$$\frac{|N(\mathrm{Pa}^{237})|_{U_0+40}}{|N(\mathrm{U}^{237})|_{U_0}}\cdot\frac{\sigma_{\mathrm{spall}}(\mathrm{U}_{92}^{A})}{\sigma_{\mathrm{spall}}(\mathrm{Pa}_{91}^{A-5})}=\frac{\omega^{\alpha}}{\omega_1^{\beta}}; \tag{13}$$

$$\alpha = U_0/(\varepsilon_n+2\overline{T})\approx U_0/8;\quad \beta=(U_0+40)/(\varepsilon_n+2\overline{T})\approx(U_0+40)/8. \tag{14}$$

The results of these calculations are presented in Table V.

The data of Table V show that the assumption of "over the barrier fission" gives results (column 3) which, in our opinion, cannot be reconciled with the experimental data (column 2). On the other hand, the results of the analysis presented in Table IV, show that relation (8) is satisfied sufficiently well and therefore this can be taken as an additional argument for "deep" emission fission of uranium and protactinium nuclei in the initial energy of excitation range under consideration.

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SOVIET PHYSICS JETP VOLUME 6(33) NUMBER 2 FEBRUARY, 1958

# *ON THE CROSS SECTION FOR PRODUCTION OF MULTIPLY CHARGED PARTICLES IN THE INTERACTION BETWEEN PROTONS AND NUCLEI*

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Submitted to JETP editor March 9, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 354-357 (August, 1957)

Nuclear emulsions were used to study the bombarding proton energy and atomic weight dependence of the cross section for production of multiply charged ($Z \geq 4$) particles in nuclear disintegrations due to fast protons. The cross section for production of particles possessing an energy greater than 1 — 2 Mev per nucleon varies from 3 to $12 \times 10^{-27}$ cm$^2$ for incident particle energies lying between 300 — 660 Mev if heavy nuclei (Ag, Br) are disintegrated and remains equal to $2 \times 10^{-27}$ cm$^2$ if light nuclei (C, N, O) are disintegrated. For a given energy of the incident particles the cross section of the reaction increases with increase of the mass number of the target nuclei.

## I. INTRODUCTION

IT is presently well known that the cross section for the reaction leading to the production of multiply charged particles increases with the increase of energy of the bombarding particles (in the range $10^2 - 10^3$ Mev). Nevertheless, neither the functioning of this dependence nor the absolute value of the cross section for the production of multiply charged fragments is yet known. When high energy particles produce disintegrations emitting multiply charged fragments, the dependence of the cross section for this reaction on the atomic number of the target nuclei, established by radiochemical methods,[1] is the same for all fragments: the cross section for such fragment production varies inversely with the atomic number of the target nuclei. Nevertheless, as has been noted previously,[2] a significant portion of the cross section for the fragment-production reaction can be accounted for the stable isotopes of light elements which are not detected by radiochemical methods, and it is not clear a priori whether the indicated dependence is valid for the total cross section of the reaction.

This article presents experimental data concerning the dependence of the fragment-production cross section ($\sigma_{frag}$) on the incident proton energy and on the mass number of the target nuclei, obtained with the aid of nuclear emulsions. The fine-grained nuclear emulsions used (Type P-9 emulsions prepared in the laboratory of N. A. Perfilov) provided the means for reliable identification of multiply charged particles for $Z \geq 4$.

## II. DEPENDENCE OF THE CROSS SECTION ON THE ENERGY OF THE INCIDENT PROTONS

The cross sections for the production of multiply charged particles in the interactions between protons of 300 — 660 Mev and the light and heavy nuclei in the emulsions were determined by two methods. In the first method, a plate was irradiated with a known perpendicular proton current and the total number of disintegrations producing fragments that occurred within a given area was counted. In this case, $\sigma_{frag} = N/N_n N_p$ (where $N$ is the number of disintegrations producing fragments per square centimeter; $N_n$ is the number of nuclei of Ag, Br, or C, N, O, per square centimerer; $N_p$ is the proton current per square centimeter).

In the second method, an emulsion was irradiated with protons of known energy, and the percentage of inelastic interactions with Ag and Br nuclei in the emulsion which led to fragments (q) was determined. The desired cross section was found by multiplying the known cross section for interaction of protons with Ag and Br by the factor q. Nuclear disintegrations with fragments, as observed in emulsions, can be explained as disintegrations of either heavy nuclei (Ag, Br) or of light nuclei (C, N, O). Differentiation between these two groups of disintegrations was accomplished by using two criteria: total charge of the particles in the disintegration and the presence or absence of tracks of residual nuclei. The presence of residual nucleus tracks is characteristic of disintegrations of heavy nuclei with multiply charged particles.

The results obtained with nuclei of Ag, Br, and C, N, O are shown in the figure below. It is necessary to note that the cross section data relate only to fragments with $Z \geq 4$ having paths longer than 12 — 15 microns. This latter condition is set by the limit of possible identification — i.e., to be identifiable, fragments must have energies greater than 1 — 2 Mev. Quite noteworthy is the difference between the energy dependence of $\sigma_{frag}$ in the case of heavy nuclei and in the case of light nuclei. While the fragment production cross section increases sharply with the energy in the case of Ag and Br, it is almost invariant with respect to energy in the case of C, N, O. This circumstance can be explained by the mechanisms of fragment production that take place for light nuclei and for heavy nuclei.

It is interesting to note that at the same time the cross section for the reaction producing splitting of Ag or Br nuclei into two fragments of nearly equal mass (such events, which resemble the fission of heavier nuclei, are occasionally observed in emulsions) is apparently not strongly dependent on the energy of the bombarding protons. The cross section for such fission of Ag and Br, determined by observations on the same plates, has a value $\sim 0.4 \times 10^{-27}$ cm$^2$ for incident particle energies of 300 and 660 Mev.

## III. DEPENDENCE OF THE CROSS SECTION ON THE MASS NUMBER OF THE TARGET NUCLEUS

The dependence of cross section on target mass number was studied using direct contact between the target and the emulsion. Plates of Al, Cd and Pb about one millimeter thick were placed on the nuclear emulsion and irradiated with a proton beam at an angle of 12 degrees with respect to the emulsion surface. The tracks made by particles with $Z \geq 4$, which entered the emulsion through its surface, were then counted.

The fragments in question were produced by disintegration of the elements under study. Since the targets used are infinitely thick to these fragments, and since the emission of fragments can be considered equally probable with respect to the dividing plane between emulsion and metal plate, the appropriate radiographic formulas are applicable.

As the result of formulas given in the work of Curie and Faraggi,[3] it is possible to write the following expression for the effective cross section of the interaction leading to the emission of multiply charged fragments:

| Target | Fragments Observed per cm² of Emulsion | $n\sqrt{A}$ |
|---|---|---|
| Al | 50±5 | 260 |
| Cd | 50±5 | 527 |
| Pb | 63±6 | 905 |

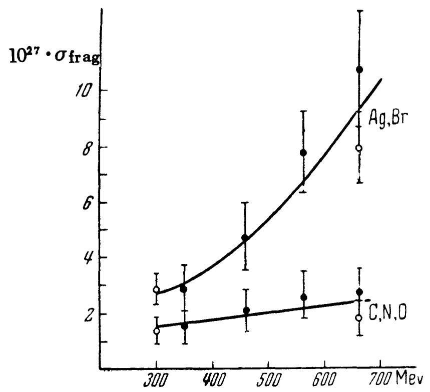
$$\sigma_{\text{frag}} = 2.08 \cdot 10^{-20} \, (A/N_p) \, n/\psi \, (\bar{R} - \rho),$$

where A is the atomic weight of the target material, $N_p$ is the proton flux, n is the observed number of fragments per square centimeter of emulsion, $\psi$ is the magnitude of the target material penetrability, which is a measure of its stopping power, $\bar{R}$ is the average particle range, and $\rho$ is the minimum range for registration. If it is assumed that the fragment range spectra are identical for Al, Cd and Pb, and that the target material penetrability is the same for these fragments as for $\alpha$-particles,[3] i.e., $\psi = \sqrt{A}$, then:

$$\sigma_{\text{frag}} \sim n\sqrt{A}.$$

The table lists the experimental values of n, obtained with 660 Mev protons, and the computed values of $n\sqrt{A}$. If the indicated assumptions are correct, the resultant dependence of $n\sqrt{A}$ on A can serve as direct evidence of the increase of the cross section for fragment production with increasing target-material mass number. Qualitative arguments in support of the assumptions made are given below.

Owing to the anisotropic angular distribution of the studied fragments in the laboratory system, the assumption of equal probability for fragment emission with respect to the dividing plane between emulsion and target material is known to be incorrect. However, in the case under consideration, it is necessary only to be sure that the uncertainty thus introduced does not change the character of the dependence of $n\sqrt{A}$ on A. Investigation of the angular distribution of fragments from disintegration of various nuclei has shown that the degree of anisotropy of the angular distribution varies inversely with the atomic weight of the target nucleus. This circumstance leads to a relative increase in the magnitude of $n\sqrt{A}$ in the case of an aluminum target, and therefore cannot alter the basic conclusion concerning the increase of $\sigma_{\text{frag}}$ with increasing A.




Dependence of $\sigma_{\text{frag}}$ on the energy of the bombarding protons. Open circles — cross sections found by the direct method ($\sigma_{\text{frag}} = N/N_n N_p$); black circles — cross sections found by the indirect method ($\sigma_{\text{frag}} = q\sigma_{\text{AgBr}}$).

The principal uncertainty in the results obtained arises from the lack of knowledge concerning the range distribution of the fragments under study. The assumption made above concerning the identical nature of the fragment range spectra for disintegrations of Al, Cd and Pb nuclei is based on the similarity found in the range distributions for fragments from Al, Cd and Pb, as recorded in the emulsion. If one also takes into account the fact that the average observed range for fragments of $Z \geq 4$ is greater in the emulsion for those coming from C, N, O nuclei than for those coming from Ag and Br nuclei, in the emulsion, then one can conclude that the increase of $n\sqrt{A}$ with increase of A is in fact due to the increase of $\sigma_{\text{frag}}$. This is confirmed by direct measurements of $\sigma_{\text{frag}}$ for C, N, O and Ag, Br in the emulsion (see figure).

The most interesting inference that can be drawn from the results given above is that with increasing target mass number there is an increase in the fraction of stable isotopes relative to all the emitted fragments, since it is known from radiochemical work[1] that the yield of radioactive isotope fragments decreases with increasing target mass number, while the overall cross section for the reaction increases, as was determined in the work in question. However, one must bear in mind that these conclusions relate to fragments having energies greater than 2 — 3 Mev per nucleon, so that correlation with radiochemical results cannot be completely valid, especially in the case of light nuclei.

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SOVIET PHYSICS JETP VOLUME 6(33) NUMBER 2 FEBRUARY, 1958

# *CLOUD CHAMBER INVESTIGATION OF THE ELECTRON-PHOTON COMPONENT OF EXTENSIVE AIR SHOWERS AT SEA LEVEL*

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Submitted to JETP editor March 11, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) 33, 358-364 (August, 1957)

The energy spectra of the electronic component of extensive air showers containing various numbers of particles were measured at different distances from the axis. No dependence of the energy spectrum on the number of particles in the shower was detected. The energy spectrum becomes softer with increasing distance from shower axis. A significant discrepancy was found to exist between the fraction of high-energy electrons observed experimentally and that computed from cascade theory for various distances from the axis. The lateral distribution of the energy carried by the electronic component can be approximated by the function $r^{-n}$, where $n = 2 \pm 0.5$ for distances between 2 and 10 meters.

IT was demonstrated[1] that, in the central region of extensive air showers, nuclear-active particles of more than $10^{11}$ ev can generate, by means of $\pi$-mesons, the electronic component near the observation level. This conclusion was reached as the result of a study of the lateral distribution of the electronic component in the central region of extensive showers. As a further study of the generation mechanism of electronic component we investigated its energy characteristics, which should depend more strongly on the production mechanism than the lateral distribution. The energy spectra of the electronic component at various distances from the shower axis were measured in course of the present work for showers containing different numbers of particles.

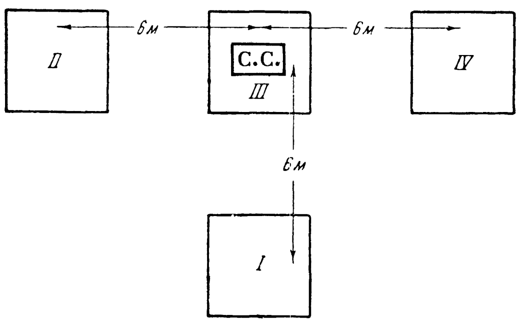


FIG. 1. Arrangement of hodoscope counter trays and the cloud chamber (C.C.)

The experimental arrangement consisted of a rectangular cloud chamber[2] with dimensions 60 × 60 × 30 cm and four groups of hodoscoped counters. A diagram of the positions of the hodoscope counter trays and the cloud chamber is shown in Fig. 1. The cloud chamber and the hodoscope were triggered by a system of counters discharged by the extensive air showers.* 2175 showers were recorded during 1189 hours of operation.

* A detailed description of the triggering system and of the hodoscope arrangement will published in Ref. 3, where the effects connected with the innacuracy in the determination of the distance from axis will be discussed as well. A possible shift of the axis position towards smaller distances cannot evidently cause a substantial change in the results of the present work.