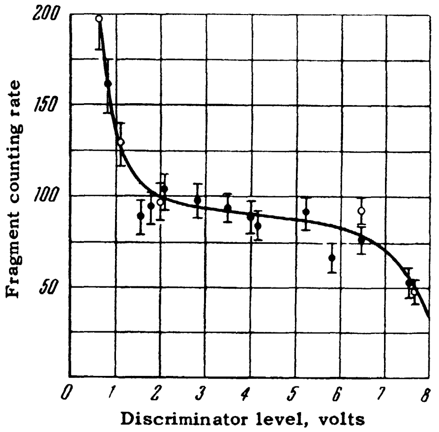

Counting response for two runs: o – at the beginning of the experiment with Am^{241}; • – at the end of the experiment.

lished the optimum conditions for counting fission fragments from Am^{241}. Measurements with Am^{241} ($\sim 60\,\mu g$) were conducted for 160 hours with a 4-volt discriminator threshold. Twenty-six pulses were recorded; control experiments showed that at least 18 of these belonged to the background. The corresponding lower limit of the spontaneous fission half-life of Am^{241} is 2×10^{14} years.

The counter was surrounded by a layer of cadmium and paraffin in order to obviate neutron-induced fission. Imitation of the observed effect by the spontaneous fission of Cm^{242} impurity is excluded since an estimate showed that not more than $10^{-10}\%$ of Cm^{242} could have been present.

In Segre's experiment[1] on the spontaneous fission of Am^{241} the target consisted of only $\sim 10^{-7}$ g and in 2700 hours three pulses from fission fragments were registered; this led to the lower limit $T_{1/2} \geq 1.4 \times 10^{13}$ years. The enhanced sensitivity of our technique resulted in a value of $T_{1/2}$ which is greater by a factor of ~ 15; this result is $\sim 10^5$ times greater than would be expected for an even-even nucleus with the given value of Z^2/A.

Approximately the same factor of lifetime increase was observed for the spontaneous fission of Pu^{239}, Bk^{249}, Cf^{249}, and $Es^{253,254}$. The spontaneous fission probabilities of the other odd nuclei must evidently be determined more precisely.

The authors wish to thank V. F. Gerasimov for a number of valuable suggestions concerning the construction of the counter.

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ANGULAR ANISOTROPY OF GAMMA QUANTA THAT ACCOMPANY FISSION

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A certain anisotropy relative to the direction of fragment divergence was recently observed for the gamma quanta that accompany nuclear fission.[1] The gamma intensity is greatest in the direction of fragment divergence, and the magnitude of the anisotropy $[W_\gamma(180°) - W_\gamma(90°)]/W_\gamma(180°)$ amounts to 9 and 5% for the fission of Pu^{239} and U^{235} respectively by thermal neutrons. Leachman's review[1] mentions also one of the possible causes of the angular anisotropy, namely that the initial deformations of the fragments, and consequently also the initial electric moments of the fragments, are correlated in a definite manner with the fission direction. This explanation, however, is subject to the objection that the time required for the nucleus to radiate gammas with energies on the order of 1 Mev is too long for any reasonable value of the electric moments. The quanta are therefore emitted by the fragments apparently already after thermal equilibrium has been established and after the neutron evaporation. This is also confirmed by the fact that both the shape of the gamma spectrum and the number of gammas (~ 4 or 5 per fragment) are close to what is observed for gammas that accompany the capture of thermal neutrons.[2]

Another possible cause of angular anisotropy of the quanta may be the presence of a large fragment angular momentum correlated with the fission direction. The momentum dependence of the density of nuclear levels leads in this case to anisotropy of the quanta even if complete thermal equilibrium is established in the nucleus.[3,4] A fragment momentum of large magnitude, oriented relative to the scattering direction, can occur, for example, if the scission of the nucleus is not strictly symmetric about the fission axis. The scission is a rapid, nonadiabatic process[5] and both the place of its occurrence and its direction can be assumed to fluctuate over a wide range. The fluctuation in the place of scission can explain the unique dependence of the number of secondary neutrons on the fragment mass,[6] if it is assumed that at the instant of scission there is concentrated in the neck a considerable mass, on the order of the fragment mass difference for the most probable asymmetric fission (private communication from O. Bohr). The presence of a transverse component of the Coulomb repulsion between the stubs, when the fission is asymmetric about the axis causes the fragments to rotate after scission in opposite directions about an axis perpendicular to the fission direction. The rotational momentum of the fragments will have an order of magnitude

$$\hbar j \approx f_{\perp}\tau R \sim (Z_1 Z' e^2/R^2)(a/R)\tau R,$$

where Z_1 and R are the charge and radius of the fragment, Z′ the charge of the stub, a a quantity on the order of the neck thickness, and τ is a characteristic time, equal to the smaller of either the time required for the fragments to diverge by a distance equal to the nuclear radius or the time required for the nucleus to resume its spherical shape. Taking $a \approx 2 \times 10^{-13}$ cm, $Z_1 = 50$, and $Z' = 5$ we find $j \approx 20$ for $\tau = 10^{-21}$ sec.

The angular distribution of the gamma quanta is calculated most readily in the following manner. The probability of emitting a quantum with momentum L is proportional to

$$\exp\{-\hbar^2(\mathbf{j}-\mathbf{L})^2/2JT\} \sim \exp\{-\hbar^2 jM/JT\},$$

where J is the moment of inertia, T the temperature, j the initial momentum of the fragment, and M the projection of the photon momentum on the direction of $\mathbf{j}$ ($\mathbf{j}$ is the classical vector).[3,4] The probability of emitting a photon making an angle θ with $\mathbf{j}$ will consequently contain the following angle-dependent factor

$$W_{\mathbf{j}}^{(L)}(\theta) = \sum_{M=-L}^{L} \exp\{-\hbar^2 jM/JT\} |\mathbf{Y}_{LM}^{(\lambda)}(\theta)|^2,$$

where $\mathbf{Y}_{LM}^{(\lambda)}$ is a vector spherical function.[7] Expanding the exponential, we get

$$W_{\mathbf{j}}^{(L)}(\theta) \approx 1 + \tfrac{1}{2}(\hbar^2 j/JT)^2 \sum_{M=-L}^{L} M^2 |\mathbf{Y}_{LM}^{(\lambda)}(\theta)|^2. \qquad (1)$$

The sum over M is easiest to calculate by using the specific expressions for the functions $\left|\mathbf{Y}_{LM}^{(\lambda)}\right|^2$ (cf. reference 7). After summation over M, only one term with $\cos^2\theta$ remains in (1). To obtain the distribution about the fragment direction, it is necessary to average this term also over the orientation of $\mathbf{j}$. Noting that the mean value is

$$\overline{\cos^2\theta} = \tfrac{1}{2}\sin^2\vartheta,$$

where ϑ is the angle to the direction of fragment divergence, we find

$$W_{\gamma}^{(L)}(\vartheta) = 1 + k_L(\hbar^2 j/JT)^2 \sin^2\vartheta,$$

where the values of k_L are $+1/8$, $-3/8$, and $-81/64$ for L = 1 (dipole radiation), 2 (quadrupole radiation), and 3 (octupole radiation) respectively. The negative sign of anisotropy for L = 1 is due to the fact that the dipole quanta are emitted predominantly along the spin ($L = |M| = 1$). When j = 10, T = 1 Mev, $J = (2/5)AmR^2$, and A = 100, the anisotropy of the fission gammas is found to be $\sim -1\%$ for dipole radiation and from +2 to +3% for quadrupole radiation. At the orientation of fragment angular momentum indicated above, the observed sign of the anisotropy leads to the conclusion that L > 1 for the anisotropic part of the radiation. The observed anisotropy is possibly connected with gamma transitions between the lower levels of the fragments, where the quadrupole radiation is relatively more probable, particularly considering that the presence of a large nuclear momentum leads, from the point of view of level density, to a certain preference for radiation with larger momentum, especially at low temperature. The increase in anisotropy with decreasing temperature also leads to an increased contribution from the transitions between the lower levels to the observed anisotropy of radiation. The smaller anisotropy of the gammas in the case of fission of U^{235} is possibly due to the poorer orientation of the fragment angular momentum at the large spin of the fissioning nucleus, the value of which is 3 or 4 for U^{235} fission and 0 or 1 in the case of Pu^{239}.

The foregoing results for the anisotropy of gamma quanta are correct also for other cases, when nuclei with large oriented momenta are obtained, for example, in the the capture of heavy ions.

I thank B. T. Geĭlikman, S. T. Belyaev, and G. A. Pik-Pichak for valuable comments.

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CROSS SECTIONS FOR ELASTIC SCATTERING OF 195-Mev POSITIVE PIONS BY CARBON AND LITHIUM NUCLEI

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THE elastic-scattering cross sections were measured at the Joint Institute for Nuclear Research with the aid of the synchrocyclotron and the same cloud chamber in magnetic field as used in the experiments with negative particles.[1] The source of positive pions was a polythene block 25 g/cm^2 thick, placed in the external 670-Mev proton beam. Particles of specified momentum were guided to the chamber by a deflecting magnet and a four-meter collimator placed in the concrete shield of the accelerator. Carbon and lithium targets (natural mixtures of the isotopes of these elements), 1.72 and 0.8 g/cm^2 thick, respectively, were placed in the working volume of the chamber. The intensity of the magnetic field in which the chamber was placed was 13,500 oe.

The experimental procedure and the processing of the photographs were the same as in the experiment with the negative pions.[1] In particular, the criterion for distinguishing elastic from inelastic scattering was the minimum measured energy loss, equal to 35 Mev. Taking into account corrections for detection efficiency in the angle interval from 10 to 180°, we registered 410 and 243 events of elastic scattering of mesons by carbon and lithium respectively.

The measured total cross sections (in millibarns) are listed in the table; to determine the absolute values of the total cross sections for elastic scattering, the total inelastic-scattering cross sections were normalized to the geometric nuclear cross sections for $R = 1.4\,A^{1/3} \times 10^{-13}$ cm.

Nucleus	Energy, Mev	Pion sign	Elastic, 10°	πR^2
C	195	+	204±26	325
Li	195	+	156±26	226
C	230	—	200±31	325

The last row of the table contains the total cross section for the elastic scattering of negative mesons by carbon.[1] Comparison of the data given for carbon nuclei shows that, within the limits of experimental error, the elastic-scattering sections are the same for positive and negative mesons with respective energies of 195 and 230 Mev. The cross sections obtained are also in satisfactory agreement with

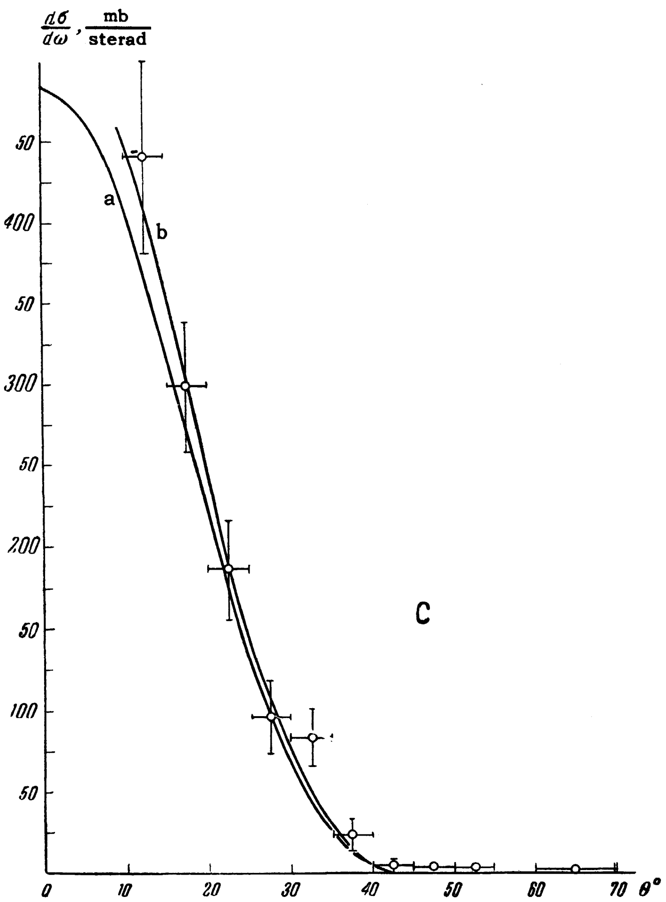

FIG. 1