

FISSION OF URANIUM NUCLEI INDUCED BY 9-Bev PROTONS

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Some characteristics of uranium fission induced by 9-Bev protons are obtained. These include the magnitude of the cross section, the dependence of the yield on the ratio of the fragment ranges, data on the number of light particles involved in fission, and the angular distributions of the fragments.

EXPERIMENTAL CONDITIONS

WE used the photographic method. Nuclear emulsions of type P-9ch with natural uranium introduced into the emulsion¹ were exposed to 9-Bev protons in the internal beam of the proton synchrotron of the Joint Institute for Nuclear Research. In scanning the emulsions, we classified as uranium-fission events also those cases of disintegration in which, along with tracks of light charged particles, essentially protons and α particles, two tracks which are similar in the darkening intensity to tracks of fragments of fission by thermal neutrons are observed. The overwhelming majority of the registered events has a light-to-heavy fragment ratio $L_l/L_h < 2$. We have, therefore, confined ourselves to that region of range ratios, particularly since for $L_l/L_h > 2$ the fragmentation admixture becomes substantial. A total of 1042 disintegrations classified as uranium fission were analyzed.

RESULTS

1. The fission cross section σ_f was calculated from the formula $\sigma_f = N_f/N_{\text{nuc}}N_p$, where N_f is the number of disintegrations per cubic centimeter, N_{nuc} is the number of uranium nuclei per cubic centimeter, and N_p is the neutron flux. The amount of uranium introduced was determined by calculating the number of tracks of α particles due to uranium decay over a known time interval. The proton flux was calculated by comparison of the number of disintegrations with fragments in the P-9ch emulsion, where the primary flux was not registered, but on which the basic experiment was performed, with that in the PR emulsion, in which the proton flux was determined by calculating the number of tracks in a known area.

The value obtained for the fission cross section was $\sigma_f = (1.3 \pm 0.4)$ b. However, in the interaction

of 9-Bev protons with nuclei of the elements contained in the emulsion, a considerable number of secondary particles of different energy, less than 9 Bev, are produced and these also contribute to the fission of the uranium introduced in the photographic emulsion. A rough estimate of this background leads to a value of $\sim 30\%$, and consequently, we have for the fission cross section of uranium by 9-Bev protons $\sigma_f \approx 0.9$ b.

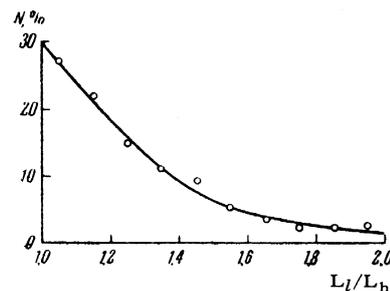


FIG. 1

2. The relations between the ranges of the light and heavy fragments in each individual fission event represent approximately the ratio of their masses.² Figure 1 shows the distribution of the fission events, accompanied by the emission of charged particles, as a function of the ratio of the ranges of the heavy and light fragments (the point of emission of the charged particles determines the point of fission). The character of the distribution is found to be similar to that observed in the fission by protons of energies on the order of hundreds of megavolts.³ Thus, in the fission of uranium nuclei by 9-Bev protons, the most probable is fission by fragments that are of nearly equal mass.

Figure 2 shows the dependence of the average total range of fission fragments of uranium on the ratio of the ranges of the light and heavy fragments. The average total range of the fragments charac-

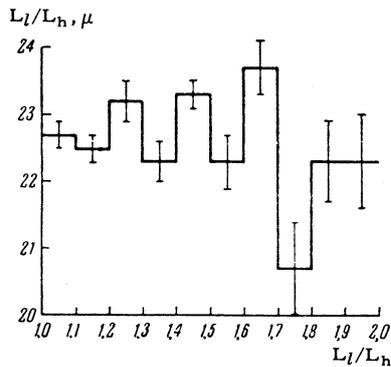


FIG. 2

terizes the liberated kinetic energy corresponding to a given type of fission as a function of the mass ratio. Figure 2 shows three maxima which are outside the limits of statistical errors. However, we shall not attempt so far to interpret them until more is known about their nature.

3. We list the results of the investigation of the angular distribution of the fission fragments — number of fissions N as a function of the angle θ between the direction of motion of the proton and the projection of the line of divergence of the fragments* on the plane of the microscope table.

	$\theta^\circ = 0-15$	$15-30$	$30-45$	$45-60$	$60-75$	$75-90$
$n_{\alpha p} \geq 1$;	$N = 125$	107	120	124	111	110
$n_{\alpha p} \geq 0$;	$N = 179$	171	179	185	173	155

The first line refers here to the number of charged particles $n_{\alpha p}$, accompanying fission, starting with unity, and the second starting with zero.

For the ratio of the number of events in the interval $0-30^\circ$ to the number of events in the interval $60-90^\circ$ we obtain

$$N(0-30^\circ) / N(60-90^\circ) = 1.07 \pm 0.11,$$

i.e., an isotropic distribution within the limits of statistical errors.

4. Figure 3 shows the distribution of fissions by the number of accompanying "black" rays (by "black" rays we mean tracks which are registered by the P-9ch emulsion). The same figure shows for comparison the data obtained earlier in our laboratory for an energy of 660 Mev. The average value $\bar{n}_{\alpha p} = 3.82$ and $E = 9$ Bev, where at $E = 660$ Mev we have $\bar{n}_{\alpha p} = 1.16$. We can, therefore, conclude that the fissioning nuclei, obtained when 9-Bev protons act on the uranium nucleus have a much higher average excitation energy.

*As a rule, in the laboratory system of coordinates the angle between the fragments is less than 180° . As the line of divergence of the fragments in the system of the fissioning nucleus we used the line joining the ends of the tracks of two fragments.⁴

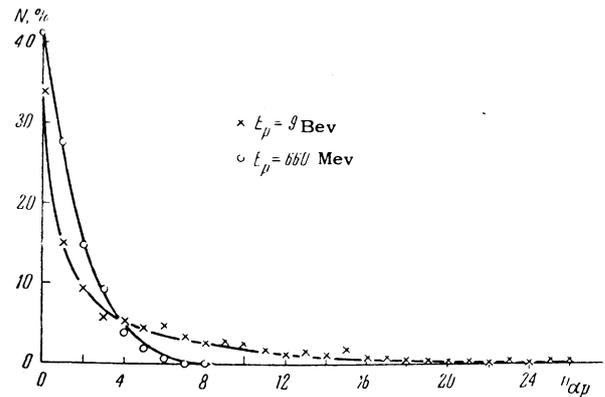


FIG. 3

5. Among the disintegrations that are produced when 9-Bev protons act on the uranium nucleus, one encounters disintegrations into two fragments of commensurate mass and a third lighter one. The relative frequency of appearance of such "triple" disintegrations with respect to "double" disintegrations is approximately 0.02, whereas at a proton energy of 660 Mev the frequency of triplet appearance is ~ 0.005 (reference 5). The average number of prongs accompanying triple fission is 11.0 and 1.6 respectively at 9 Bev and 660 Mev. We see that both the number of triple disintegration relative to the double ones, and the average number of charged particles accompanying the triple disintegration, increase considerably with increasing proton energy from 660 Mev to 9 Bev.

In conclusion, the authors express their gratitude to the staff of the high-energy laboratory of the Joint Institute for Nuclear Research for help in the irradiation.

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