ENERGY SPECTRA AND ANGULAR DISTRIBUTION OF Li^8 *FRAGMENTS PRODUCED IN THE INTERACTIONS BETWEEN 660-MeV PROTONS AND ALUMINUM NUCLEI*

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The angular distribution and energy spectra of Li^8 fragments produced in the disintegration of aluminum nuclei induced by 660 MeV protons are studied experimentally. The absence of the B^8 isobar among the disintegration products and the identity of the Li^8 spectra at angles of 90° and 47° with the respective spectra for disintegrated carbon nuclei are discussed from the viewpoint of the model of intranuclear reaction with nucleon clusters localized on the surface of the nucleus. The angular distribution of Li^8 fragments from aluminum, calculated on basis of this model, are found to agree well with the experimental data.

THE question of the connection between the phenomenon of fragmentation and such a singularity of nuclear structure as the formation of nucleon clusters in nuclei [1] was raised in the literature many times in recent years. The opinion was advanced that the bulk of the observed fragments are clusters that are knocked out quasielastically [2]. In this case an analysis of the experimental data could yield information on the character of the clustering of the nucleons in the target nucleus. However, as indicated by us in an earlier paper [3], when fast particles interact with nucleon clusters, a large role may be played also by the unique intranuclear reactions, which lead to the destruction of such clusters. In addition to this effect, one cannot exclude in principle the emission of a compound particle by the strongly excited nucleus.

The separation of the foregoing three mechanisms on the basis of some theoretical considerations is at present an almost unsolvable problem, although its solution is extremely necessary, since the first and third mechanisms yield direct information on the structure of the nucleus essentially in excited states, whereas the mechanism of intranuclear reactions can mask the contribution made of each of them (giving nevertheless definite information concerning the behavior of the substructures in the diffuse region of the nucleus).

The relation between the quasielastic knockout and the mechanism of intranuclear reactions can be obtained by comparing data on the formation of multiply charged particles on the lightest nuclei with the corresponding results for the heavier nuclei. It is obvious that this relation is dedetermined to a high degree by the relation between the cross sections for the quasielastic scattering and for the simplest reactions and the reduced widths for the states of the corresponding type. We therefore deem it necessary to make a detailed investigation of the formation of each specific isotope over a wide range of incident-particle energies and target-nucleus masses. The study which we undertook of the formation of Li^8 nuclei in interactions between 660 MeV protons and aluminum nuclei was carried out within the framework of this program.

A thin aluminum foil 2.4 mg/cm^2 thick was irradiated in a vacuum chamber by the extracted 660-MeV proton beam from the proton synchrotron of the Nuclear Problems Laboratory of the Joint Institute for Nuclear Research. The total proton flux to the target was approximately 10^{13} cm^{-2}. The products of the nuclear reactions between the protons and the aluminum nuclei were registered with the aid of nuclear emulsions at angles 20.5 ± 3.5, 29 ± 5, 47 ± 7, 65 ± 7, 90 ± 8, 115 ± 7, 137 ± 7, and 159.5 ± 3.5 deg to the proton beam. P—9_0 emulsions were used in the experiments, making it possible to avoid overloading of the plates by the background of cascade protons, and yielding a reliable particle discrimination.

In the present work we selected T-shaped tracks in the emulsion, corresponding to the nuclei Li^8, Li^9, Be^8, and B^8. From the total of 818 T-shaped tracks obtained, only nine could be ascribed (judging from the angle between the alpha-particle tracks) to the isotope Li^9. Ionization measurements made by the so-called scale method [4] have shown a total absence of the isobar B_5^8 (among 204 processed tracks ≥ 35 μ long). Figure 1 shows the distributions of the T-shaped

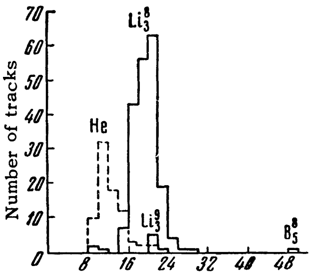

FIG. 1. Distribution of alpha-particle tracks and observed T-shaped tracks with respect to a parameter characterizing the ionization. The track of the ion B_5 was obtained in the same emulsion, but it was not connected with the disintegration of the target nucleus, having entered the emulsion from the glass base.

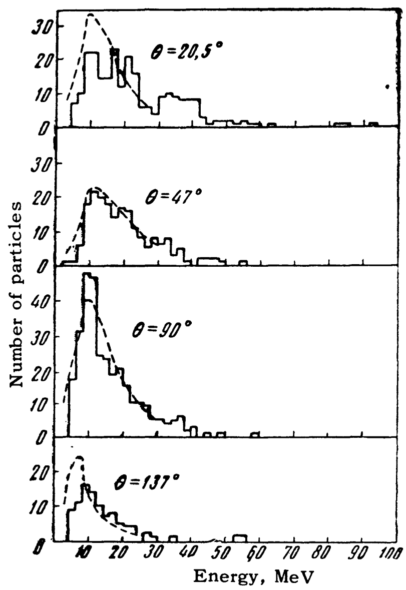

FIG. 3. Energy spectra of Li^8 in the disintegration of aluminum nuclei. Dashed curves—corresponding distribution of Li^8 in the disintegration of carbon nuclei [3].

tracks and alpha-particle tracks relative to the parameter characterizing the ionization.

To construct the angular distribution, 50 Li^8 tracks were obtained for each angle of observation (with the exception of the angle 159.5°, at which 12 fragments were observed). To exclude the inhomogeneities of the proton current over the target area, the solid angle for the registration of the Li^8 fragments at a given angle to the proton beam was determined from the fission fragments, by replacing the aluminum target with a gold target. Figure 2 shows the obtained angular distribution of the Li^8 fragments produced in the disintegration of the aluminum nuclei.

Figure 3 shows the energy spectra of Li^8, taken at 20.5, 47, 90, and 137 deg (without corrections for the deceleration in the target, the half-length of which is equivalent to approximately 1 MeV).

It is of interest to compare our experimental data on the production of Li^8 from aluminum with the results of studies of the spectra of Li^8 in the disintegration of carbon nuclei at $E_p = 660$ MeV[3] and aluminum at $E_p = 2.2$ BeV[5]. The dashed line of Fig. 3 shows the Li^8 energy spectra observed in the disintegration of carbon nuclei by 660 MeV protons[3] at the same angles relative to the incident protons. What is striking is the remarkable agreement between the spectra for 47° and 90°; in the case of disintegrations of aluminum nuclei, the spectra of Li^8 have only longer "tails" (as obtained by Katcoff[5] at 2.2 BeV). At the same time, the spectra of Li^8 at angles 20° and 137° differ from the spectra obtained for the disintegrations of carbon nuclei: at 20° the spectrum of Li^8 from aluminum is broader and flatter, while at 137° it harder than in the case of disintegration of carbon nuclei.

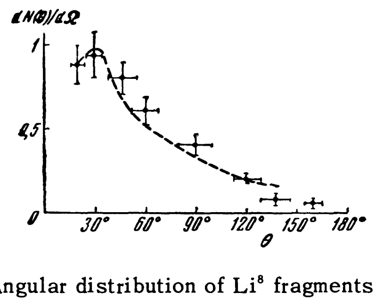

FIG. 2. Angular distribution of Li^8 fragments produced in the disintegration of aluminum nuclei by protons with energy 660 MeV. Dashed curve—theoretical.

The angular distribution has in the case of aluminum a smoother appearance than for carbon[3]. It must be noted that both for carbon and for aluminum the spectra at the corresponding angles are practically the same at proton energies of 660 MeV and 2.2 BeV.

The observed similarity of the energy spectra of Li^8 produced from aluminum and carbon, and also the absence in both cases of the B^8 isobar, calls for a verification of the naturally arising hypothesis that in both cases the Li^8 is produced essentially in the same process. Inasmuch as it is hardly possible to assume that in the case of disintegration of carbon nuclei large momenta are transmitted to the Li^8 during the course of the decay of the excited residual nuclei[3], we have assumed that such a common mechanism should be the direct process which occurs on the surface of the nucleus in the case of aluminum. If we assume that the Li^8 is produced from aluminum only by reactions between the primary protons and substructures which are not heavier than C^{12}, for which the angular distribution of the Li^8 is assumed to be close to the angular distribution attained for carbon, then we can qualitatively explain the difference in the angular distributions of the Li^8 from the aluminum and the carbon, as well as the similarity between the energy spectra of the Li^8 at angles 90 and 47° and their difference at angles 20 and 137°.

The dashed line in Fig. 2 shows the angular distribution of Li^8, obtained for the disintegrations of aluminum nuclei by recalculation from the angular distribution obtained for the disintegration of carbon nuclei [3]. In this calculation the aluminum nucleus was regarded as a heavy core, on the surface of which there are distributed, with equal probability, substructures of the type indicated above. The attenuation of the primary proton beam is assumed to occur when the beam passes through the core. The ratio of the radius of that part of the nucleus which remains after the substructure is separated on its surface to the mean free path of the proton in this core was assumed equal to 1.2. It was also assumed that the core absorbs all the fragments which move towards it and which are produced as a result of the reactions of the incident protons with the substructure.

As can be seen from Fig. 2, the angular distribution of Li^8 obtained by such a calculation agrees with the experimental value if the distributions are normalized against the height of the maximum. It can be thought that the agreement will become even better if we take into consideration the reactions on the substructures, produced by the cascade nucleons and consequently leading to a smoothing of the angular distribution of the fragments. Another factor acting in the right direction is that if the fragment is emitted tangentially to the surface of the nucleus, it must overcome a centrifugal barrier which is proportional, in the quasiclassical approximation, to its energy. This effect is particularly important for the form of the energy spectrum of the fragments at small angles to the photon beam, for in this case the fragments produced on the side surface of the nucleus (the main fraction of the fragments) overcome the highest barrier and the resultant spectrum from the front part of the nucleus and its side surface turns out to be broader and flatter. As to the spectrum of the Li^8 fragments at 137°, it is sufficient to assume that it contains a certain fraction of backward scattered fragments, produced on the rear surface of the nucleus.

The appearance of faster fragments in the energy spectra of Li^8 from aluminum than in the spectra of Li^8 from carbon can be attributed in the simplest fashion to assuming some momentum distribution of the substructures in the nucleus of the aluminum.

Thus, the correspondence indicated above between the calculated and experimental angular distributions of Li^8 gives grounds for hoping that the experimentally obtained detailed information on the reactions with production of fragments on the lightest target nuclei will make it possible to separate the contribution of the processes which proceed via reactions on substructures localized on the surface of the nucleus.

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