ANGULAR ANISOTROPY OF THE GAMMA QUANTA ACCOMPANYING U^{235} FISSION

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The angular anisotropy of the γ radiation emitted in U^{235} fission induced by thermal neutrons is determined. It is found that $(12 \pm 2)\%$ more γ quanta are emitted in the direction of fragment motion than in the perpendicular direction.

SOME unpublished results of the measurement of the angular distributions of the γ radiation accompanying the fission of U^{235} and Pu^{239} were reported in the review articles by Whitehouse and Litchman.[1,2] According to these results, Rose and Wilson found that in U^{235} fission induced by thermal neutrons the intensity of the γ radiation is 20% larger at 0° to the direction of fragment motion than at 90°. Litchman[2] notes that an even more strongly pronounced preferred emission of γ quanta in the fragment-motion direction was observed according to other unpublished data.

These results raised certain doubts, since one could not exclude the finite probability of the detector (NaI crystal) registering along with the γ quanta also the prompt fission neutrons, for which there is a strong anisotropy in the laboratory system of coordinates. In this connection, Hoffman[3] measured the angular anisotropy of the γ radiation in U^{235} and Pu^{239} fission by thermal neutrons under conditions when the quanta were segregated by time of flight with the aid of a coincidence circuit with resolution time 2×10^{-8} sec and a base of 70 cm. Such apparatus could guarantee the segregation of 90% of the prompt neutrons, by their time-of-flight differences. The fragment collimator used in the measurements was such that the difference in the amount of substance that had to be traversed by the γ quanta on the path from the fragment to the detector at different measurement angles was small. The first measurements have shown that the γ-radiation distribution is isotropic. Later on, according to a communication by Litchman[2], Hoffman obtained an anisotropy $5.4 \pm 2.5\%$ in the fission of U^{235} by thermal neutrons. This result was regarded as preliminary, but no further communications were published.

The present investigation was undertaken in order to determine the angular anisotropy of the γ quanta in U^{235} fission by thermal neutrons, with better geometry and the registration of prompt fission neutrons practically eliminated. We also measured the angular anisotropy for the hard part of the spectrum of the γ-rays accompanying the fission.

A multichannel time analyzer with 3—5 nsec resolution was used to exclude the influence of the neutrons.

The γ quanta were registered with a stilbene crystal (80 mm diameter, 40 mm high) and a FÉU-33 photomultiplier. The γ-quantum detector was surrounded, to reduce the background, by 10 cm of lead. The registration threshold of the γ quanta was estimated by comparing the amplitude distributions of the γ-counter pulses produced by the γ radiation of Ce^{141}(E_γ = 140 keV) and Cs^{137} (E_γ = 660 keV). These estimates have shown that in the measurements performed the γ-quantum registration threshold corresponded to a ~ 100-keV γ radiation. The distance between the layer of the fissioning matter and the γ-quantum detector used in the anisotropy measurements was 75 cm.

In the preliminary measurements the fragments were registered with a gas scintillation counter. In this case the fragment motion direction was set by a copper collimator of very high transparency. The overall collimator diameter was 28 mm and its height 1 mm. The maximum angle of deflection of the fragment motion from the normal to the surface was 20°. A uranium oxide layer was deposited on an aluminum substrate 0.5 mm thick. The anisotropy obtained in these measurements was 25—30%.

So large a value of the anisotropy seemed doubtful, so that control measurements were made to ascertain the influence of the collimator and the substrate. To this end the Cs^{137} source was deposited in the form of a round spot on an aluminum substrate, placed in a gas counter at the location of the uranium-oxide layer, covered with the copper collimator, and the intensity of the γ radiation at 0° and 90° to the normal to the surface measured under these conditions. It was noted that the count at 90° was 17% less than at 0°. The count at 90° to the normal was approximately 7% less in the absence of the collimator. This indicates that noticeable absorption of the γ quanta is produced both by the collimator and by the substrate when the γ quanta move along the plane of the substrate. In this connection one might think that the larger anisotropy obtained in the earlier experiments can be partially due to the absorption of γ quanta in the collimators and substrates.

All further measurements were made under conditions in which the influence of the collimator and substrate was eliminated. The general setup of the apparatus is shown in Fig. 1. The fragments were detected by flashes in a thin scintillation film. The flashes were registered with a FÉU-33 photomultiplier. Fragments of specified direction were segregated by placing a target with the layer of fissioning matter at a certain distance from the detector. A uranium-oxide layer containing 97.9% U^{235} was deposited by electrolysis on an aluminum substrate 0.1 mm thick in the form of a round spot 2 cm in diameter, and was placed in a vacuum aluminum chamber in such a way as to cause the target plane to make an angle of 45° with the chamber axis. The distance from the target center to the detector plane was 60 mm. The thickness of the wall chambers was 0.5 mm, and the operating pressure was 10^{-2} mm Hg. Under these conditions the absorption of rays by the substrate was the same at 0° and at 90° to the chamber axis. The considerable thickness of the uranium-oxide layer (2 mg/cm^2), the nonlinear dependence of the flash in the scintillator on the particle energy, and also the dependence of the light yield on the type of registered particle have made it impossible to discriminate completely, on the basis of the pulse amplitude, between pulses due to fragments and pulses due to other particles and γ quanta. In this connection the discrimination threshold was set such as to register only part (about 80%) of the fission events. In this case no other particles were registered, as verified both by comparing the number of registered γ quanta per fission at different discrimination thresholds for the pulses from the fragment detector, and by measurements made without a uranium-oxide layer in the chamber. An increase in the discrimination threshold from 50 to 80 V did not change the number of registered γ quanta per registered fission, although the fragment counting rate doubled. The measurement of the counting rate of the pulses from the chamber in the absence of a uranium-oxide layer have shown that under the operating conditions (50-V threshold) the extraneous pulses registered amounted to < 0.05% of the number of registered fragments.

Figure 2 shows the pulse time distribution obtained in one of the measurement series for γ quanta at zero and 90° to the chamber axis. Under the conditions of this experiment, the time resolution was somewhat worse because of the differ-

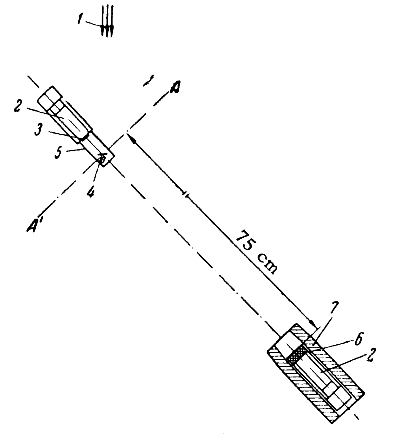

FIG. 1. Arrangement of the apparatus in measurements of the γ-ray intensity along the chamber axis: 1 – neutron beam, 2 – FÉU-33 photomultiplier, 3 – terphenyl film, 4 – uranium-oxide layer, 5 – vacuum chamber, 6 – stilbene crystal, 7 – lead shield. For measurements at 90° to the chamber axis the chamber was rotated about the point O and aligned with the AA′ axis.

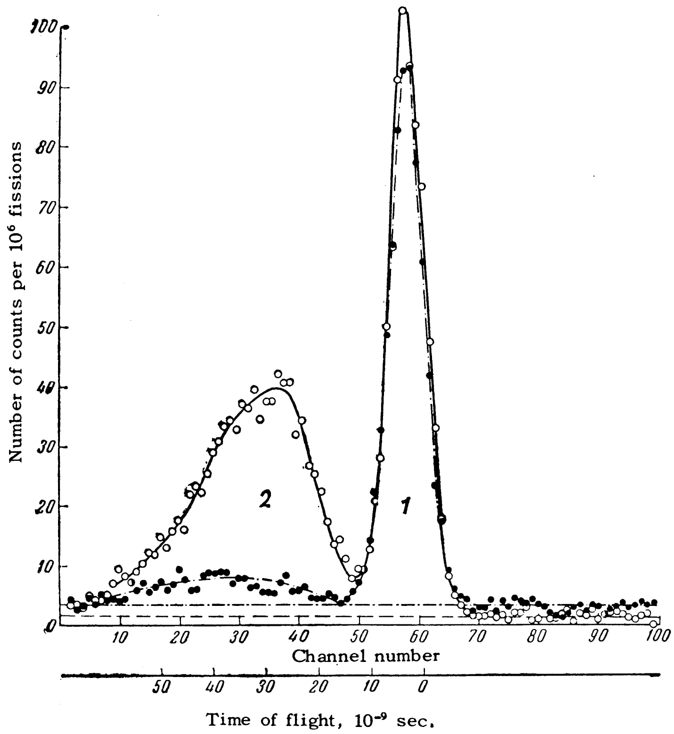

FIG. 2. Time distribution of the pulses obtained in measurements at 0° and 90° to the chamber axis: ○ – measurements at 0°; ● – measurements at 90°; dashed line – background in measurements at 0°; dash-dot line – background in measurements at 90°; 1 – γ quanta, 2 – fission neutrons.

ence in the time of flight of the fragments from the target to the detector. In this connection, the width of the γ-quantum peak at half its height was 8 nsec.

Altogether 19.5×10^6 fission events were accumulated in five series of measurements for registration of γ quanta in the direction of the chamber axis, and 19.8×10^6 events in the registration of γ quanta at 90° to the chamber axis. At the same time, 13,063 and 12,069 γ quanta were registered at zero and 90° to the chamber axis, respectively (after subtracting the background).

The experimental value of the obtained anisotropy was 10 ± 2%. The error is due to the statistical scatter, and the average deviation of the anisotropy obtained in different measurement series (±1.5%) does not exceed the statistical scatter. It should be noted that in measurements along the chamber axis the distance from the gamma-emitting fragments to the γ-quantum detector increases somewhat. The increase in distance is due to the fact that the lifetime of the fragments relative to the emission of γ quanta is of the order of 10^{-9} sec, while the average velocity of the fragment is $\sim 10^9$ cm/sec. This reduces the solid angle on the crystal by an average of 1%, thus increasing the anisotropy to (11 ± 2)%. The direction of fragment motion does not coincide, in the mean, with the chamber axis. It is therefore necessary to introduce a correction for the fragment collimation angle. This increases the anisotropy further to (12 ± 2)%.

Several series of measurements were made with a lead filter 10 mm thick placed along the flight path of the γ quanta. In this case the intensity of the registered γ radiation decreased by a factor of 3, and the spectrum of the registered γ quanta became much harder. The anisotropy under these conditions remained the same within the limits of accuracy. Its value, corrected for the solid angle and for the fragment collimation angle, is (13 ± 3)%. This indicates that the γ-radiation spectra at 0 and 90° to the fission direction are essentially the same. In addition, it is seen from this that the γ-quantum discrimination threshold does not influence the anisotropy.

It follows thus from the performed measurement that angular anisotropy of the γ quanta accompanying the fission occurs in the fission of U^{235} by thermal neutrons. The value of this anisotropy is

$$(W_\gamma(0°) - W_\gamma(90°))/W_\gamma(90°) = (12 \pm 2)\%$$

where $W_\gamma(0°)$ and $W_\gamma(90°)$ are the probabilities of emission of γ quanta at 0 and 90° to the fragment direction.

In comparing the results obtained with Hoffman's measurements[3] account must be taken of the fact that in Hoffman's work the maximum angle of deflection of the fragments from the fixed direction was 45°, which should greatly decrease the experimental value of the anisotropy. If we take this circumstance into account, the discrepancies obtained are greatly reduced.

In Strutinskiĭ's opinion[4] a possible reason for the angular anisotropy of the γ quanta may be the presence of a large angular momentum in the fragments, correlated with the direction of motion of the fragments. The occurrence of such a momentum may be due to the Coulomb repulsion of the "stubs" of the fragments after fission.

From the results we obtained we can estimate the average momentum of the fragments, which might cause the existing anisotropy. The dependence of the γ-radiation intensity on the angle has the form

$$W_\gamma(\theta) = 1 + k_L (\hbar^2 j/JT)^2 \sin^2\theta,$$

where $K_L = -3/8$, $J = (2/5)mAR^2$ is the moment of inertia of the nucleus, A = 115 is the mass number, R is the nuclear radius, m is the nucleon mass, T is the nuclear temperature, equal to 1 MeV.

If we assume that the γ radiation has essentially a quadrupole character (according to Strutinskiĭ, the character of the anisotropy implies that it is due to γ radiation of multipolarity $L \geq 2$), then the value obtained for the fragment momentum is $j \sim 25$—30. For L = 3 (octupole radiation) the value obtained for j is ~ 15—20.

So large a fragment momentum should make the prompt neutrons anisotropic in the fragment system. Assuming the dependence of the neutron emission probability as obtained by Ericson[5], we find that the anisotropy of the prompt neutrons should be ~ 5—7% for j = 25—30.

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