$\pm 10\%$ (for Pb and U) and $\pm 20\%$ (for Fe and Cu). The accuracy of determining the integral cross section also depends on the accuracy of the determination of the absolute intensity of the neutron beam, being approximated as $\pm 10\%$. For checking this, the yield of neutrons from pure carbon was compared to that from carbon in paraffin. This was done to determine if scattered-unwanted-neutrons would be detected as well as the photoneutrons. The yields were shown to be identical within the limits of error of the measurements, demonstrating the absence of scattered-unwanted-neutrons. In the Table are shown the results of the experiments.

According to the maximum yield of photoneutrons from lead and uranium the determination of the integral cross section for these elements agreed with other data in the literature[2,3].

This agreement is evident from the applicability of the proposed method for determining the integral cross section. The assumption that for uranium $(\sigma_{\gamma n})_{int} = 92/82\, (\sigma_{\gamma n_{Pb}})_{int}$, gives for the photofission of uranium for $\nu_n = 2.5$ the value $(\sigma_{fiss})_{int} = (8.2 - 5.8)/2.5 \approx 1$ Mev-bn. The maximum coefficient for converting into photoneutrons of the photons from bremsstrahlung with energies from the threshold of the (γ, n) reaction for lead (6 Mev) to 250 Mev is equal to

$$\alpha_{\gamma n} = Q_{\text{макс}} \Big/ \int\limits_{E_1}^{250\text{MeV}} \frac{a}{E}\, dE \approx 0{,}04.$$

For Fe and Cu the maximum yield of photoneutrons was not determined, because the geometrical conditions of our experiment required the approximation of a point source, and since the dimensions of the blocks were $10 \times 10 \times 10$ cm, only in the case of the heavy nuclei was the electron-photon shower completely developed, and the limiting value of the yield of the neutrons reached. Approximate appraisal of the maximum yield of photoneutrons from Fe and Cu can be made, since certain energy resonances of the (γ, n) reaction, as for Pb and U, do not lie below the critical energy, by assuming that the ratio Q_n / Q_{max} is identically dependent for all the enumerated elements on the thickness of the block in t-units. Such an approximation gives an integral cross section of 1.3 Mev-bn for iron and 2.1 Mev-bn for copper.

Likewise, measurements of the yield of photoneutrons were made for the light nuclei (C, Al). However, in the cubes of 10 cm thickness in the case of these substances, the electron-photon shower was even less developed. Therefore, there is required the use of the more complicated computation of the shower theory, whose description goes beyond the limits of the present communication.

The method of determining the integral (γ, n)-cross section and the maximum yield of photoneutrons by means of a simple calculation for an equilibrium shower spectrum can certainly be useful, also for the light nuclei. In this case it is necessary to use a block of larger dimensions, determining the number of photoneutrons not by means of a slowing down curve, but by a direct method, i.e., by detecting the photoneutrons being emitted at the various angles by means of a flat boron counter or a fission chamber of U^{235}.

In conclusion, the determination of the maximum yield of photoneutrons by means of developing showers from photons of high energy shows an interesting possibility for calculating the conversion of the electron-photon components of cosmic rays into nucleons.

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The Fission of Uranium Nuclei Under the Action of Slow Π^- Mesons and High Energy Particles

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(Submitted to JETP editor March 9, 1955)

J. Exper. Theoret. Phys. USSR **28**, 729-732 (June, 1955)

In this work, investigation was made of the fission of uranium nuclei by slow π^- mesons[1,2] * by fast neutrons up to 460 mev, and by γ rays up to 250 mev[6]. For the recording of the fission of uranium nuclei, photographic plates were used with an emulsion of 100 μ thick, into which there was introduced uranium acetate[7]. The plates permitted observation of protons up to 30 mev. The irradiation of the plates by slow π^- mesons and fast neutrons was performed in the synchrocyclotron of the Institute for Nuclear Problems, Academy of Sciences, USSR. Irradiation with gamma rays was performed in the synchrotrons of the Institute of Physics, Academy of Sciences, USSR.

Among more than 300 π^- mesons stopped in the emulsion, there were observed 96 π^- mesons which produced fission of uranium nuclei. Out of this total, division into two fragments took place in 81 cases (Fig. 1) and in 15 cases a third fragment was emitted, (Fig. 2). As a rule, the two fragments resulting from the fission fly away in opposite directions. An evaluation of the probability of fission of uranium nuclei under the action of slow π^- mesons results in a value of 0.5, i.e., in approximately 50% of the cases the π^- meson captured by the nucleus causes its fission.

In the plates irradiated with a neutron beam of a uniform energy spectrum up to 460 mev, there were found 309 cases of uranium fission, and among them 69 cases in which the fission was accompanied by the emission of one or more charged particles of long path (Figs. 3 and 4).

Data were also obtained on the fission of uranium by neutrons of maximum energies of 180 mev and also by neutrons of 14 mev. Comparison of the experimental results for the neutrons of the three energy values shows that the number of uranium nuclei fissions which are accompanied by the emission of long path particles increases rapidly with the increase of the energy of the primary neutrons.

On the plates irradiated with γ rays of maximum energy of 250 mev, there were found 2066 cases of fission, and among them 45 cases accompanied by

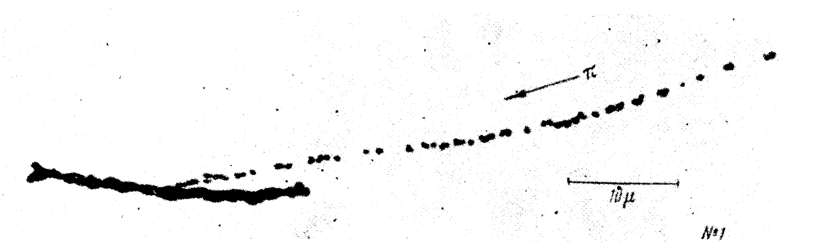

FIG. 1. Fission of a uranium nucleus by a π^- meson into two fragments.

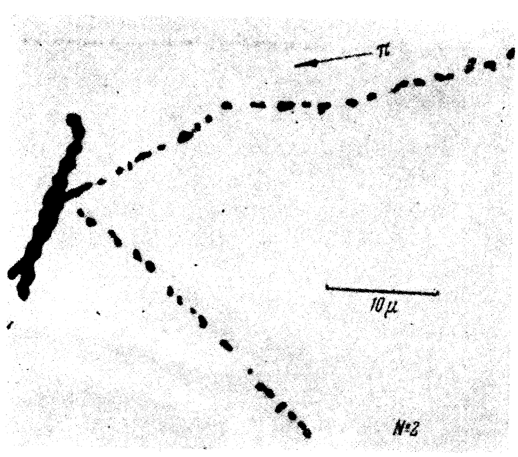

FIG. 2. Fission of a uranium nucleus by a π^- meson accompanied by the emission of a proton of 18 mev energy.

FIG. 3. Fission of a uranium nucleus by a fast neutron accompanied by the emission of a 16 mev proton and an α particle of energy greater than 8 mev.

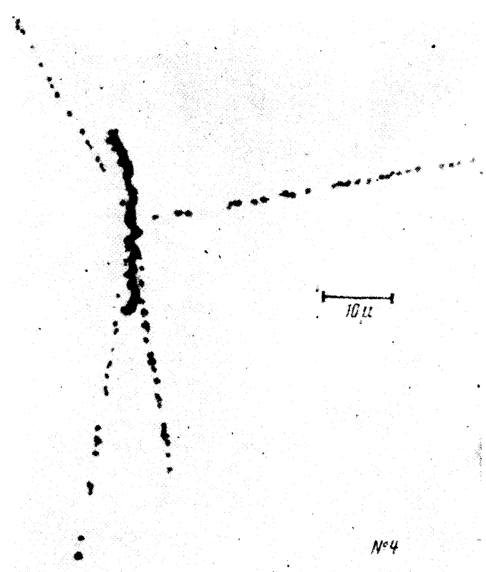

FIG. 4. Fission of a uranium nucleus by a fast neutron accompanied by the emission of 4 protons of 27, 23, 23 and 30 mev.

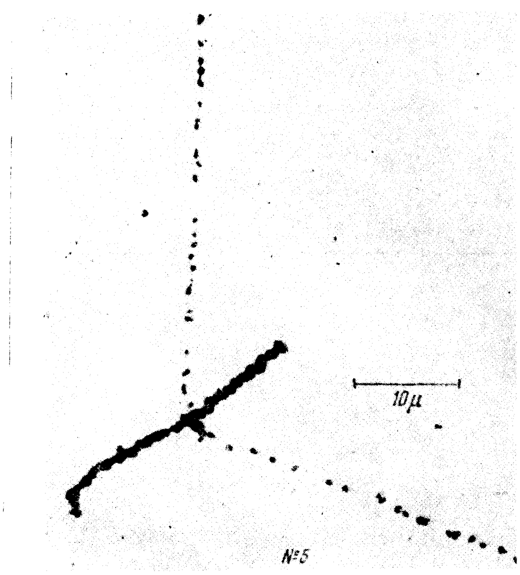

FIG. 5. Fission of a uranium nucleus by a γ quantum up to 250 mev accompanied by the emission of two protons of 11 and 15 mev.

the emission of one or more charged particles of long path (Fig. 5) On the plates irradiated with γ rays of maximum energy of 80 mev, there were found 614 cases of fission and among them three cases accompanied by the emission of a long path particle. Finally, on the plates irradiated with γ rays of energies up to 30 mev, there were found 717 cases of fission, and among them one was accompanied by the emission of an α particle of long path. No emissions of charged particles were observed.

The combined results obtained by us show that fission accompanied by the flight of fast charged particles is actually caused by high energy photons and this permits us to refute the previously prevailing assumption that the effective cross section of fission of uranium nuclei, under the action of γ rays of energy greater than 100 mev, is nearly zero (as is the case for the energy interval 30-100 mev[8]).

This result is confirmed by the data obtained in a recently published work[9], performed with γ rays of energies up to 300 mev.

Multiple paths, i.e., paths of pairs of fragments resulting from uranium nuclei fission under the action of slow π^- mesons, fast neutrons of energies up to 460 mev and γ rays up to 250 mev, fall within the same limits as the paths of the fission fragments under the action of low energy neutrons (several mev), and this agrees with the results of references 10 and 11. It follows that the energy introduced by these agents into the uranium nucleus, as a rule, is not transformed into kinetic energy of the fragments but is spent in other processes.

The comparison of the paths of light and heavy fragments formed in the process of fission by π^- mesons, fast neutrons and gamma rays of high energy** on one hand and slow neutrons on the other, points to the more symmetrical nature of the fission process under the action of high energy particles. Similar results were obtained in recently published works of references 12 and 13.

The majority of the charged particles accompanying the fission of uranium nuclei by the π^- mesons, fast neutrons and high energy γ rays are of a single charge, and are mainly protons (although the possibility is not excluded that a small fraction of these particles are deuterons and tritons), and the remainder, a small number, proved to be α particles. The energy of the protons, evaluated from the measurements of grain density along the trace, lies within the limits 10 to 30 mev. It should be borne in mind that flights of protons of energies greater than 30 mev could not be observed by us because of the limited sensitivity of the plates. The energy of the α particles lies within the limits 14 to 35 mev.

The angular distribution of α particles with respect to the direction of motion of the fragments is anisotropic. Flights at angles close to 90° to the direction of motion of the fragment are predominant. Similar angular distribution is observed for ∝ particles emitted with the fission of uranium nuclei under action of slow neutrons. This characteristic, as known, is explained by the fact that ∝ particles are emitted in the process of fission and upon leaving (the nucleus) are subjected to the action of the Coulomb field of the two departing fragments. It is therefore natural to assume that the majority of the ∝ particles observed by us were also emitted in the process of fission.

The angular distribution of single charged particles with respect to the direction of motion of the fragments is nearly isotropic. The angular distribution with reference to the direction of the primary neutron beam is generally in the forward direction. The direction of emission of the majority of protons forms an angle less than 90° with the direction of the neutron beam.

For fission under the action of high energy photons, the angular distribution of single charged particles with reference to the direction of the incident γ ray beam is characterized by the existence of a maximum angle close to 90°. Such form of angular dependence allows us to make the statement that the majority of the single charged particles accompanying uranium fission are emitted by the uranium nucleus before the process of fission. The absence of isotropic angular distribution of particles of such energy thus indicates that they are basically emitted not in the process of evaporation but are recoil nucleons formed as a result of direct interaction between the primary neutrons, γ quantum or π^- meson with the nucleons in the nucleus, or as a result of a developed cascade process in the nucleus, caused by the primary particle. In this way the emission mechanism of single charged particles accompanying uranium nuclear fission differs substantially from the emission mechanism of the majority of ∝ particles.

We must conclude, on the basis of obtained experimental data, that the special characteristic of the uranium nuclear fission at high excitation energies, is the high probability of emission of fast protons and ∝ particles. These particles carry away only a relatively small portion of the energy received by the uranium nucleus from the primary particle. Since the mean energy of the fragments thereby remains the same as in the case of fission by slow neutrons, it follows that the major part of the energy introduced into the nucleus by π^- mesons, fast neutrons and high energy γ rays, is spent in the emission of neutrons of various energies. A considerable number of these neutrons must be emitted before the fission.

A more detailed communication of results obtained is now in press and will be published in this journal.

In conclusion, we express our thanks to Profs. M. G. Meshcheriakov, G. P. Dzhelepov and E. L. Grigor'ev for the help in carrying out the experiments with the π^- mesons and fast neutrons and to Prof. V. I. Veksler and Iu. S. Ivanov for their cooperation in experiments with high energy γ rays.

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* The energy spectrum of neutrons from the recharge of 670 mev protons (acting) on beryllium was measured by V. B. Fliagin.

* Fission of uranium by π^- mesons was also investigated independently by Ivanova and Perfilov[3]. References 4 and 5 are also devoted to this problem.

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