Study of the angular distributions of the products of the interaction of 1-GeV protons with ^{40}Ar nuclei

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A hybrid gas-liquid chamber was used to investigate the angular distributions of the particles produced in the disintegration of nuclei by 1-GeV protons. It is shown that the results can be described by the intranuclear cascade method. The regions with condensation of nuclear matter, which are produced in the development of the cascade process in the nucleus, are calculated.

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Hydrodynamic calculations[1–3] predict the formation of shock waves and of characteristic and energy distributions of the product particles in nuclei. The experimental observation of these predictions has been the subject of a number of studies.[4–9] However, the results of the investigations performed to date are contradictory. An analysis of the angular distributions of the products of the disintegration of nuclei by different particles, carried out in[4–7], has enabled the authors to conclude that the data obtained by them agree with the predictions of the theory. While the possible existence of shock waves in nuclei is predicted in[8], it is indicated there that the results differ from those obtained earlier in[5]. Finally, some workers[9] point to the absence of the secondary-particle angular correlations that are to be expected if particle emission is connected with formation of a shock-wave front in the nucleus. It should be noted that the organization of an experiment under conditions close enough to those assumed in the theoretical analysis is not a simple matter. This hinders the analysis and the comparison of the experimental data. We indicate in this paper that the largest compression of nuclear matter occurring when fast particles interact with nuclei should be expected when the tranport length of the incident nucleon in the nucleus is minimal ($E_0 \sim 800$—1000 MeV/N). From this point of view, it

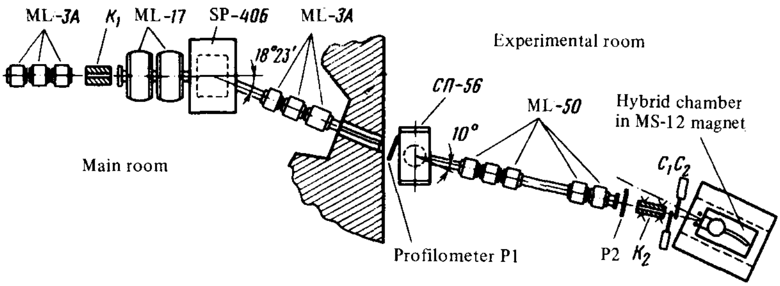

FIG. 1. Experimental setup.

is expedient to perform the experiment with a proton beam of energy ~1 GeV. For the analysis of the interaction of the protons with the nuclei at this energy, there is a reliable theoretical model, namely the intranuclear cascade method (ICM), and the multiplicity is a sufficiently reliable criterion of the central character of the collision. The situation in the analysis of the interaction of the ions with the nuclei[10] is in this sense much less definite. It seems more justified therefore to seek effects connected with the formation of shock waves in nuclei, by going from light particles (protons) to heavier ones, gradually increasing the mass of incident nucleus.

Our aim was to investigate the angular distributions of the products of the disintegration nuclei by fast protons under conditions close enough to those on which the theoretical analysis was based. It seemed important to use in the experiment a pure nuclear target and thus consider the situation at the simplest

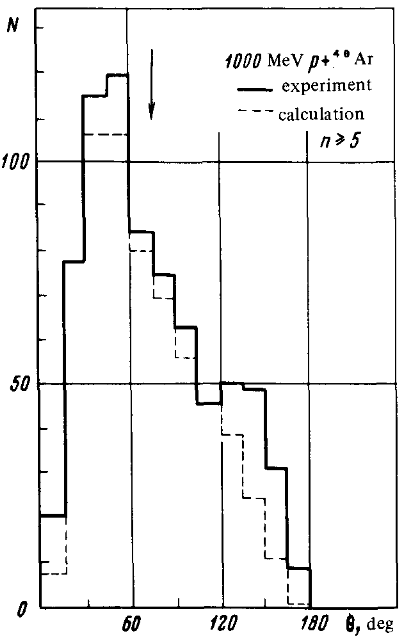

FIG. 2. Angular distributions of charged particles from disintegrations of ^{40}Ar by 1-GeV protons.

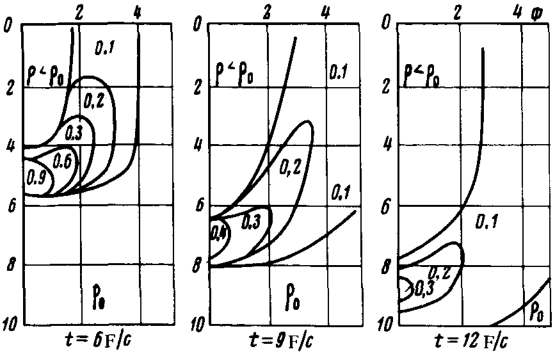

FIG. 3. Change of density of nuclear matter in the development of a cascade at three different instants of time. The figure shows the excess of the density of nuclear matter over the initial value.

level. We bombarded ^{40}Ar nuclei with 1-GeV protons, using a hybrid gas—liquid chamber.[11] The number of impurity nuclei in the target did not exceed 0.5%. The experimental setup is shown in Fig. 1. We chose for the analysis 113 events of disintegration with multiplicity $n \geq 5$ (736 tracks). Interactions that occur within 5 cm (along the beam) of the gas-target wall were disregarded. Figure 2 shows the angular distribution of the secondary particles relative to the direction of the incident protons for this selection. Figure 2 shows also the analogous distribution calculated in accordance with the ICM and normalized to the number of selected interactions. It is seen that the two distributions are quite close, whereas the expected position of the maximum, calculated within the framework of the hydrodynamic model[2] (arrow in Fig. 2) differs noticably from that observed in experiment. Inasmuch as the effectiveness of the track selection was not equal to unity, we took into account in the theoretical analysis the geometrical limitations. With the aid of the ICM, which describes our data quite well, we calculated the change in the nucleon density in the model of the nucleus during the time of the development of the cascade. We considered central collisions of the proton with a nucleus of constant density. Calculation has shown that during the course of the development of the cascades there are produced in the nucleus condensation regions, which propagate through the nucleus in the course of time (see Fig. 3). It is seen that in a considerable fraction of the volume of the nucleus the densities are 10—20% higher than the initial value. The development of the condensed regions is such that during the time that they pass through the nucleus no clear cut shock-wave front manages to be produced in the form described in[2,5] It should be noted that the model calculations for large-dimension nuclei show that the front becomes even less sharp in them in the course of time.

The results of our investigation demonstrate the following: the angular distributions of the secondary particles are sufficiently well described by the ICM; examination of the development of the cascades in the nucleus within the framework of the ICM shows that 1-GeV protons energy produce in the nucleus a condensation wave that moves with time; this wave differs substantially in form from that predicted by the hydrodynamic model[2]—there is no clear cut shock-wave front, nor the associated Mach cone. The position of the angles of the most probable emission of the charged particles from the ^{40}Ar nuclei does not agree with the calculation in accordance with this model.

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