}$Am with half-lives of 14 μsec and 1.1 msec respectively, a pulsed neutron beam was employed and the fission fragment yield was measured in the period between neutron pulses. In the case of the isomer $^{236}$U with half-life 70 nsec the delayed coincidences of conversion electrons and fission fragments were measured during a continuous thermal neutron flux. The measured cross-sections for the formation of spontaneously fissionable isomers reveal a correlation with the induced fission cross-sections. This correlation is evidently a reflection of the complex structure of the fission barrier.

Table

Cross-sections for formation of spontaneously fissionable isomers

| Isomer | Neutron energy | Cross-section, mbarn |
|---|---|---|
| $U^{236}$ | 0,025 eV | ~ 60 |
| $Am^{242}$ | 0,025 eV | 0,3 ± 0,I |
| | I,0 MeV | 0,04± 0,0I5 |
| | 2,0 MeV | 0,03± 0,0I |
| $Am^{244}$ | 0,025 eV | < 0,0I |
| | I,0 MeV | 0,04± 0,0I5 |
| | 2,0 MeV | 0,025±0,008 |
| | 3,0 MeV | 0,0I5±0,005 |

## ORIENTED TARGETS AND POLARIZED NEUTRONS IN NEUTRON PHYSICS

V.P. Alfimenkov

On the basis of the relevant literature the author considers experiments that have been performed and possible future experiments involving polarized slow neutrons and oriented nuclear targets. Particular attention is devoted to measurement of the spin components of the cross-section for slow neutron interaction with nuclei, the determination of neutron resonance spins and determination of the magnetic and electric moments of excited nuclear states.

## STUDY OF THE INTERACTION BETWEEN A NEUTRON AND AN ELECTRON, MADE WITH THE PULSED FAST REACTOR OF THE JOINT INSTITUTE OF NUCLEAR RESEARCH

Yu.A. Aleksandrov, A.M. Balagurov, A.I. Vasilenko
T.A. Machekhina, G.S. Samosvat

The time-of-flight method was used to measure the intensity of Bragg reflections from single crystals of tungsten enriched in $^{186}W$. The isotopic compounds of the specimens were such that their total coherent scattering amplitudes were of different signs. A value of $a_{re} = (-1.32 \pm 0.11) \times 10^{-16}$ cm was obtained for the neutron-electron scattering amplitude. The prospects of further study in this direction are considered.

## THE IBR-30 AND IBR-2 PULSED REACTORS WITH INJECTORS AS SOURCES FOR NEUTRON SPECTROSCOPY IN THE RESONANCE ENERGY REGION

Yu.S. Yazvitsky

This paper describes some features of the IBR-30 and IBR-2 pulsed reactors of the Joint Institute of Nuclear Research. The IBR-30 reactor was commissioned in 1969 and has a mean capacity of 25 kW. Construction of the IBR-2 reactor was commenced in 1969 and its mean rated capacity is 4 MW. The IBR-30 and IBR-2 reactors have linear electron accelerators as injectors and they can operate under boosted conditions.

Characteristics of the IBR-30 and IBR-2 reactors and their injectors are given in Tables 1 and 2. The number of neutrons in the 1-eV energy range bombarding an area of 1 $cm^2$ at a distance $L_M$ from the reactor is given by the formulae:

For IBR-30 (experimental)

$$I = 2.7 \times 10^6 \frac{W}{E^{0.9} L^2}$$

For IBR-2 (theoretical)

$$I = 1.5 \times 10^6 \frac{W}{EL^2}$$

W is the capacity in kilowatts.

Under boosted conditions a power level of 2.5 kW is attained on IBR-30 with a frequency of 100 pulses/sec and $\vartheta_{\frac{1}{2}} \approx 3$ µsec. The capacity of the IBR-2 under boosted conditions with $\vartheta_{\frac{1}{2}} > 1$ µsec is expressed by the formulae:

$$W = 1.4 \times 10^{-1} \vartheta_{\frac{1}{2}} \text{ MW}$$

Table 1

Characteristics of the IBR-30 and IBR-2 under normal reactor conditions

| | IBR-30 | IBR-2 |
|---|---|---|
| Mean power level (kW) | 25 | 4000 |
| Pulse frequency (pulses/sec) | 4-100 | 5-50 |
| Mean neutron yield (pulses/sec) | $1.3 \times 10^{15}$ | $1.8 \times 10^{17}$ |
| Neutron lifetime (sec) | $1.6 \times 10^{-8}$ | $4.2 \times 10^{-8}$ |
| Power between pulses (kW) | 1.2 | 220 |
| Power at pulse peak with a frequency of 5 pulses/sec (MW) | 120 | 8000 |
| Neutron yield at pulse peak with a frequency of 5 pulses/sec | $5.6 \times 10^{18}$ | $3.6 \times 10^{20}$ |
| Pulse half-width (µsec) | 70 | 90 |

Table 2

Characteristics of the injectors of the IBR-30
(LUE-40) and of the IBR-2 (LIU-30)

| | LUE-40 | LIU-30 |
|---|---|---|
| Electron energy (MeV) | 40 | 30 |
| Electron current in a pulse (A) | 0.2 | 250 |
| Current pulse duration (μsec) | 1.6 | 0.5 |
| Frequency (pulses/sec) | 100 | 50 |

INSTITUTE OF EXPERIMENTAL AND THEORETICAL PHYSICS

# THE NUCLEAR MAGNETIC RESONANCE OF BETA-ACTIVE $^{8}$Li NUCLEI FORMED IN POLARIZED NEUTRON CAPTURE IN SINGLE CRYSTALS OF LiF

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(Paper submitted to Zh. éksp. teor. Fiz.)

Measurements were carried out at room temperature of the nuclear magnetic resonance of polarized beta-active $^{8}$Li nuclei obtained in the capture of polarized thermal neutrons. Three single crystal LiF samples were used, oriented in the planes (100), (110) and (111) perpendicular to the magnetic field, and also two powdered samples of LiF and $^{7}$LiF (with depleted $^{6}$Li content). The shape of the peak was studied in terms of the resolution of the angular anisotropy of beta radiation of polarized $^{8}$Li nuclei by a magnetic radiofrequency field $H_I$. Theoretical calculation of the shape of the peak was performed, assuming dipole-dipole interaction for a hard lattice. The secondary moments of the resonance peak were calculated. Comparison with experimental results shows that the internal local fields in the case of $^{8}$Li nuclei have a Gaussian distribution which deviates towards the Lorentz shape only in the wings ($\sim 10^{-2}$ of the maximum value). The shape of the resonance peak did not seem to be significantly affected by lattice disturbances caused by gamma-recoils of $^{8}$Li nuclei.

NUCLEAR RESEARCH INSTITUTE OF THE ACADEMY OF SCIENCES
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# THE USE OF TWO DETECTORS FOR MEASURING TOTAL CROSS-SECTIONS IN THE THERMAL REGION

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(Paper presented at the Conference on
Neutron Physics, Kiev, May 1971)

The authors propose the use of two detectors with different path lengths for studying the effect of diffraction scattering of slow neutrons by grains. The following results were obtained for the energy dependence of the total cross-sections of osmium isotopes in the 0.07-0.3 eV energy range:

for osmium-187 $\sigma_{tot} = /7.4 + \frac{7.04 \times 10^5}{v} /$ barn

for osmium-190 $\sigma_{tot} = /17.8 + \frac{1.52 \times 10^4}{v} /$ barn

for osmium-192 $\sigma_{tot} = /16.6 + \frac{2.42 \times 10^4}{v} /$ barn

The scattering cross-section for osmium-186, 187, 190, 192 and natural osmium, obtained by extrapolating $\sigma_{tot}$ to t = 0 are, respectively: 18 ± 5, 75 ± 6, 18 ± 2, 17 ± 1 and 15 ± 3 barn. The radiation capture cross-sections for these isotopes are 80 ± 13, 320 ± 10, 16 ± 5 and 11 ± 5 b. However, in view of the possibility of small angle scattering occurring with all isotopes, these figures give only the lower limit except for $^{187}$Os. In the case of ytterbium-168 the total cross-section for v = 2200 m/sec is 4100 ± 700 b. The large cross-section is mainly due to the resonance of $^{168}$Yb at E = 0.6; however, a negative level contribution was also observed.

# DETERMINATION OF TOTAL CROSS-SECTIONS FOR THE SCATTERING OF SLOW NEUTRONS BY ATOMIC NUCLEI

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(Paper presented at the Conference on
Neutron Physics, Kiev, May 1971)

On the VVR-M reactor of the Nuclear Research Institute of the Academy of Sciences of the Ukrainian SSR the time-of-flight method was used to measure the total neutron scattering cross-sections for a number of isotopes in the 0.01-10 eV energy range. The resolution was 3-6 μsec/m. The measurements were performed with respect to vanadium, the scattering cross-section of which was taken to be 5.1 b.

The method of measurement is quite sophisticated. The detector consists of a battery of SNM-37 counters filled with helium-3 to a pressure of 7 atm. This makes it possible to increase the neutron recording efficiency to almost 100% and at the same time reduce corrections for variations in recording efficiency due to angular anisotropy of the scattered neutrons and variation in neutron energy during scattering. Methods have been developed for determining the background from the walls of the container for $n\sigma_t < 0.1$ and $n\sigma_t \geq 0.1$ (when using powders). Analytical formulae are given for correcting for multiple scattering and absorption of neutrons in the sample. Calculations using these formulae agree with calculations by the Monte Carlo method to within 2-3%.

The results of measurements of total cross-sections for scattering by metal foils made from natural holmium, erbium, ytterbium, dysprosium and thulium are given in the table, where $E_n$ is neutron energy in eV; $\sigma_3$ is the total neutron scattering cross-section (without deduction of the magnetic scattering cross-section $\sigma_M$/; $\bar{\sigma}_\delta \equiv \sigma_3 - \sigma_M$). By comparing the total cross-sections for neutron scattering by oxides and metals it can be deduced that the magnetic scattering of neutrons by the ions $Er^{3+}$, $Ho^{3+}$, $Dy^{3+}$, $Yb^{3+}$, $Tm^{3+}$ is practically identical in oxides and metals.

Allowing for possible systematic errors, the authors recommend the following cross-sections for scattering of neutrons by atomic nuclei of holmium, ytterbium and thulium in the 0.02-1.4 eV energy interval: 12.4 ± 0.6, 25.0 ± 0.6 and 12.0 ± 0.4 b respectively; and for erbium in the 0.02-0.12 eV energy interval: 11.0 ± 0.3 b.

## Table

Cross-sections for neutron scattering by nuclei of holmium, dysprosium, ytterbium, thulium and erbium

| $E_n$, eV | Ho | | Dy | | Yb | | Tm | | Er | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\bar{\sigma}_s$, barn | $\sigma_s$, barn | $\bar{\sigma}_s$, barn | $\sigma_s$, barn | $\bar{\sigma}_s$, barn | $\sigma_s$, barn | $\bar{\sigma}_s$, barn | $\sigma_s$, barn | $\bar{\sigma}_s$, barn | $\sigma_s$, barn |
| I,38 | I2,2 ± I,0 | I2,8 ± 0,8 | 50,0 ± I0 | 50,0 ± I0 | 23,2±0,6 | 23,3±0,6 | I2,2 ± 0,8 | I2,3 ± 0,6 | | |
| 0,62 | I2,0 | I3,4 | 59,7 ± 3 | 6I,0 ± 3 | 26,0±0,6 | 26,2±0,5 | II,8 | I2,2 | | |
| 0,35 | I2,I | I4,4 | 68,9 | 7I,0 | 25,0 | 25,6 | II,9 | I2,8 | | |
| 0,22 | I2,I | I5,I | 73,7 | 76,5 | 25,2 | 25,8 | I2,I | I3,3 | | |
| 0,I5 | I2,0 | I6,2 | 76,4 | 80,0 | 25,0 | 25,9 | I2,3 | I4,0 | | |
| 0,I2 | I2,0 | I7,3 | 78,9 | 84,0 | 25,2 | 26,I | I2,I | I4,8 | II,0 | I5,0 |
| 0,09 | I2,8 ± 0,5 | I9,8 ± 0,3 | 78,5 ± 3 | 85,0 ± 2 | 25,0±0,4 | 26,2±0,4 | I2,2 ± 0,3 | I5,0 ± 0,3 | I0,8 ± 0,4 | I6,I ± 0,4 |
| 0,07 | I3,0 | 22,0 | 79,7 | 88,0 | 25,I | 26,6 | I2,0 | I6,2 | I0,8 | I7,7 |
| 0,055 | I2,4 | 23,4 | 80,0 | 90,0 | 24,7 | 26,6 | I2,0 | I6,4 | II,2 | I8,7 |
| 0,05 | I2,2 | 25,2 | 8I,2 | 93,2 | 24,5 | 26,7 | I2,0 | I7,0 | I0,9 | 20,6 |
| 0,04 | I3,0 ± 0,5 | 28,2 ± 0,3 | 82,3 ± 3 | 96,5 ± 3 | 24,8±0,4 | 27,4±0,4 | I2,I ± 0,3 | I8,0 ± 0,3 | I0,8 ± 0,2 | 22,6 ± 0,2 |
| 0,032 | I2,9 | 30,9 | 83,2 | 99,5 | 24,6 | 27,6 | II,9 | I8,7 | II,2 | 24,3 |
| 0,028 | I2,0 | 33,5 | 83,6 | I02,0 | 24,4 | 28,2 | II,9 | I9,4 | II,0 | 26,5 |
| 0,0253 | I2,0 ± 0,6 | 37,0 ± 0,5 | 85,5 ± 4 | I06,0 ± 4 | 25,0 ±0,6 | 28,9±0,5 | I2,I ± 0,4 | 20,9 ± 0,3 | II,0 ± 0,3 | 28,5 ± 0,3 |
| 0,020 | I2,9 ± 2,0 | 40,0 ± I,0 | 90,0 ±I0 | II3,0 ± 6 | 24,6 ±I,0 | 29,0±0,8 | II,9 ± 0,8 | 23,5 ± 0,6 | II,0 ± 0,5 | 30,0 ± 0,5 |

# STUDY OF THE INTERACTION OF SLOW NEUTRONS WITH ISOTOPES OF A NUMBER OF ELEMENTS IN THE MASS NUMBER RANGE 168-192

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(Paper presented at the Conference on Neutron Physics, Kiev, May 1971)

With the VVR-M reactor of the Nuclear Research Institute of the Academy of Sciences of the Ukrainian SSR measurements were made of the transmission of samples enriched in osmium-186, 187, 189, 190, 192 and ytterbium-168, using a resolution of ~ 50 nsec/m, for neutrons of energy less than 1000 eV. Table 1 shows the resonance parameters of the osmium isotopes and Table 2 shows the distances observed between levels $\bar{D} = \Sigma^{Di}/n$ and $D^* = (\frac{\pi}{4M}\,\Sigma^{Di^2})_y^2$; Table 3 shows the strength functions $S^* = \frac{\Gamma n^o}{D^*}$bm and $S' = \frac{\Sigma\Gamma n^o}{\Delta E}$bm (most probable values). Table 4 shows the resonance parameters of $^{168}$Yb (the measurements were carried out on a sample with 17.1% $^{168}$Yb enrichment). The $^{168}$Yb levels were identified using the results for $^{170}$Yb given in BNL-325, Supplement No. 2 (1966). The mean distance between levels for $^{168}$Yb was $\bar{D} = (4.5 \pm 1)$ eV and $D^* = (4.3 \pm 0.9)$ eV. Of interest here is the smallness of the $^{192}$Os strength function compared with the other osmium isotopes. The distances between levels (referred to a nuclear excitation energy of 6.5 MeV and D = 0) of even-odd compound osmium nuclei come into the region of the minimum of the gross structure of $D_0$ as a function of N. For even-odd compound nuclei of ytterbium a dependence is observed in $D_0$ relative to N which is typical of the erbium, dysprosium and gadolinium isotope families.

Table 1

Levels of osmium isotopes

| № | $E_0$, eV | $\Gamma_n^0$, meV | № | $E_0$, eV | $\Gamma_n^0$, meV |
|---|---|---|---|---|---|
| | | Osmium-186 | | | |
| 1. | 22,37 ± 0,08 | 2,4 ± 0,3 | 4. | 89,5 ± 0,7 | - |
| 2. | 44,3 ± 0,25 | 12,3 ± 1 | 5. | 136 ± 1 | ~ 30 |
| 3. | 65,9 ± 0,45 | 10,4 ± 3,7 | 6. | 274 ± 4 (?) | - |
| | | Osmium-188 | | | |
| 1. | 38,4 ± 0,2 | 6,9 ± 0,6 | 5. | 314 ± 5 | - |
| 2. | 44,3 ± 0,25 (?) | 0,48 ± 0,16 | 6. | 332 ± 5 | - |
| 3. | 78,5 ± 0,5 | 52 ± 4 | 7. | 386 ± 6 | - |
| 4. | 187 ± 2 | - | | | |
| | | Osmium-190 | | | |
| 1. | 11,14 ± 0,03 | - | 4. | 165 ± 1,5 | - |
| 2. | 90,8 ± 0,7 | ≳ 2,6 | 5. | 323 ± 5 (?) | ~ 83 |
| 3. | 144 ± 1 | ≳ 7,5 | 6. | 563 ± 10 | - |
| | | Osmium-192 | | | |
| 1. | 20,33 ± 0,08 | $(1,7 \pm 0,5) \cdot 10^{-3}$ | 4. | 523 ± 10 | ~ 25 |
| 2. | 126 ± 1 (?) | 0,40 ± 0,04 | 5. | 585 ± 11 | - |
| 3. | 241 ± 3 | ~ 16 | 6. | 717 ± 16 | ~ 5 |

Table 1 (continued)

Osmium-187

| № | $E_0$, eV | $2g\Gamma_n^0$, meV | № | $E_0$, eV | $2g\Gamma_n^0$, meV |
|---|---|---|---|---|---|
| I. | 9,46±0,02 | 0,88±0,06 | 6. | 47,3±0,26 | 3,3±0,3 |
| 2. | I2,70±0,03 | 3,84±0,06 | 7. | 50,0±0,3 | 8,I±2,8 |
| 3. | 20,I9±0,07 | 0,58±0,05 | 8. | 63,4±0,4 | I0 |
| 4. | 40,4 ±0,2 | 4,4 ±0,6 | 9. | 89,5±I,5 | - |
| 5. | 43,4 ±0,22 | - | I0. | I24 ±I | 54 ± 9 |

Osmium-I89

| | | | | | |
|---|---|---|---|---|---|
| I. | 6,75±0,0I | I,I6±0,04 | II. | 4I,2±0,2 | 0,I0±0,08 |
| 2. | 8,97±0,02 | 2,8 ±0,2 | I2. | 43,0±0,2 | 0,24±0,05 |
| 3. | I0,30±0,03 | I,2 ±0,I | I3. | 50,0±0,3 | 4,5 ± 0,4 |
| 4. | I6,69±0,07 | I,2 ±0,I | I4. | 54,I3±0,3 | 3,8 ± 0,6 |
| 5. | 22,04±0,08 | I,8 ±0,3 | I5. | 60,3 ±0,4 | 0,88± 0,I4 |
| 6. | 22,7I±0,08 (?) | - | I6. | 64,2 ±0,4 | ~ I0 |
| 7. | 27,48±0,I | I,0 ±0,2 | I7. | 74,3 ± 0,5 | - |
| 8. | 28,I8±0,I2 | 3,8 ±I | I8. | 86,9 ± 0,6 | - |
| 9. | 30,I8±0,I2 | 0,I9±0,02 | I9. | 90,8 ± 0,7 (?) | - |
| I0. | 38,4 ±0,2 | 0,47±0,08 | 20. | I03 ± I,0 | - |

| № | $E_0$, eV | № | $E_0$, eV | № | $E_0$, eV |
|---|---|---|---|---|---|
| 2I. | I08±I | 26. | I38±I,2 | 3I. | 200 ± 2 |
| 22. | II2±I(?) | 27. | I44±I,2 | 32. | 2I4 ± 3 |
| 23. | II6±I | 28. | I55±I,5 | 33. | 235 ± 3 |
| 24. | I20±I,2(?) | 29. | I6I,5±I,5 | 34. | 260 ± 4 |
| 25. | I26±I,2 | 30. | I72 ± 2(?) | 35. | 323 ± 5(?) |

Table 2

Mean distances between levels of osmium isotopes

| ISOTOPE | $\bar{D}$ (eV) | $D^*$ (eV) | ISOTOPE | $\bar{D}$ (eV) | $D^*$ (eV) |
|---|---|---|---|---|---|
| I86 | 22 ± 6 | 22 ± 6 | I87 | 8 ± I,6 | 9 ± I,8 |
| I88 | 47 ± I0 | 57 ± I2 | I89 | 3,8 ± 0,7 | 4,5± 0,8 |
| I90 | 52 ± I4 | 52 ± I4 | | | |
| I92 | I40 ± 35 | I44 ± 35 | | | |

Table 3

Strength functions of osmium isotopes

| ISOTOPE | $S^* \times 10^4$ | $S' \times 10^4$ | ISOTOPE | $S^* \times 10^4$ | $S' \times 10^4$ |
|---|---|---|---|---|---|
| I86 | $5{,}6^{+7{,}8}_{-2{,}3}$ | $5{,}6^{+7{,}8}_{-2{,}3}$ | I87 | $2{,}0^{+2{,}0}_{-0{,}8}$ | $2{,}4^{+2{,}4}_{-1{,}1}$ |
| I88 | $5^{+9}_{-2{,}5}$ | $5^{+9}_{-2{,}5}$ | I89 | $2{,}0^{+1{,}0}_{-0{,}6}$ | $2{,}2^{+1{,}1}_{-0{,}7}$ |
| I92 | $0{,}6^{+0{,}9}_{-0{,}2}$ | $0{,}6^{+0{,}9}_{-0{,}2}$ | | | |

Table 4

Resonance parameters of $^{168}Yb$

| № | $E_0$ (eV) | $\Gamma_n^0$ (meV) | $\Gamma_\gamma$ (meV) | № | $E_0$ (eV) |
|---|---|---|---|---|---|
| I. | $E_0 < 0$ | | | II. | 78,5 ± 0,5 |
| 2. | 0,600 ±0,008 | 2,66±0,26 | 90 ± 6 | I2. | 80,7 ± 0,6 |
| 3, | 3,925 ±0,008 | 0,053±0,006 | 75 ± 25 | I3. | 253 ± 4 |
| 4. | 8,I7 ±0,03 | - | - | I4. | 289 ± 4 |
| 5. | 9,74 ±0,03 | 0,05 ±0,02 | I40± 30 | | |
| 6. | 22,60 ±0,05 | I0,5 ±I,I | - | | |
| 7. | 27,48 ±0,I | I ±0,4 | - | | |
| 8. | 40,8 ±0,2 | - | - | | |
| 9. | 56,8 ±0,4(?) | - | - | | |
| I0. | 66,8 ±0,4 | I6 ± 2 | - | | |

# TOTAL NEUTRON CROSS-SECTIONS OF EUROPIUM, GOLD AND WATER IN THE 0.008-0.3 eV ENERGY RANGE

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Using the VVR-M reactor of the Nuclear Research Institute of the Academy of Sciences of the Ukrainian SSR, the authors applied the time-of-flight method in measuring the total neutron cross-sections of europium-153 and natural europium, and the results were then used to calculate the cross-section of europium-151. The resolution was 3.5 μsec/m. The $^{153}Eu$ sample was in the form of the oxide $^{153}Eu_2O_3$ with 99.3% enrichment and a thickness of $1.35 \times 10^{21}$ nuclei/cm$^2$. It was shown experimentally that the contribution of highly absorbent impurities [Gd] to the $n\sigma t$ value of the sample amounts to $(5 \pm 3)$% and this was allowed for when calculating the total cross-section of europium-153.

For checking purposes the measurements of the total cross-section of natural europium were carried out on three types of samples:

(1) High-purity $Eu_2O_3$ powder (total impurity of highly absorbent elements $10^{-5}$);

(2) The same $Eu_2O_3$ powder mixed with graphite;

(3) Europium nitrate solution in heavy water.

The cross-sections for powdered samples are 4-4.7% greater than cross-sections obtained with the liquid sample. These differences are due to the inhomogeneity of the powdered samples. Results obtained by statistical averaging over all the samples agree for all practical purposes with the results for the liquid sample.

Table 1 shows the total neutron cross-sections of europium-151, europium-153 and natural europium in relation to neutron energy. The reduced error includes the statistical error, which was < 1%, the error due to uncertainty of the contribution of highly absorbent elements and also the inaccuracy in the determination of the sample concentrations. It should be noted that the cross-section of natural europium was determined with respect to the cross-section of water at 20°C (Table 2) which was determined using the measured thickness of the container. Table 2 also shows the total neutron cross-sections for gold measured in relation to neutron energy.

Table 1

Energy dependence of the total neutron cross-sections of $^{151}$Eu, $^{153}$Eu and natural Eu

| Neutron energy i.. eV | Total cross section of $^{153}$Eu in barns | Total cross section of $^{151}$Eu in barns | Total cross-section of natural europium in barns |
|---|---|---|---|
| 0,3 | 63 ± 4 | 4770 ± I70 | 23IC ± 90 |
| 0,25 | 67 | 3260 ± I20 | I590 ± 60 |
| 0,2 | 88 | I950 | 970 ± 40 |
| 0,I5 | I07 | I660 ± 60 | 850 ± 30 |
| 0,I | I34 | 2040 ± 70 | I045 ± 35 |
| 0,09 | I46 ± 5 | 2230 | II40 |
| 0,085 | I50 | 2420 | I230 |
| 0,080 | I55 | 2590 | I3I0 |
| 0,075 | I59 | 2700 | I370 |
| 0,070 | I63 | 2950 ± 90 | I500 ± 50 |
| 0,065 | I7I | 3260 | I650 |
| 0,060 | I8I | 3520 | I780 |
| 0,055 | I87 | 3953 | I970 |
| 0,050 | I99 | 4483 | 2250 |
| 0,045 | 2I0 ± 7 | 5II7 | 2560 |
| 0,040 | 225 | 5805 | 2850 |
| 0,035 | 239 | 67I0 ± 200 | 2340 ± 70 |
| 0,030 | 262 | 7990 | 3960 |
| 0,0253 | 282 ± 9 | 9490 ± 290 | 4690 ± I40 |
| 0,020 | 3I3 | II540 ± 360 | 5680 ± I70 |
| 0,0I9 | 3I8 | I2260 | 6040 |
| 0,0I8 | 334 | I2550 | 6260 |
| 0,0I7 | 346 | I3350 ± 4I0 | 6570 ± 200 |
| 0,0I6 | 358 | I3970 ± 440 | 6870 ± 2I0 |
| 0,0I5 | 364 ± II | I4670 ± 460 | 72I0 ± 230 |
| 0,0I4 | 376 | I5250 ± 480 | 7600 ± 240 |
| 0,0I3 | 395 | I5990 ± 500 | 8020 ± 260 |
| 0,0I2 | 405 ± I3 | I7030 ± 560 | 8420 ± 280 |
| 0,0II | 429 | I8480 ± 680 | 9060 ± 340 |
| 0,0I0 | 452 ± I5 | I9590 ± 840 | 9620 ± 420 |

Table 2

Energy dependence of total neutron cross-sections of gold and water

| Neutron energy in eV | Total cross-section of gold in barns | Total cross-section of $H_2O$ in barns |
|---|---|---|
| I | 29,I | 46 ± I,5 |
| 0,3 | 38,4 | 53,5 |
| 0,25 | 40,5 ± I,5 | 56,8 |
| 0,2 | 43,8 | 58,6 |
| 0,I5 | 5I,0 | 64 |
| 0,I | 57,5 | 7I,3 |
| 0,09 | 60,2 | 72,7 |
| 0,085 | 62,3 | 73,8 |
| 0,080 | 64,0 | 74,8 ± I |
| 0,075 | 65,5 | 75,5 |
| 0,070 | 66,8 ± 0,8 | 76,8 |
| 0,065 | 69,I | 78,3 |
| 0,060 | 70,8 | 80 |
| 0,055 | 74,I | 83,0 |
| 0,050 | 76,7 | 85,4 |
| 0,045 | 82 | 88,8 |
| 0,040 | 85,2 | 92,2 ± 2 |
| 0,035 | 90,2 | 96,9 |
| 0,030 | 96,6 | I03,I |
| 0,0253 | I05,I ± 0,5 | II0,0 ± 3 |
| 0,020 | II6,2 | II7,6 ± 3 |
| 0,0I9 | II9 | I20,I |
| 0,0I8 | I2I,7 | II8,I |
| 0,0I7 | I25,6 ± 0,5 | I30,5 |
| 0,0I6 | I28 | I26,9 |
| 0,0I5 | I33 | I3I,5 |
| 0,0I4 | I38 | I35,0 |
| 0,0I3 | I40 | I32 |
| 0,0I2 | I50 | |
| 0,0II | I55 ± 5 | |
| 0,0I0 | I62 | |

# THE DENSITY OF THE LEVELS OF COMPOUND NUCLEI IN THE REGION A = 130–200 AND OTHER NUCLEAR PROPERTIES

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(Paper presented at the Conference on Neutron Physics, Kiev, May 1971)

The following notation is used: $\bar{D}_0$ is the mean distance between levels referred to an excitation energy of 6.5 MeV and J = 0; $\bar{D}_{obs}$ is the experimentally observed mean distance between neutron resonances; $P_z$ is the proton pair interaction energy according to Cameron and Gilbert; $B_N$ is the neutron binding energy of a compound nucleus and N is the number of neutrons.

It is shown that the results of calculations according to the formula

$$\mathcal{D}_c\,(6.5\,\text{MeV}) = \bar{\mathcal{D}}_{obs}\,(2J+1)\left(\frac{6.5-P_z}{B_N-P_z}\right)^2 \exp\left[2\sqrt{a(B_N-P_z)}\left(1-\sqrt{\frac{6.5-P_z}{B_N-P_z}}\right)\right]$$

for the distances between levels (referred to an excitation energy of 6.5 MeV and J = 0) for even-odd compound nuclei in the range A = 130–200 in relation to N – the number of neutrons – display the following features:

(1) There are gross structure maxima of $D_0$ at N = 82,126 and in the region of N ≃ 100–110 with minima at N ≃ 90 and N ≃ 115;

(2) For each family of isotopes there is a characteristic isotopic dependence:

If $N < 90$, $D_0$ increases as N = 82 is approached;

If $N \gtrsim 115$, $D_0$ increases as N = 126 is approached.

In the interval N=90-115 each family has a maximum of $D_0$ at N ≃ 100–110. There are correlations in the relationships between the number of neutrons and the mean distances between levels (irrespective of their nature) in the region of the Fermi level and $D_0$ 165 MeV. Similar correlations are observed also in the proton and neutron pairing energies. These behaviour patterns agree with the well-known theoretical work of V.M. Strutinsky, who showed that the position of closed shells varies with deformation of the atomic nuclei. It is worth noting that the entropies determined in the experiment for a number of nuclei in the rare earth range are 20–30% greater than the theoretical values, if only single-particle degrees of freedom are taken into account.

# CORRELATION AND ANTICORRELATION OF THE REDUCED PROBABILITIES IN $(n,\gamma)$ AND $(d,p)$ REACTIONS FOR NUCLEI WITH $A \leqslant 81$

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(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

In Ref. [1] correlations were discovered between the reduced probabilities of E1 transitions in the thermal-neutron reaction $(n,\gamma)$ and the proton groups from the p-levels in the $(d,p)$ reaction for even-odd nuclei with $25 \leqslant A \leqslant 67$.

According to theory in Ref. [2] this is explained by the presence of a mechanism involving direct capture of the S-neutron by the p-level of the nucleus. Systematic investigation of the E1 transitions in the $(n,\gamma)$ reaction for nuclei with $67 \leqslant A < 81$ [3] has shown that in this range of nuclei the correlations become weaker, whilst for $^{69}Zn$, $^{71}Ge$, $^{73}G$ and $^{81}Se$ there are anticorrelations. The latter point to a thermal neutron capture mechanism differing from direct capture. It is assumed that there exists here a mechanism involving the formation of "input states" of the nucleon-phonon type. Ref. [4] reports an attempt to find a basis for this mechanism. Fig. 1 shows the dependence of the correlation coefficient on the atomic number of even-odd nuclei with $25 \leqslant A \leqslant 81$. The shaded points correspond to data which the authors obtained [3] for the $(n,\gamma)$ reaction.

The correlation coefficient was calculated on the basis of data from the literature for the $(n,\gamma)$ and $(d,p)$ reactions, using the formula

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\left[\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2\right]^{\frac{1}{2}}}$$

where x represents the reduced probability of an E1 transition, which is proportional to $I_\gamma / E_\gamma^3$, which is determined experimentally in the $(n,\gamma)$ reaction: ($I_\gamma$ is the intensity of the gamma peak, $E_\gamma$ is the energy of the gamma peak) and y represents the reduced neutron width, which is proportional to the spectroscopic factor $S(2j_f + I)$ which was experimentally determined in the $(d,p)$ reaction [5].

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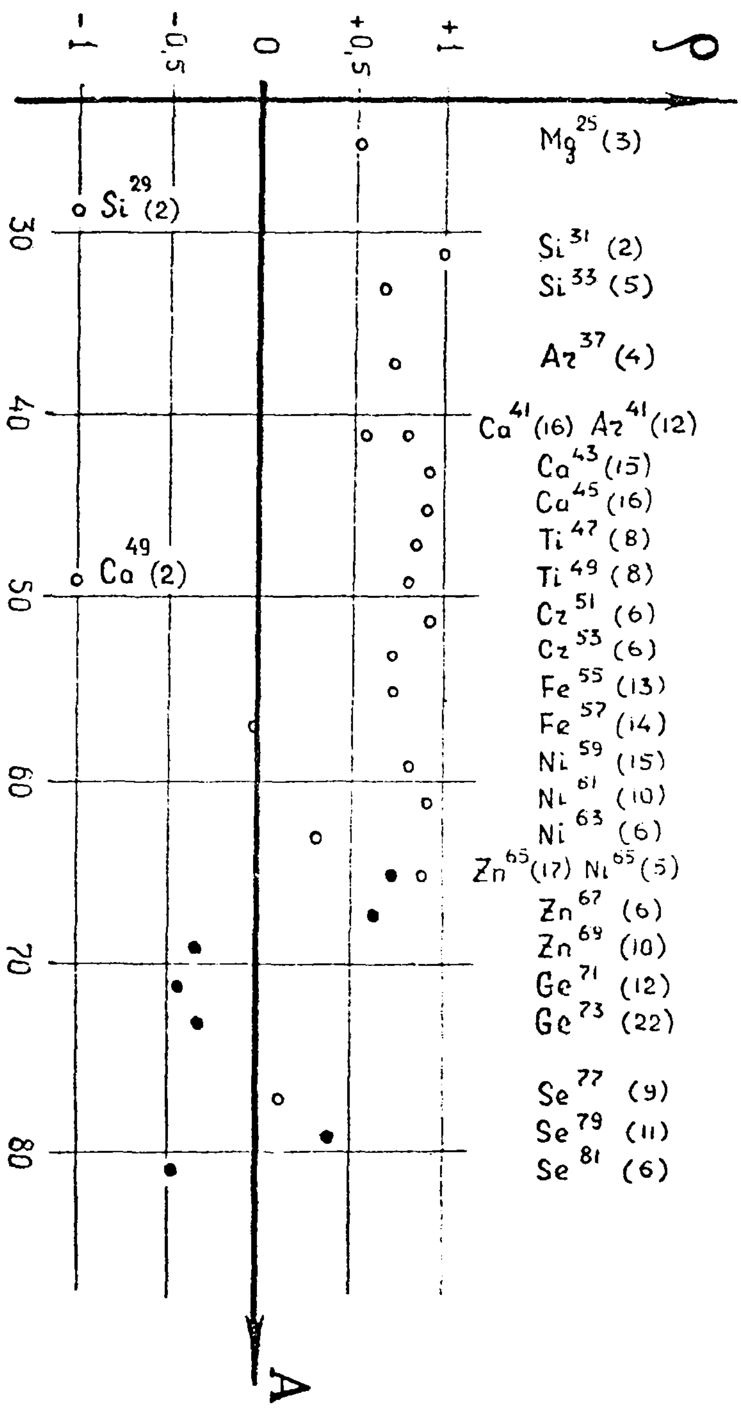
ρ
-1
-0,5
0
+0,5
+1
A
30
40
50
60
70
80
Mg25 (3)
Si29 (2)
Si31 (2)
Si33 (5)
Ar37 (4)
Ca41 (16) Ar41 (12)
Ca43 (15)
Ca45 (16)
Ti47 (8)
Ca49 (2)
Ti49 (8)
Cr51 (6)
Cr53 (6)
Fe55 (13)
Fe57 (14)
Ni59 (15)
Ni61 (10)
Ni63 (6)
Zn65 (17) Ni65 (5)
Zn67 (6)
Zn69 (10)
Ge71 (12)
Ge73 (22)
Se77 (9)
Se79 (11)
Se81 (6)

Fig. 1

# ENERGY AND ISOTOPE-SPIN DEPENDENCE OF THE OPTICAL POTENTIAL DERIVED FROM DATA ON NEUTRON SCATTERING

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(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

This paper presents the results of an optical model analysis of data on the elastic scattering of polarized and non-polarized neutrons by nuclei in the mass number range $48 < A < 137$ for four neutron energies in the range 1.5-6.1 MeV. For calculating the total and differential cross-sections as well as the polarizing capacities of the nuclei the authors employed a local optical potential which takes into account the surface absorption and spin-orbital interaction. The optimum sets of potential parameters ($V_c$, $W_c$, $V_{so}$, a) were obtained by fitting the computed data to the experimental data using the method of least squares. The parameters $r_o$ and b were taken as constant:

$r_o$ = 1.25 f, and b = 0.98 f.

For each of the neutron energies investigated (1.5 MeV [1], 3.2 MeV [2], 4 MeV [3], 6.1 MeV) the best parameters were determined for all the nuclei concerned. The potential parameters corresponding to the best fits for neutron energy 6.1 MeV are given in Table 1. By averaging the parameters obtained for this energy, it was possible to obtain the optical potential parameters independent of mass. The averaged potential parameters were used for determining the energy dependence of the parameters. The averaged parameters $V_{so}$ and a, which are practically independent of neutron energy, are 7.5 MeV and 0.65 f respectively. The real and imaginary parts of the central potential in the neutron energy range investigated are described by the equations:

$$V_c = (48.7 - 0.33\ E)\ \text{MeV}$$
$$W_c = (7.2 + 0.66\ E)\ \text{MeV}$$

Optical model analysis of our data on the scattering of polarized neutrons with energies of 1.5 MeV by medium nuclei enables us to establish the dependence of the real part of the central potential on the symmetry parameter $\alpha = (N - Z)/A$ as:

$$V_c = (51.8 - 30\ \alpha)\ \text{MeV}$$

The energy and isotope-spin relationships obtained for the real part of the central potential are in good agreement with the data of other authors (see Table 2).

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Table 1

Optimum values of the optical model parameters obtained from three-parameter analyses of data on the scattering of 6.1 MeV neutrons by medium nuclei. Comparison of the computed and experimental total cross-sections [4]

| Element | $V_c$ MeV | $W_c$, MeV | $a$, fermi | $\sigma_t^{comp.}$, barn | $\sigma^{ex}$ barn |
|---|---|---|---|---|---|
| V | 48,0 | 9,5 | 0,66 | 3,392 | 3,5I ± 0,07 |
| Cr | 46,5 | I0,0 | 0,73 | 3,552 | 3,66 ± 0,08 |
| Mn | 47,5 | I0,0 | 0,67 | 3,553 | 3,62 ± 0,08 |
| Co | 47,0 | II,0 | 0,69 | 3,689 | 3,74 ± 0,07 |
| Ni | 46,5 | I3,0 | 0,74 | 3,693 | 3,74 ± 0,07 |
| Cu | 46,5 | I2,5 | 0,74 | 3,826 | 3,84 ± 0,05 |
| Zn | 46,5 | I3,0 | 0,73 | 3,798 | 3,85 ± 0,07 |

Table 2

Comparison of the energy dependences of the real part of the central potential obtained by different authors

| Range of neutron energies covered | Energy dependence | Literature references |
|---|---|---|
| I ÷ 25 MeV | 48 - 0,29 E | [5] |
| 4,I ÷ I4 MeV | 48 - 0,3 E | [6] |
| 0,2 ÷ 24 MeV | 49,3- 0,33 E | [7] |
| 6 ÷ 24 MeV | 48 - 0,35 E | [8] |
| I,5 ÷ 6,I MeV | 48,7- 0,33 E | Data of this paper. |

# STUDY OF POLARIZATION IN THE ELASTIC SCATTERING OF 1.5 MeV NEUTRONS BY MEDIUM NUCLEI

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N.M. Pravdivy, I.E. Sanzhur

(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

The polarizing capacities of nuclei of Ti, Cr, Fe, Co, Ni, Cu, Zn, Ge, Zr, Nb, Mo, Cd, Sn and Sb were determined for neutrons of energy 1.5 MeV in the 20–145$^{\circ}$ angle range from measurements of right-left asymmetry in the scattering of partially polarized neutrons, produced by the reaction $T(p,n)^3He$ ($P_2(30^{\circ}) = 36 \pm 2\%$). The differential elastic scattering cross-sections of non-polarized neutrons were determined as the half sums of the cross-sections for scattering through the corresponding angles to the right and left of the bombarding neutron flux direction. The results of the measurements were corrected for neutron flux attenuation in the sample, finite geometry and multiple scattering.

The differential cross-sections are represented in the form of a Legendre polynomial expansion: $\sigma(\vartheta)\Sigma_{\ell=0} A_{\ell} Pe(\cos\vartheta)$. On the basis of measurements of $\sigma(\vartheta)$ the authors determined the total elastic scattering cross-sections $\sigma_{el}$, the transport cross-sections $\sigma_{trel}$ and the mean values of the cosine of the elastic scattering angle, cos $\vartheta$. The values of the calculated constants and the coefficients $A_{\ell}$ are given in Table 1. Data on the polarizing capacities of Ge, Cd, Sn and Sb nuclei are given in Table 2. Data on Ti, Cr, Fe, Co, Ni, Cu, Zn, Zr, Nb and Mo nuclei are contained in Ref. [1].

Experimental data on the angular distributions and the polarizing capacities of the investigated nuclei are analysed on the optical model. Theoretical calculations are performed using a six-parameter potential as proposed by Bjorklund and Fernbach.

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## Table 1

| Element | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $\sigma_{el}$, barn | $\sigma_{trel}$, barn | $\overline{\cos\theta}$ |
|---|---|---|---|---|---|---|---|---|---|
| Ge | 0,I8I±0,002 | 0,237±0,007 | 0,222±0,008 | 0,I46±0,0I2 | 0,059±0,0II | 0,0I4±0,0II | 2,273±0,045 | I,282±0,064 | 0,436±0,0I7 |
| Cd | 0,382±0.009 | 0,56I±0,022 | 0,574±0,027 | 0,I90±0,033 | 0,II3±0,026 | 0,0I0±0,03I | 4,798±0,096 | 2,447±0,I08 | 0,490±0,020 |
| Sn | 0,47I±0,003 | 0,62I±0,006 | 0,645±0,009 | 0,I68±0,0II | 0,I56±0,0I0 | 0,032±0,0I4 | 5,9I6±0,I36 | 3,3I9±0,I40 | 0,439±0,020 |
| Sb | 0,382±0,002 | 0,603±0,005 | 0,59I±0,006 | 0,2I7±0,0I0 | 0,066±0,008 | 0,025±0,009 | 4,798±0,082 | 2,274±0,I25 | 0,526±0,0I8 |



## Table 2

| | $P_2(\theta)$ | | | |
|---|---|---|---|---|
| $\theta^{\circ}$ l.s.c.* | Ge | Cd | Sn | Sb |
| 20° | -0,06I ± 0,05I | -0,043 ± 0,030 | -0,04I ± 0,029 | -0,069 ± 0,033 |
| 30° | -0,072 ± 0,045 | -0,057 ± 0,038 | +0,00I ± 0,043 | -0,046 ± 0,024 |
| 40° | -0,059 ± 0,036 | -0,074 ± 0,030 | -0,035 ± 0,033 | -0,045 ± 0,026 |
| 55° | -0,068 ± 0,050 | -0,035 ± 0,04I | +0,00I ± 0,032 | -0,0I5 ± 0,033 |
| 70° | -0,0I8 ± 0,044 | -0,I04 ± 0,054 | +0,006 ± 0,045 | -0,033 ± 0,039 |
| 85° | +0,0I5 ± 0,039 | -0,I37 ± 0,06I | -0,078 ± 0,067 | -0,02I ± 0,046 |
| I00° | -0,032 ± 0,049 | -0,I65 ± 0,062 | -0,I35 ± 0,062 | +0,0I2 ± 0,060 |
| II5° | -0,0I5 ± 0,068 | -0,058 ± 0,08I | -0,007 ± 0,080 | +0,I50 ± 0,072 |
| I30° | +0,048 ± 0,060 | +0,I48 ± 0,067 | +0,092 ± 0,058 | +0,203 ± 0,055 |
| I45° | +0,057 ± 0,053 | +0,206 ± 0,063 | +0,I79 ± 0,046 | +0,I63 ± 0,048 |

* Laboratory system of co-ordinates.

# ANALYSIS OF DATA ON THE SCATTERING OF 2.9 MeV NEUTRONS BY NICKEL ISOTOPES

M.B. Fedorov, T.I. Yakovenko

(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

The time-of-flight method was used to investigate the neutron spectrum resulting from elastic and inelastic scattering by the even-even isotopes $^{58}$Ni, $^{60}$Ni and $^{62}$Ni with excitation of the lowest levels 2+ for an incident neutron energy of 2.9 MeV.

The differential cross-sections of elastically scattered neutrons are given in Table 1 (mb/sr).

Table 1

| $\cos\theta$ | $Ni^{58}$ | $Ni^{60}$ | $Ni^{62}$ |
|---|---|---|---|
| 0,87 | 527 ± 30 | 4I2 ± 32 | 596 ± 30 |
| 0,7I | 202 ± 27 | I74 ± 22 | 378 ± 30 |
| 0,50 | 80 ± 25 | 79 ± I6 | I48 ± 28 |
| 0,26 | 40 ± I2 | 3I ± 9 | 55 ± I7 |
| 0,00 | 39 ± I2 | 74 ± I5 | 43 ± I2 |
| -0,26 | 205 ± I4 | 97 ± I4 | I46 ± I5 |
| -0,50 | I0I ± I5 | 94 ± I3 | I58 ± I6 |
| -0,7I | 97 ± I5 | II0 ± I5 | I02 ± I4 |

Table 2 shows the differential cross-sections of inelastic scattering with excitation of the lowest levels of the nickel isotopes (mb/sr).

Table 2

| $\cos\theta$ | $Ni^{58}$ | $Ni^{60}$ | $Ni^{62}$ |
|---|---|---|---|
| 0,87 | 5I ± 3 | 39 ± 3 | 39 ± 3 |
| 0,50 | 5I ± 3 | 42 ± 3 | 50 ± 3 |
| 0,26 | 44 ± 3 | 4I ± 3 | 44 ± 4 |
| 0,00 | 42 ± 3 | 45 ± 3 | 45 ± 3 |
| -0,26 | 45 ± 3 | 40 ± 3 | 50 ± 3 |
| -0,50 | 53 ± 3 | 40 ± 3 | 42 ± 3 |
| -0,7I | 52 ± 3 | 4I ± 3 | 35 ± 4 |

The results are comparable with optical model calculations in accordance with the statistical theory of Hauser, Feshbach and Moldauer.

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## SLOW NEUTRON CAPTURE CROSS-SECTION FOR $^{231}Pa$

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(Article submitted to Atomnaja Energija)

Irradiation of $^{231}Pa$ in the reactor results in accumulation of $^{232}U$ according to scheme:

$$Pa^{231}(n,\gamma)\,Pa^{232}\xrightarrow{\beta} U^{232}$$

Since the ratio of periods of alpha-decay of the initial $^{231}Pa$ and the final $^{232}U$ is quite high ($\frac{T_{231_{Pa}}}{T_{232_U}} = 439$), a noticeable increase in the alpha activity of the target occurs during short irradiations of a few hours in a flux of $\sim 10^{14}$ n/cm$^2$sec. The slow neutron capture cross-section for $^{231}Pa(\sigma_c)$, the integral neutron flux and the increase in the alpha activity of irradiated and cooled (for $\sim 10T_{232_{Pa}}$) $^{231}Pa$ are associated with the relation:

$$\sigma_c = \frac{1}{\varphi t}\cdot\frac{T_{U^{232}}}{T_{Pa^{231}}}\left[\left(\frac{S_{U^{232}}}{S_{Pa^{231}}}\right)_{\text{without Cd}} - \left(\frac{S_{U^{232}}}{S_{Pa^{231}}}\right)_{\text{with Cd}}\right],$$

where $\varphi$ is the neutron flux density;
t is the irradiation time;
$S_{232_U}$ and $S_{231_{Pa}}$ are the areas of the alpha peaks of $^{232}U$ and $^{231}Pa$ in the irradiation of cadmium-plated and plain targets.

The neutron flux at the location of the samples was measured using $^{237}Np$ targets.

The alpha spectra of irradiated and cooled targets with $^{231}Pa$ were measured on an alpha spectrometer with a surface-barrier gold-silicon detector. Since the relative measurements of the areas of the alpha peaks can be performed with an error of ~1%, the main part of the measuring error of $\sigma_c(^{231}Pa)$ is due to the measuring error of the neutron flux density and amounts to 4%.

As a result, the thermal neutron capture cross-section for $^{231}Pa$ was found to be 260 $\pm$13 b and the resonance capture integral ($I_c$) 1180 $\pm$ 120 b, the resonance capture integral for neptunium being taken as 945 b.

## EXCITATION FUNCTIONS OF THE REACTIONS $^{27}Al(n,p)^{27}Mg$ AND $^{27}Al(n,\alpha)^{24}Na$

Yu.A. Nemilov, Yu.N. Trofimov

The sample activation method was used to measure the excitation functions of the reactions $^{27}Al(n,p)^{27}Mg$ and $^{27}Al(n,\alpha)^{24}Na$ in the neutron energy range 7.7–9.3 MeV. The reaction $^{2}H(\alpha,n)^{3}He$ was used to obtain monochromatic neutrons.

## EXPERIMENTAL METHODS OF DETERMINING $\bar{\nu}(^{252}Cf)$

K.A. Petrzhak, E.A. Shlyamin

(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

On the basis of foreign literature a survey is made of experimental work in the past 10 years on absolute methods of determining $\bar{\nu}(^{252}Cf)$. The 2% disagreement which exists in the results can not as yet be explained by systematic errors in one or another experiment. The summarized experimental results, corrected according to Hanna and Westcott [1], the weighted mean value and also the fitted value for $\bar{\nu}(^{252}Cf)$ are shown in Table 1.

Table 1

Mean total number of neutrons per fission for $^{252}Cf$

| Authors | Method of measurement | Experimental values of $\bar{\nu}(^{252}Cf)$ with Hanna correction |
|---|---|---|
| Asplund-Nilsson et al. [2] | Liquid spin-p | $3.830 \pm 0.037$ |
| Hopkins, Diven [3] | Liquid spin-p | $3.793 \pm 0.031$ |
| Colvin, Sowerby [4] | "BORON" reactor | $3.713 \pm 0.015$ |
| Moat et al. [5] | Mn-bath | $3.727 \pm 0.056$ |
| Colvin et al. [6] | Mn-bath | $3.700 \pm 0.031$ |
| White and Axton [7] | Mn-bath | $3.796 \pm 0.031$ |
| Axton [8] | Mn-bath | $3.700 \pm 0.020$ |
| De Volpi, Porges [9] | Mn-bath | $3.739 \pm 0.017$ |
| Weighted mean value | | $3.743 \pm 0.016$ |
| Fitted value | | $3.7653 \pm 0.0104$ |

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## PROMPT NEUTRONS AND KINETIC ENERGY OF FRAGMENTS FROM SPONTANEOUS FISSION OF $^{244}Cm$

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(Article submitted to Jadernaya Fizika)

The authors measured the total number of prompt neutrons and the kinetic energy of both fragments for the spontaneous fission of $^{244}Cm$ in one fission event. This made it possible to obtain the dependence of the mean number of prompt neutrons per fission on the type of fission, as determined by the total kinetic energy and the mass of a heavy fragment. The number of neutrons in a fission event was measured using a liquid scintillation counter with an efficiency of $0.571 \pm 0.011$, which was determined from the mean number (known from the literature) of prompt neutrons $\bar{\nu}$ in the spontaneous fission of $^{244}Cm$ [1, 2]. The fragment energies were measured with semiconductor detectors. The calibration and processing of the energy measurements are described in Ref. [3].

The measurements of neutrons from spontaneous fission of $^{244}Cm$ are recorded in Table 1. The accuracy of the data supplied is determined by the measuring statistics and the known accuracy of the neutron counter efficiency, which depends on the error in the literature data for $\bar{\nu}$ from spontaneous fission of $^{244}Cm$ (it was assumed that $\bar{\nu} = 2.78 \pm 0.05$ after recalibration with a more accurate value of $\bar{\nu}$ for spontaneous fission of $^{252}Cf$) than that supplied in Refs [1, 2].

The slight errors introduced when correcting for counting errors due to coincidence of neutron pulses and for the background of the neutron counter (0.10 ± 0.01) were not taken into account. No corrections were introduced to cover variations in the neutron data due to energy dispersion during the measurements. The table shows the mean numbers of prompt neutrons per fission as a function of the total kinetic fragment energy and the mass of the heavy fragment. The latter data provided a means of calculating the relationship between the excitation energy consumed in neutron escape and the mass of the heavy fragment (Table 2). The mean fragment excitation energy associated with the escape of one neutron was determined as 7.2 ± 1.0 MeV.

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Table 1

Mean number of prompt neutrons per fission $\bar{\nu}$ for spontaneous fission of $^{244}Cm$ as a function of total kinetic fragment energy $E_K$ and heavy fragment mass M

| $E_K$ \ M | I22 | I24 | I26 | I28 | I30 | I32 | I34 | I36 | I38 | I40 | I42 | I44 | I46 | I48 | I50 | I52 | I54 | I56 | I58 | I60 | I62 | $\bar{\nu}(E_K)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 220 | I,56 | 0,36 | I,I3 | I,59 | I,96 | I,00 | 0,39 | I,I4 | | | | | | | | | | | | | | I,08 |
| 2I8 | I,84 | I,0I | I,25 | I,68 | I,88 | I,38 | 0,70 | I,35 | | | | | | | | | | | | | | I,I4 |
| 2I6 | I,68 | I,09 | I,6I | I,77 | I,39 | I,27 | I,I4 | I,4I | | | | | | | | | | | | | | I,I5 |
| 2I4 | I,40 | I,34 | 2,23 | I,92 | I,23 | I,2I | I,04 | 0,85 | 0,42 | 0,26 | | | | | | | | | | | | I,08 |
| 2I2 | I,56 | I,77 | 2,20 | I,66 | I,42 | I,38 | I,I2 | 0,8I | 0,62 | 0,60 | 0,34 | | | | | | | | | | | I,I9 |
| 2I0 | 2,33 | 2,36 | 2,I0 | I,60 | I,50 | I,62 | I,32 | I,I0 | I,06 | 0,76 | 0,I8 | | | | | | | | | | | I,33 |
| 208 | I,96 | 2,58 | 2,I9 | I,76 | I,72 | I,69 | I,48 | I,23 | I,I3 | I,06 | 0,28 | 0,I6 | | | | | | | | | | I,44 |
| 206 | 2,04 | 2,36 | 2,23 | I,76 | I,86 | I,79 | I,63 | I,44 | I,26 | I,I9 | 0,60 | 0,78 | | | | | | | | | | I,60 |
| 204 | I,86 | 2,36 | 2,38 | 2,04 | I,96 | I,89 | I,7I | I,60 | I,48 | I,32 | I,05 | 0,90 | | | | | | | | | | I,72 |
| 202 | I,94 | 2,22 | 2,34 | 2,I9 | 2,08 | 2,02 | I,9I | I,75 | I,70 | I,46 | I,I9 | I,08 | I,08 | | | | | | | | | I,85 |
| 200 | I,72 | 2,I9 | 2,06 | 2,I9 | 2,27 | 2,I8 | 2,09 | I,89 | I,84 | I,69 | I,4I | I,I7 | I,24 | I,23 | | | | | | | | I,97 |
| I98 | 2,25 | 2,30 | 2,I3 | 2,22 | 2,37 | 2,35 | 2,25 | 2,I0 | 2,03 | I,86 | I,58 | I,39 | I,30 | I,26 | I,32 | | | | | | | 2,09 |
| I96 | 2,43 | 2,37 | 2,43 | 2,34 | 2,36 | 2,46 | 2,39 | 2,29 | 2,I7 | 2,02 | I,66 | I,54 | I,44 | I,2I | I,46 | | | | | | | 2,20 |
| I94 | 2,56 | 2,53 | 2,78 | 2,45 | 2,49 | 2,62 | 2,64 | 2,49 | 2,33 | 2,20 | I,9I | I,72 | I,55 | I,65 | I,58 | I,53 | | | | | | 2,35 |
| I92 | 2,9I | 2,54 | 2,79 | 2,76 | 2,66 | 2,76 | 2,80 | 2,65 | 2,54 | 2,40 | 2,07 | I,88 | I,92 | 2,I2 | I,82 | I,32 | 0,85 | | | | | 2,49 |
| I90 | 2,50 | 2,66 | 2,88 | 3,08 | 2,88 | 2,90 | 2,89 | 2,75 | 2,70 | 2;57 | 2,35 | 2,0I | 2,20 | 2,I2 | I,87 | I,32 | 0,59 | 2,3I | | | | 2,62 |
| I88 | I,92 | 2,54 | 2,97 | 3,04 | 3,05 | 3,06 | 2,95 | 2,86 | 2,78 | 2,67 | 2,57 | 2,33 | 2,35 | 2,09 | I,87 | I,63 | 0,88 | 2,42 | 2,42 | | | 2,72 |
| I86 | 2,36 | 2,66 | 3,I8 | 2,95 | 3,I7 | 3,I9 | 3,0I | 2,98 | 2,96 | 2,85 | 2,78 | 2,47 | 2,36 | 2,I8 | I,83 | I,72 | I,60 | I,69 | | | | 2,82 |
| I84 | 2,3I | 2,60 | 2,93 | 3,00 | 3,26 | 3,28 | 3,I3 | 3,07 | 3,I9 | 3,02 | 2,89 | 2,70 | 2,44 | 2,34 | 2,I2 | 2,02 | 2,09 | I,9I | I,86 | | | 2,93 |
| I82 | 2,49 | 2,66 | 2,78 | 3,00 | 3,25 | 3,40 | 3,35 | 3,2I | 3,26 | 3,I4 | 2,99 | 2,82 | 2,62 | 2,47 | 2,29 | 2,32 | 2,I4 | 2,0I | I,83 | I,00 | | 3,04 |
| I80 | 2,50 | 2,78 | 3,05 | 3,I5 | 3,25 | 3,48 | 3,48 | 3,44 | 3,45 | 3,24 | 3,03 | 2,96 | 2,79 | 2,70 | 2,57 | 2,57 | 2,22 | 2,II | 2,05 | 0,60 | I,69 | 3,I5 |
| I78 | 2,69 | 2,90 | 3,22 | 3,2I | 3,34 | 3,58 | 3,63 | 3,60 | 3,59 | 3,49 | 3,I4 | 3,II | 3,00 | 3,00 | 2,80 | 2,75 | 2,60 | 2,36 | 2,27 | 2,0I | 2,34 | 3,26 |
| I76 | 2,50 | 2,90 | 3,I3 | 3,33 | 3,4I | 3,72 | 3,78 | 3,65 | 3,69 | 3,50 | 3,32 | 3,32 | 3,I0 | 3,00 | 2,82 | 2,82 | 2,70 | 2,52 | 2,55 | 2,42 | 2,35 | 3,32 |
| I74 | 2,54 | 2,83 | 2,88 | 3,28 | 3,48 | 3,82 | 3,93 | 3,75 | 3,70 | 3,46 | 3,49 | 3,46 | 3,I7 | 3,I2 | 3,02 | 2,97 | 2,84 | 2,65 | 2,46 | 2,50 | I,95 | 3,40 |
| I72 | 2,37 | 2,8I | 2,86 | 3,I8 | 3,37 | 3,68 | 3,86 | 3,72 | 3,7I | 3,58 | 3,64 | 3,6I | 3,34 | 3,26 | 3,I9 | 3,I9 | 3,20 | 2,87 | 2,55 | 2,42 | I,62 | 3;45 |
| I70 | 2,7I | 2,73 | 2,47 | 3,04 | 3,25 | 3,38 | 3,64 | 3,74 | 3,87 | 3,7I | 3,77 | 3,74 | 3,37 | 3,39 | 3,40 | 3,38 | 3,34 | 3,03 | 2,60 | 2,53 | 2,42 | 3,47 |
| I68 | 3,I2 | 2,92 | 2,95 | 3,I7 | 3,29 | 3,35 | 3,43 | 3,76 | 3,77 | 3,74 | 3,89 | 3,80 | 3,48 | 3,48 | 3,40 | 3,42 | 3,37 | 2,92 | 2,67 | 2,44 | 2,55 | 3,48 |
| I66 | 2,95 | 3,06 | 3,30 | 3,35 | 3,63 | 3,6I | 3,68 | 3,86 | 3,55 | 3,63 | 3,76 | 4,06 | 3,73 | 3,48 | 3,22 | 3,42 | 3,36 | 2,79 | 2,82 | 2,69 | 2,22 | 3,46 |

Table 1 (continued)

| I | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | I0 | II | I2 | I3 | I4 | I5 | I6 | I7 | I8 | I9 | 20 | 2I | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I64 | 2,63 | 2,97 | 3,I6 | 3,00 | 3,73 | 3,79 | 3,65 | 3,80 | 3,7I | 3,76 | 3,82 | 3,96 | 3,96 | 3,47 | 3,52 | 3,47 | 3,48 | 3,20 | 2,82 | 2,84 | 2,44 | 3,49 |
| I62 | 2,86 | 3,08 | 3,28 | 3,34 | 3,56 | 3,74 | 3,80 | 3,87 | 3,89 | 3,95 | 3,89 | 3,8I | 3,80 | 3,48 | 3,53 | 3,52 | 3,44 | 3,42 | 3,I6 | 2,90 | 3,I2 | 3,55 |
| I60 | 2,8I | 2,90 | 3,20 | 3,56 | 3,47 | 3,48 | 3,86 | 3,60 | 3,62 | 4,I2 | 3,90 | 3,77 | 3,84 | 3,74 | 3,87 | 3,74 | 3,60 | 3,38 | 3,48 | 3,32 | 3,57 | 3,57 |
| I58 | 2,77 | 2,74 | 3,II | 3,24 | 3,39 | 3,09 | 3,34 | 3,I7 | 3,36 | 3,8I | 3,87 | 3,74 | 3,8I | 3,82 | 3,93 | 3,96 | 3,88 | 3,60 | 3,5I | 3,35 | 3,54 | 3,55 |
| I56 | 2,65 | 2,98 | 3,I5 | 2;80 | 2,87 | 2,82 | 3,I0 | 3,I3 | 3,36 | 3,90 | 3,99 | 3,48 | 3,77 | 3,75 | 3,87 | 3,94 | 3,82 | 3,60 | 3,37 | 3,I6 | 3.50 | 3.45 |
| I54 | 3,29 | 3,46 | 3,59 | 3,I0 | 2,74 | 2,98 | 3,I2 | 3,06 | 3,55 | 3,83 | 4,I2 | 3,93 | 4,02 | 3,68 | 3,87 | 3,92 | 3,86 | 3,46 | 3,23 | 3,I8 | 3,I8 | 3,43 |
| I52 | 3,43 | 3,36 | 3,36 | 3,09 | 2,9I | 2,93 | 2,94 | 3,I6 | 4,I6 | 3,63 | 3,79 | 3,99 | 3,77 | 3,28 | 3,80 | 3,95 | 4,I6 | 3,67 | 3,23 | 3,27 | 3,25 | 3,45 |
| $\bar{\nu}(M)$ | 2,62 | 2,72 | 2,78 | 2,7I | 2,69 | 2,7I | 2,74 | 2,70 | 2,74 | 2,7I | 2,67 | 2,70 | 2,79 | 2,87 | 2,93 | 2,95 | 3,04 | 3,04 | 3,0I | 2,90 | 2,9I | 2,78 |



Table 2

Excitation energy per fission consumed on neutron escape $E_{xn}$
in relation to heavy fragment mass M

| M | I26 | I28 | I30 | I32 | I34 | I36 | I38 | I40 | I42 | I44 | I46 | I48 | I50 | I52 | I54 | I56 | I58 | I60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_{xn}$ | 22,2 | 2I,7 | 2I,5 | 2I,I | 20,6 | 20,2 | I9,7 | I9,0 | I8,6 | I7,I | I7,3 | I8,I | I9,2 | I9,3 | 20,5 | 2I,3 | 2I,I | 20,7 |

Table 3

Root mean square errors $\Delta\nu(E_K,M)$, $\Delta\nu_{EK}$ and $\Delta\nu_M$ for data of Table 1

| $E_K$ \ $M$ | I24 | I30 | I40 | I50 | I60 | $\Delta\nu_{E_K}$ |
|---|---|---|---|---|---|---|
| 220 | | I,48 | | | | 0,47 |
| 2I0 | I,4I | 0,23 | | | | 0,I5 |
| 200 | 0,64 | 0,I9 | 0,I4 | | | 0,08 |
| I90 | 0,59 | 0,22 | 0,I4 | 0,44 | | 0,08 |
| I80 | 0,6I | 0,35 | 0,I9 | 0,30 | | 0,I0 |
| I70 | 0,65 | 0,55 | 0,35 | 0,33 | 0,79 | 0,20 |
| I60 | 0,78 | 0,85 | 0,78 | 0,66 | I,0 | 0,26 |
| I50 | I,27 | I,27 | I,20 | 0,98 | I,27 | 0,40 |
| $\Delta\nu_M$ | 0,20 | 0,I2 | 0,09 | 0,I9 | 0,65 | |

## MEASUREMENT OF THE MEAN KINETIC ENERGIES OF FRAGMENTS OF THE FISSIONABLE NUCLEI $^{238}Pu$, $^{239}Pu$ AND $^{240}Pu$

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(Paper presented at the Conference on Neutron Physics, Kiev, 1971)

Relative measurements were made of the mean kinetic energies of fragments of the fissionable nuclei $^{238}Pu$, $^{239}Pu$ and $^{240}Pu$ produced during neutron-induced fission of $^{238}Pu$ and $^{239}Pu$ and by spontaneous fission of $^{238}Pu$. The experiments involved the use of reactor neutrons and also monochromatic fast neutrons of energy 1100 ± 80 keV. The mean kinetic energies of the fragments were determined by measuring the diameters of the tracks of fragments slowed down in glass [1], using a calibration curve constructed on the basis of data for well-known isotopes. It is shown that the total kinetic energies of fragments of the fissionable nuclei $^{239}Pu$ and $^{240}Pu$ coincide within the error limits, whilst for the corresponding energies in the case of $^{238}Pu$ and $^{240}Pu$ there is a deviation of 5.5 ± 3 MeV out of line with the trend for the total kinetic energy to be proportional to the parameter $Z^2/A^{1/3}$.

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## ANGULAR ANISOTROPY IN THE FISSION OF $^{226}Ra$ BY NEUTRONS WITH ENERGIES OF 4-10 MeV

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V.B. Funshtein

(Paper submitted to Jadernaja Fizika)

The authors have studied the fission of $^{226}Ra$ by neutrons in the 4-10 MeV range. The measurements carried out complement similar measurements reported earlier [1]. The angular distributions of fragments from the fission of $^{226}Ra$ by neutrons with E = 8-10 MeV were obtained. The neutrons were obtained from the reaction $D(d,n)^3He$. The deuterons were accelerated to an energy of 6.7 MeV on the cyclotron of the Radium Institute and moderated with platinum foils. The radium fission fragments were recorded by means of mica detectors processed in the usual way [2] after irradiation. The radium target weighing 220 ± 7 μg was obtained by evaporating $RaCl_2$ in a vacuum onto a nickel backing with a thickness of ~500 $\mu g/cm^2$. The results of the measurements are given in the table.

Table

Relative differential cross-sections, $\frac{\sigma(\vartheta^o)}{\sigma(90^o)}$, for neutron-induced fission of $^{226}Ra$

| $\theta$ \ $E_n$ (MeV) | 7,9 ± 0,I | 9,0 ± 0,I | 9,7 ± 0,I |
|---|---|---|---|
| II° | I,30 ± 0,06 | I,29 ± 0,06 | I,50 ± 0,06 |
| 2I° | I,36 ± 0,06 | I,38 ± 0,06 | I,46 ± 0,06 |
| 34° | I,27 ± 0,06 | I,32 ± 0,06 | I,I9 ± 0,06 |
| 47° | I,II ± 0,06 | I,2I ± 0,06 | I,22 ± 0,06 |
| 6I° | I,20 ± 0,06 | I,07 ± 0,05 | I,07 ± 0,05 |
| 76° | I,0I ± 0,06 | I,07 ± 0,05 | 0,95 ± 0,05 |
| 90° | I,00 ± 0,06 | I,00 ± 0,05 | I,00 ± 0,05 |

The anisotropies were calculated on the basis of these and the earlier measurements [1] of the angular distributions of fragments, which were processed by the method of least squares with expansion in terms of the Legendre polynomials $P_0$ and $P_2$ (Fig. 1b). These results were used to calculate the dispersions of the projection of the total angular momentum onto the axis of symmetry of the nucleus at the saddle point, $K_0^2$ (Fig. 1c). Analysis of the energy dependence and the value of $K_0^2$ in conjunction with data on the energy dependence of the neutron-induced fission cross-section of $^{226}Ra$ (Fig. 1a) indicates that the parameter $2\Delta f$ of the energy gap at the saddle point of $^{227}Ra$ increases to a value of $2.7 \pm 0.7$ MeV. This value of the parameter $2\Delta f$ can be explained by the significant increase in the surface area of a nucleus at the saddle point in the case of relatively light fissionable nuclei.

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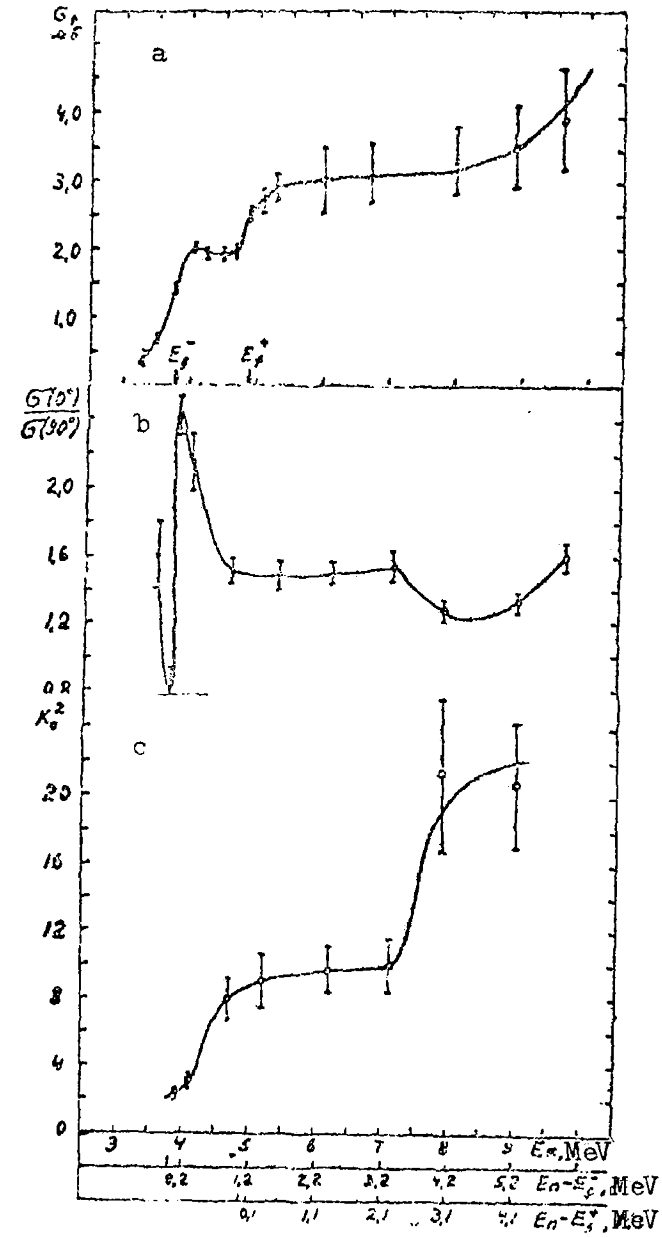


Fig. 1

Neutron energy dependence of: fission cross-section (a), anisotropy of fragment divergence (b) and dispersion in the distribution of the projection of the total angular momentum onto the axis of symmetry of a nucleus at the saddle point (c)

O = data of this paper

● = data from Ref. [1]

# NEUTRON EMISSION ANISOTROPY AND TOTAL KINETIC ENERGY OF $^{252}Cf$ FISSION FRAGMENTS

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The authors investigate the dependence of the neutron emission anistropy A on the total kinetic energy of fragments $E_k$ from spontaneous fission of $^{252}Cf$. The relationship $A(E_k)$ was also calculated using the neutron evaporation model. The experimental and theoretical data agree satisfactorily in the region of low $E_k$ and deviate appreciably as $E_k$ increases. This points to the existence of fission neutrons not associated with the evaporation mechanism.

| $E_K$ | A exp. | A theor. |
|---|---|---|
| I53 | 4,55 | 4,30 |
| I57 | 4,65 | 4,75 |
| I6I | 4,27 | 5,25 |
| I65 | 4,84 | 5,70 |
| I69 | 5,03 | 6,I5 |
| I73 | 5,I0 | 6,63 |
| I77 | 5,25 | 7,II |
| I8I | 5,I0 | 7,54 |
| I85 | 5,36 | 8,00 |
| I89 | 5,25 | 7,46 |
| I93 | 5,25 | 8,40 |
| I97 | 5,I8 | 9,33 |
| 20I | 4,8I | 9,85 |
| 205 | 4,75 | I0,3 |
| 209 | 4,66 | I0,8 |
| 2I3 | 4,63 | - |
| 2I7 | 4,25 | - |

## DEPENDENCE OF NUMBER OF NEUTRONS ON ALPHA-PARTICLE ENERGY IN TERNARY FISSION OF $^{252}Cf$

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The authors investigate the dependence of the number of neutrons on alpha-particle energy for the angles $0^{\circ}$, $90^{\circ}$ and $180^{\circ}$ between the directions of movement of an alpha particle and a neutron for ternary spontaneous fission of $^{252}Cf$. The alpha particles were recorded with a silicon detector and the neutrons with a stilbene crystal, the signals from neutrons and gamma rays being separated by the shape of the light flash. The experiment showed a difference in the number of neutron-alpha particle coincidences "in" and "against" the direction of movement of the alpha particles. Quantitatively this difference is expressed by the ratio $N_{co"in"}/N_{co"ag"} = 1.19 \pm 0.03$, i.e. 19% more neutrons are emitted in the direction of the alpha particles then in the opposite direction. After introducing a correction for the difference in the shape of the spectrum, the angular distribution, the number of neutrons from light and heavy fragments and the effect of the $\alpha$,n reaction in the detector material the figure is reduced to $17 \pm 3\%$. The alpha particle spectrum for $0^{\circ}$ was displaced 3.5 MeV in the direction of lower energies. These data indicate that the asymmetry effect is due to neutron emission by the isotope $^{5}He$ or $^{6}He$, since the $^{6}He$ spectrum is displaced 4 MeV towards lower energies. The yield of this isotope with respect to the number of coincidences at an angle of $90^{\circ}$ is $5.3 \pm 0.9\%$. The data obtained in this study do not allow any conclusions to be drawn as to the preferential yield of $^{5}He$ or $^{6}He$.

## FINE STRUCTURE IN THE MASS DISTRIBUTION OF FISSION FRAGMENTS

V.A. Korostylev, D.K. Ryazanov, V.A. Safonov

The authors measured the neutron and gamma ray yield for a fine structure in the mass distribution of $^{235}U$ thermal fission fragments, when the kinetic energy of a light fragment $E_1 = 108.5$ MeV.

The number of neutrons emitted by a heavy fragment was established to be as follows:

| | |
|---|---|
| For A = 132 | $\nu = 0.1 \pm 0.05$ |
| A = 134 | $\nu = 0.6 \pm 0.10$ |
| A = 140 | $\nu = 0.75 \pm 0.15$ |
| A = 148 | $\nu = 1.00 \pm 0.15$ |
| A = 154 | $\nu = 1.70 \pm 0.15$ |

The number of gamma rays does not vary very much with the mass and, on average, is seven rays per fission event.

## THE MASS DISTRIBUTION OF LONG-RANGE PARTICLE FISSION FRAGMENTS

V.G. Bogdanov, V.S. Bychenkov, Z.I. Soloveva, O.E. Shigaev

To construct the mass distribution of long-range particle fission fragments from the relation $E_\Lambda m_\Lambda = K E_m m_T$, it is necessary to know the coefficient K which allows for the alpha-particle recoil effect.

$$K = \left( \frac{\sin \varphi_T}{\sin \varphi_\Lambda} \right)^2$$

where $\varphi_T$ and $\varphi_\Lambda$ are the angles formed by an alpha particle with a light and a heavy fragment.

The authors derive the values of K for different mass ratios R of fragments from long-range particle fission of $^{235}U$ by thermal neutrons and of $^{238}U$ by fast neutrons.

| $R$ | No. of cases | $\varphi_\Lambda$ deg. | $\bar{\varphi}_T$ deg. | $\bar{K}$ averaged |
|---|---|---|---|---|
| $1,0 \leq R < 1,3$ | I50 | 83,7 | I0I,5 | 0,979±0,008 |
| $1,3 \leq R < 1,6$ | 2I2 | 82,4 | I02,I | 0,973±0,007 |
| $1,6 \leq R < 2,0$ | I37 | 80,3 | I04,6 | 0,958±0,008 |
| $R \geq 2,0$ | 45 | 79,I | I07,I | 0,903±0,030 |
| Total | 544 | 8I,9 | I02,3 | 0,965±0,004 |

SCIENTIFIC RESEARCH INSTITUTE FOR ATOMIC REACTORS

## DELAYED NEUTRONS FROM SPONTANEOUS FISSION OF $^{252}$Cf

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In this study experiments were performed to determine the energy, emission time and the number of delayed neutrons emitted during spontaneous fission of $^{252}$Cf. The time-of-flight method was used to determine the energy of separate groups of delayed neutrons. The measurements were performed on a path length of 3.5 m. The recorded spectrum clearly showed the separate peaks formed by the delayed neutrons. The peak energies are: 0.5 ± 0.01 MeV, 0.7 ± 0.01 MeV, 1.16 ± 0.02 MeV, 1.6 ± 0.03 MeV, 2.6 ± 0.1 MeV. The delayed neutron emission times have been estimated for certain peaks and these are shown in Table 1.

Table 1

| No. | Peak energy MeV | Emission time nsec |
|---|---|---|
| 1 | 0.7 ± 0.01 | 5 - 10 |
| 2 | 1.16 ± 0.02 | 2 - 3 |
| 3 | 1.6 ± 0.03 | 5 - 10 |

The method of delayed coincidences was used to determine the emission times of separate groups of delayed neutrons and their yield. These data are given in Table 2.

Table 2

| No. | Emission times of groups of delayed neutrons, T, nsec | Yield of delayed neutrons as % of total number of neutrons per fission |
|---|---|---|
| 1. | 2 ± 0.5 | 2.7 ± 0.4 |
| 2. | 7 ± 1 | 0.6 ± 0.1 |
| 3. | 30 ± 2 | 0.11 ± 0.03 |
| 4. | 80 ± 5 | |
| 5. | 120 ± 20 | |

THE D.I. MENDELEEV ALL-UNION INSTITUTE FOR
METROLOGY RESEARCH (VNIIM)

# DETERMINATION OF THE INTEGRAL PARAMETERS OF NEUTRON INTERACTION WITH CARBON

V.T. Shcheboleva

The author describes a method for determining the distance of constant spectral sensitivity in graphite to neutrons emitted by various sources. This was found to be 0.82 m for the VNIIM facility.

The diffusion length in graphite was determined by the "negative" source method, the result being 0.520 ± 0.002 m. The method of comparing the normalized distribution curves of thermal neutrons with the theoretical curves was used to measure the neutron moderation lengths in graphite. The results were 0.2270, 0.2054, 0.2022, 0.1991 and 0.1911 m respectively for the sources $T(d,n)^4He$, Pu-Be($\alpha$,n), Ac-Be($\alpha$,n) and PoB($\alpha$,n). The maximum error in measuring the age is 0.8%. It was found that the average energy of the Ac-Be($\alpha$,n) source should be taken as 4.1 MeV, i.e. 11% less than that quoted hitherto.

ALL-UNION INSTITUTE OF PHYSICOTECHNICAL AND RADIOTECHNICAL RESEARCH

## APPLICATION OF AN ITERATION METHOD FOR RAPID CONSTRUCTION OF ARBITRARY SPECTRA

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(Article published in the Bulletin, issue No. 7, 1970)

An iteration method is used for constructing a fast neutron spectrum from the results of activation measurements based on effective thresholds and cross-sections. On the basis of data supplied in graph form, a spectrum is constructed without the aid of a computer. The error in the values for the differential neutron flux density is estimated as 15%.