MEASUREMENT OF THE $\alpha$ VALUE AT $^{235}$U RESONANCES


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Formulation of the Problem. The ratio $\alpha$ of the capture cross section of neutrons to the fission cross section of $^{235}$U is one of the basic constants used in the design of nuclear reactors. The ratio must be determined with an error of less than 5% in a wide range of neutron energies. But the available information on the $\alpha$ value does not satisfy the accuracy requirements.

The errors in the measurement of $\alpha$ have two main reasons: 1) methodological difficulties of uniquely separating neutron capture events from the background of fission events and capture events of scattered neutrons and fission neutrons in the structural materials; and 2) errors in the determination of the parameters of the setup, which relate the experimentally measured spectra with the $\alpha$ value, i.e., errors in the calibration.

A number of known $\alpha$ values (calibration values) are used for calibration in some neutron-energy range which overlaps with the range of the measurements. The precision in the determination of $\alpha$ depends greatly upon both the position and the variability range of the $\alpha$ values of the calibration. One usually employs $\alpha$ values of the thermal energy range of the neutrons for calibration; in this range, the absolute value of the parameter is known with great precision. But the calibration values of $\alpha$ do not provide the high accuracy required at the present time because the variability range of $\alpha$ is not broad enough in the case of thermal neutrons and difficulties are encountered in the determination of the background level at these neutron energies.

The goal of our work was to obtain absolute calibration values of $\alpha$ at resonances of $^{235}$U. The resonance range is advantageously distinguished from the thermal range by the fact that the $\alpha$ values at the resonances change in a greater variability range from 0.08 to approximately 8, and the resonances proper can be separated from the background, i.e., in the case of the resonances, the background influences the precision of the measurements to a lesser degree.

The measurements were based on the spectrometry of the multiplicity of the radiation from excited nuclei [1-3]. The method made it possible to distinguish with high accuracy between capture events and fission events, to substantially reduce the background of the scattered neutrons and the fission neutrons, and, owing to the almost 100% recording efficiency, to obtain in the resonance region absolute $\alpha$ values without employing additional calibration values. The error made in the determination of $\alpha$ amounted to at most 2% in the majority of resonances. In addition to the improved calibration data, our work made it possible to verify the various methods of measuring $\alpha$, which were used in the energy range including the resonances. More specifically, it is interesting to compare the results of our work with the results of the Oak Ridge Laboratory [4] because the data of the preceding $\alpha$ measurements which were made in the I. V. Kurchatov Institute of Atomic Energy on $^{235}$U by spectrometry of the multiplicity [3] at 0.1-10 keV were systematically below the results given in [4].

Details of the Measurements and of the Resonance Range. In the present work, as in [3], the spectrometry of the multiplicity was employed. But a transition into resolved resonances...
(E_n ≤ 30 eV) made it possible to employ a thinner (n, γ) converter, the thickness of which suf-
ficed for shielding from scattered neutrons. As a consequence, the absorption in the converter of
the γ quanta leaving the sample could be substantially reduced. This helped to improve the
separation of capture events from fission events. The efficiency of recording interactions
of neutrons with nuclei increased and reached almost 100%. The high efficiency made it pos-
sible to obtain absolute α values without using calibration values and to exclude the back-
ground resulting from fission products, i.e., the fission neutrons and the emission from fis-
sion fragments. The background could be eliminated by shutting off the electronic equipment
of the detector after each recording of an interaction. The level of the remaining background
was determined from the region near a resonance and eliminated by subtracting the "uranium
substrate." Part of the useful events can be assumed as background because in regions neigh-
boring a resonance, the neutron cross sections are small but nonvanishing. When the back-
ground is taken into account in this way, the α value obtained differs to some extent from
the true α value. Therefore, when the values indicated were used for calibration (or for com-
parison with the results of other authors), an operation which is the analog of the subtrac-
tion of the "noise base" must be made in the calibrated (or compared) data within the same
energy limits.

Let us note that our measurements were made with a new spectrometer of the multiplicity,
which guaranteed high reliability of the results. The spectrometer volume (~200 liters),
was about two times greater than the volume of the spectrometer used in [3]. The volume of
the detector sections was also increased and the mutual shielding of the sections was reduced.
In this way, the efficiency of recording γ quanta was increased and the number of efficiently
working sections was raised.

Method and Measurements. The measurements were made on the 26-m flight base of the Lin-
ear Electron Accelerator of the I. V. Kurchatov Institute of Atomic Energy; a 48-section scin-
tillation detector (48SSD) with the NaI(Tl) crystal and a 10B converter with a thickness of
~0.3 g/cm² was used (Fig.1). The detector sections consisted of individual blocks in the
form of rectangular parallelepipeds. The central part of the detector consisted of crystals
with a size of 300 × 132 × 132 mm; the detector faces were composed of crystals with a size
of 150 × 132 × 132 mm. The smallest thickness of the scintillator in the direction of the
gamma quanta leaving the sample was ~13 cm; the geometrical efficiency of the detector was
~98%. The total scintillator volume was ~200 liters. The inner detector cavity had a size
of 40 × 40 × 45 cm. The detector was shielded on its outside with ~150-mm-thick boron carbide
and with 100-200-mm-thick lead layers.

An electron pulse of the accelerator had a duration of 100 nsec; the pulse frequency was
270 Hz. Filters of cadmium (1 mm thick), aluminum (16 mm thick), and lead (5 mm thick) were
placed on the path of the beam. The 235U sample under inspection was placed in the center
of the converter. In order to reduce the absorption of γ quanta in the sample, the sample
was given the form of six identical disks with a diameter of 29 mm and a thickness of 0.06 g/
cm²; the spacing of the disks was 1 cm. The amount of material in the converter and the sam-
ple cassette was minimized.

Each of the detector sections was viewed with an FEU-110 photomultiplier. The photomul-
tiplier signal was split into two channels. In the first channel, the signal passed through
an integral discriminator, was shaped to a standard pulse with a length of 0.3 µsec, and was
applied to an encoder of the multiplicity of coincidences. In the second channel, the photo-
multiplier signal was applied to a summing stage wherein the amplitudes of the pulses of all
detector sections were linearly superimposed. The output pulse of the summing stage was ap-
p lied to four integral discriminators ID_j (j = 1, 2, 3, 4) at which discrimination levels
corresponding to the energy liberation E_γ within the entire detector volume were adjusted
to 0.6, 0.8, 1.1, and 1.5 MeV. A 0.6-µsec-long strobing pulse from the first discriminator
was applied to the input of the encoder of the frequency of coincidences. During this pulse,
pulses from the integral discriminator of the detector sections could be received. The cod-
ing pulse generated by the encoder of the frequency of coincidences and the pulse of the dis-

criminators ID_j of the summing stage were applied to a time encoder and a computer. A time
channel had a width of 160 nsec; 32,767 channels were available.

As a result of the measurements in each time channel (interval) j corresponding to a cer-
tain neutron energy, four groups (j = 1-4) of spectra of the frequency of coincidences of 1-15
events were stored in the computer under the condition that the energy dissipation in the
entire detector volume had exceeded 0.6, 0.8, 1.1, or 1.5 MeV. A coincidence frequency above