FRAGMENTATION CHANNELS OF RELATIVISTIC ^{7}Be NUCLEI IN PERIPHERAL INTERACTIONS

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Abstract

Nuclei of ^{7}Li were accelerated at the JINR Nuclotron. After the charge-exchange reaction involving these nuclei at an external target a second ^{7}Be beam of energy 1.23A GeV was formed. This beam was used to expose photo-emulsion chambers. The mean free path for inelastic ^{7}Be interactions in emulsion λ=14.0±0.8 cm coincides within the errors with those for ^{6}Li and ^{7}Li nuclei. More than 10% of the ^{7}Be events are associated with the peripheral interactions in which the total charge of the relativistic fragments is equal to the charge of the ^{7}Be and in which charged mesons are not produced. An unusual ratio of the isotopes is revealed in the composition of the doubly charged ^{7}Be fragments: the number of ^{3}He fragments is twice as large as that of ^{4}He fragments. In 50% of peripheral interactions, a ^{7}Be nucleus decays to two doubly charged fragments. The present paper gives the channels of the ^{7}Be fragmentation to charged fragments. In 50% of events, the ^{7}Be fragmentation proceeds only to charged fragments involving no emission of neutrons. Of them, the ^{3}He+^{4}He channel dominates, the ^{4}He+d+p and ^{6}Li+p channels constitute 10% each. Two events involving no emission of neutrons are registered in the 3-body ^{3}He+t+p and ^{3}He+d+d channels. The mean free path for the coherent dissociation of relativistic ^{7}Be nuclei to ^{3}He+^{4}He is 7±1 m. The particular features of the relativistic ^{7}Be fragmentation in such peripheral interactions are explained by the ^{3}He+^{4}He 2-cluster structure of the ^{7}Be nucleus.

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*URL: http://becquerel.jinr.ru; URL: http://pavel.jinr.ru

I. EXPOSURE OF EMULSIONS TO A ^{7}BE BEAM

In order to form a ^{7}Be beam at the JINR Nuclotron, ^{7}Li nuclei were accelerated to an energy of 2.87Z GeV. The extracted ^{7}Li beam was delivered to a target of organic glass. The ^{7}Be nuclei produced at the target due to a ^{7}Li charge exchange reaction were focused by magnetic elements and a secondary beam was thus formed. The charges of the particles of this beam were determined by particle energy losses in a scintillation monitor. According to these measurements, the admixture of Z=3 particles in the beam was 7% of the number of Z=4 particles.

Photo-emulsion chambers assembled out of emulsion layers, the thickness and dimension of which were 550 μm and 10×20 cm^2, respectively, were exposed to the ^{7}Be beam [1]. The exposed emulsion layers were parallel to a beam axis. The standard BR-2 emulsion was used in which singly and doubly charged relativistic particles were well identified by sight. The particle charges larger than 2 were determined by the density of the gaps in the particle tracks using a computer analysis of a digitized image of a vision field on a microscope with an automatic track lock-on. According to the measurements of the particle charges in emulsion, the triply charged particles in the beam are about 15% of the particles with Z=4. ^{7}Be interactions in emulsion were sought with the aid of microscopes by selecting the particle tracks with the largest ionization density.

II. THE MEAN FREE PATH FOR INELASTIC ^{7}BE INTERACTIONS IN EMULSION

Inelastic nucleus-nucleus interactions were sought in emulsion by viewing the tracks of particles starting with their entrance into the emulsion by means of a microscope with a magnification of ×900. In order to determine the mean free path of ^{7}Be inelastic interactions in emulsion $\lambda(^7\mathrm{Be})$, use was made of 294 inelastic interactions detected over the viewed track length of 41.222 m in one emulsion chamber. Table I gives the result obtained for the ^{7}Be nucleus and the values of the mean free path of inelastic interactions of ^{6}Li and ^{7}Li in emulsion determined in [2, 3, 4, 5, 6]. The measured values for all these nuclei are within the errors nearly identical. The Table gives also the values calculated by a geometric model with a set of parameters employed for the description of the mean free path of the inelastic

TABLE I: Mean free paths of ^{6}Li, ^{7}Li, and ^{7}Be nuclei for inelastic interactions in emulsion.

Nucleus	λ_{exp}, cm	λ_{calc}, cm	Energy	Paper
^{6}Li	14.1±0.4	16.5-17.2	27	[4]
^{7}Li	14.3±0.4	16.0-16.3	21	[6]
^{7}Be	14.8±0.8	16.0-16.3	86	[6]

interactions of nuclei of homogeneous density in emulsion. The fact that the experimental values of the mean free path for all these nuclei are smaller than the calculated ones is accounted for by an additional contribution from peripheral inelastic interactions of nuclei having a loosely bound cluster structure.

III. THE ISOTOPIC COMPOSITION OF FRAGMENTS AND THE ^{7}BE FRAGMENTATION CHANNELS IN PERIPHERAL INTERACTIONS OF ^{7}BE NUCLEI IN EMULSION

Of 1400 inelastic nucleus-nucleus interactions detected, more than 200 are peripheral interactions in which the total charge Q of relativistic particles with 15° emission angle is equal to the charge of the primary ^{7}Be nucleus. In about 150 peripheral interactions there is observed no charged meson production. In such interactions, the particular features of the structure of the nucleus most strongly affect the character of the nuclear fragmentation and, first of all, the charge and mass composition of the fragments. Table II displays the charge topology of such events. The events involving no target fragments (n_b=0) are separated from the events involving one or a few fragments (n_b >0). In a half of the interactions each of them contains two doubly charged fragments, while in the other half each event contains one helium and two singly-charged fragments. 10% of events contain a relativistic Li nucleus accompanied by a single-charged fragment. A large fraction of events which are due to the dissociation of ^{7}Be nuclei into two helium fragments suggests that a clustering of this type in the ^{7}Be structure is very possible.

The isotopic composition of fragments was studied by measuring the multiple Coulomb scattering of particles in emulsion. The values of pβc, where p is the momentum and β the particle velocity, were determined. The momenta of singly and doubly charged particles

TABLE II: Fragment charge composition in events Q=4.

Relativistic fragments	Target	Number of events
2He	n_b =0	41
2He	n_b >0	18
He+2H	n_b =0	42
He+2H	n_b >0	33
4H	n_b =0	2
4H	n_b =1	1
Li+H	n_b =0	9
Li+H	n_b >1	3
Total		149

were measured in 240 interactions of ^{7}Be nuclei with the emulsion nuclei. The experimental pβc distribution of relativistic doubly charged particles is satisfactorily approximated by two Gauss functions with peaks at pβc equal to 4.5 GeV and 6.3 GeV. A relative fraction of ^{3}He and ^{4}He fragments estimated over the areas covered by the approximating curves is 70% and 30%, respectively. In the interactions of all other relativistic nuclei in emulsion which were investigated earlier the fraction of ^{4}He fragments is larger than that of ^{3}He fragments. Such a anomalous ratio of the He isotopes observed in ^{7}Be interactions is explained by the 2-cluster structure of the ^{7}Be nucleus in which the nucleons not involved to the α particle core are bound into a ^{3}He cluster. The pβc distribution of singly charged relativistic particles in an interval to pβc=5 GeV is satisfactorily described by two Gauss functions with peaks at pβc equal to 1.5 GeV and 3.2 Gev. The proton to deuteron ratio is estimated to be 3:1. The number of particles of momenta higher than 5 GeV/c constitutes about 2% of the total number of singly charged fragments. The results of these measurements were used to determine the fragment mass in each event and identify the ^{7}Be fragmentation channels.

Table III presents the numbers of the events detected in various channels of the ^{7}Be fragmentation. Of them, the ^{3}He+^{4}He channel noticeably dominates, the channels ^{4}He+d+p and ^{6}Li+p constitute 10% each. Two events involving no emission of neutrons in the three-body channels ^{3}He+t+p and ^{3}He+d+d were registered. The reaction of charge-exchange of ^{7}Be nuclei to ^{7}Li nuclei was not detected among the events not accompanied by other

TABLE III: ^{7}Be fragmentation channel (number of events)

Channel	2He	2He	He+2H	He+2H	4H	4H	Li+H	Li+H	Sum
	n_b =0	n_b >0	n_b =0	n_b >0	n_b =0	n_b >0	n_b =0	n_b >0	
^{3}He+^{4}He	30	11							41
^{3}He+^{3}He	11	7							18
^{4}He+2p			13	9					22
^{4}He+d+p			10	5					15
^{3}He+2p			9	9					18
^{3}He+d+p			8	10					18
^{3}He+2d			1						1
^{3}He+t+p			1						1
3p+d					2				2
2p+2d					1				1
^{6}Li+p							9	3	12
Sum	41	18	42	33	2	1	9	3	149

secondary charged particles.

The events containing only two helium fragments are given in Fig.1 by points the coordinates of which are the measured pβc fragment values. The larger value of pβc (max.) is taken as an abscissa and the smaller value of pβc (min.) as an ordinate. All the events over the ordinate axis are located below 5 GeV. This value implies the lower boundary of pβc for ^{4}He nuclei. The ^{3}He+^{3}He events are seen to be to the left of the pβc(max.) boundary, while the ^{3}He+^{4}He events are to the right of the boundary. The fraction of the ^{3}He+^{4}He channel of all the ^{7}Be dissociation events, which amounts to 30%, may be sought of as an estimate of the lower value of the probability of this configuration in the ^{7}Be nucleus. The mean free path for the coherent dissociation of relativistic ^{7}Be nuclei to ^{3}He+^{4}He in emulsion is 7$\pm$1 m . The mean free paths of ^{6}Li, ^{7}Li and ^{7}Be for the 2-particle channels of the coherent dissociation involving no neutron emission have close values. Direct estimates of the fact that the ^{6}Li nucleus can be in the state of an α particle core and a quasi-free deuteron cluster, which were obtained by a 1 GeV π^- mesons sounding of a ^{7}Li target in experiment

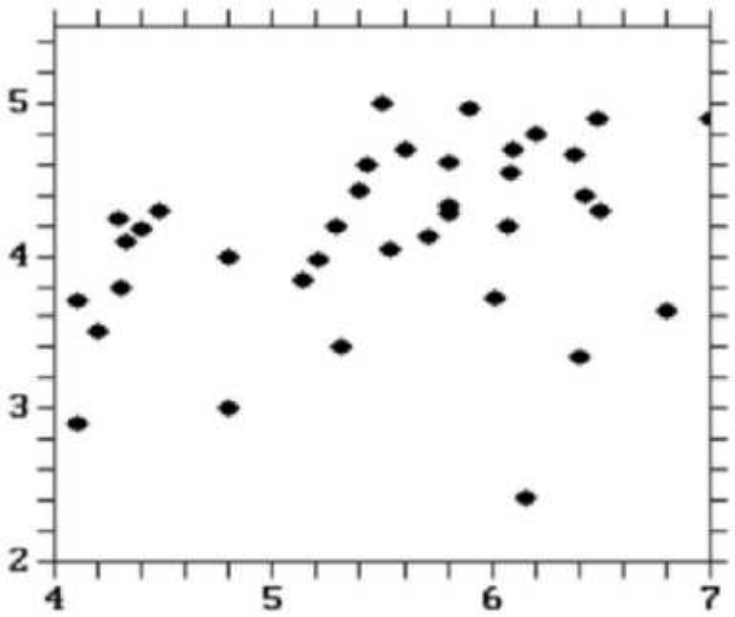

FIG. 1: Distribution of 2He events over the fragment momenta. The events are indicated as dots with coordinates corresponding to measured pβc values. The maximum pβc value is attributed to the ordinate, and the minimum one to the abscissa.

[7], exceed 0.75.

Fig. 2 shows the distribution of the ^{3}He+^{4}He channel events depending on E= 1.59+E_t, where E_t is equal to the transverse kinetic energy of the fragments and the value 1.59 MeV is equal to the threshold energy of the channel. In more than 80% of events the E values do not exceed 10 MeV. The same energy region is also occupied by the ^{7}Be excitation levels the positions of which are indicated by arrows. The separation of individual levels in the experimental distribution is not observed.

The fragment system energy may also be characterized by the transverse momenta of fragments in the coordinate frame of reference associated with a fragmenting nucleus. The difference in the average values of the fragment momenta for mirror nuclei may be viewed as a manifestation of the influence of the Coulomb interaction of charged clusters in nuclei and in the process of fragmentation of these nuclei. The mean values of the transverse momenta of the fragments in the ^{3}He+^{4}He channel in their c.m.s. is 147$\pm$5 MeV/c. A noticeable exceeding of this value with respect to the average values of the transverse momenta of the fragments in the ^{7}Li$\rightarrow^3$H+^{4}He fragmentation channel equal to 108 MeV/c may be treated as an effect of the Coulomb interaction of the clusters in these nuclei.

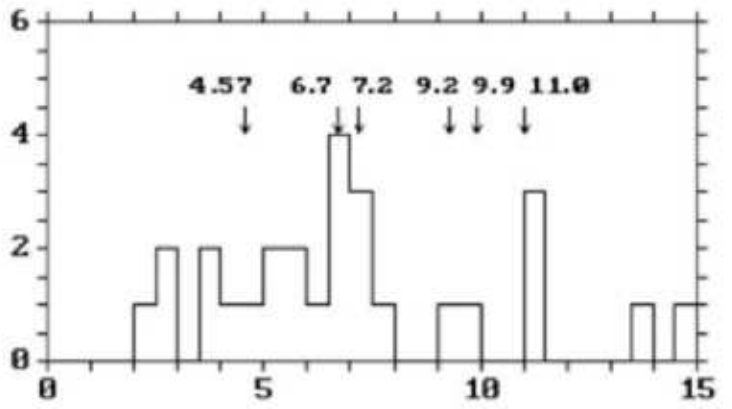

FIG. 2: Distribution of ^{3}He+^{4}He events over the value E.

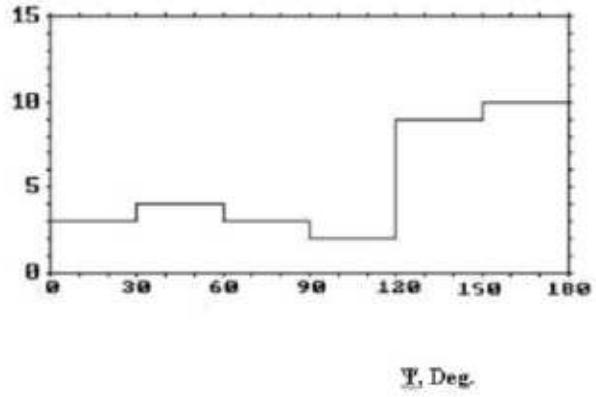

FIG. 3: Distribution of azimuthal angles ψ between fragments ^{3}He and ^{4}He.

Fig.3 shows the distribution of the ψ angles between the ^{3}He and ^{3}He fragments in the asymuthal plane in ^{3}He+^{4}H events. Large angles between the fragments are dominant. This distribution is, to a large extent, defined by the momenta transferred to fragmenting nuclei. The ψ angles close to 180° correlate with small momenta transferred to the ^{7}Be nucleus. A relatively large number of the events close to 180° angles and having low values of the transferred momenta may be due to the contribution of the Coulomb dissociation of ^{7}Be by heavy nuclei of the emulsion.

IV. CONCLUSIONS

Thee secondary ^{7}Be beam of energy 1.23A GeV was formed at the JINR Nuclotron by means of the charge exchange reaction involving ^{7}Li nuclei in an external target. This beam was used to expose nuclear emulsion stacks. The mean free path for inelastic ^{7}Be interactions in emulsion $\lambda(^7\text{Be})=14.0\pm0.8$ coincides within the errors with those for inelastic ^{6}Li and ^{7}Li interactions. Of 1400 inelastic ^{7}Be interactions with emulsion nuclei, there were detected 149 peripheral interactions in which the total charge of the relativistic ^{7}Be fragments was equal to the ^{7}Be charge and in which charged mesons were not produced. In 50% of such interactions, each event involves two helium fragments. An unusual ratio of isotopes is observed in the composition of the ^{7}Be doubly charged fragments: the fraction of ^{3}He fragments is as twice as large than that of ^{4}He fragments. The channels of fragmentation are given in the present paper. In 50% of the events, the fragmentation proceeds only to charged framents involving no neutron emission. Of them, the ^{3}He+^{4}H channel is dominant. The mean free path for the coherent dissociation of relativistic ^{7}Be nuclei to ^{3}He+^{4}He in emulsion is 7±1 m. A ^{7}Be dissociation process is registered in the ^{6}Li+p channel. The main characteristics of the relativistic ^{7}Be fragmentation are determined by the 2-helium cluster structure of the ^{7}Be nucleus. The mean value of the fragment transverse moments 147±5 MeV/c in the channel of the coherent fragmentation of ^{7}Be nuclei to ^{3}He+^{4}He is observed to exceed the value 108±2 MeV/c for the channel of ^{7}Li dissociation to ^{3}H+^{4}He. This fact may be associated with the Coulomb interaction of fragments in these processes. A relatively large number of events having ψ angles in the region of 180° and low transverse momenta may be due to the contribution of the Coulomb dissociation of ^{7}Be nuclei on heavy emulsion nuclei.

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