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EMISSION OF Li^8 *FRAGMENTS FROM* Ag *AND* Br *NUCLEI INDUCED BY 9 BeV PROTON BOMBARDMENT*

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The production of Li^8 from Ag and Br nuclei in a photographic emulsion bombarded by 9 BeV protons is investigated. A total of 358 Li^8 tracks were found in stars containing eight or more black prongs. The yield per disintegration and energy and angular distributions are consistent with a mechanism of Li^8 evaporation from a highly excited nucleus. However the large width of the energy spectrum is not in agreement with this picture.

THE emission of particles with large charge from nuclei, called fragments, was investigated in many researches both by radiochemical means and using nuclear emulsions. When a fragment is observed in emulsion, the determination of its charge and mass is connected with known methodological difficulties and cannot always be carried out with sufficient reliability, particularly for fragments with short ranges. In this respect, the fragments Li^8, Li^9, and B^8, which disintegrate with formation of characteristic hammer tracks, are of special interest, since they permit reliable identification of the fragments.

In the present investigation we studied the emission of these fragments, in disintegrations of silver and bromine under the influence of 9-BeV protons. In such disintegrations, according to [1-2], Li^8 is emitted much more frequently than Li^9 and B^8, so that all the hammer tracks were attributed to Li^8.

In the area-scanning of the NIKFI-R emulsions exposed in the proton synchrotron to 9-BeV protons, we selected stars with $N_b \geq 8$ black tracks. This condition is sufficient to identify the disintegrations of Ag and Br. On the other hand, it singles out a definite class of disintegrations, characterized by high excitation of the nucleus, if it is assumed that the number of black prongs reflects to one degree or another the extent of excitation. Area scanning was carried out at a magnification of $20 \times 15 \times 1.5$. All the prongs of each disintegration were considered in a single layer at a magnification $60 \times 7 \times 1.5$. Altogether 15,724 stars with $N_b \geq 8$ were found; 344 of them contained one Li^8 track and seven contained two such tracks. The content of Li^8 in such tracks was about 3 per cent. The distribution of these tracks by the number of black prongs N_b and the Li^8 yield per disintegration are listed in the table.

The fragment numbers actually obtained are indicated in the fourth column of the table, while the fifth lists the true values after geometrical correction is introduced for the loss of fragments which did not stop in a given layer. Figure 1 shows the yield of Li^8, obtained at a proton energy 5.7 BeV [3] together with the data of the present work. It shows the number of Li^8 fragments per star as a function of N_b. It is evident that with increasing number of black prongs the yield of Li^8 fragments continues to increase also in the region of large N_b.

If we use the well known formula relating the number of black prongs with the excitation energy of the nucleus, $U = 42\,(N_b + 1)$ MeV [4], and compare the experimental value of the yield of Li^8 as a function of the excitation with the calculations based

Number of black tracks, N_b	Average number of N_b	Number of stars	Number of Li^8 fragments	Corrected number of Li^8 fragments	Yield
8—10	8.9	5460	58	68	0,012±0,002
11—13	12.2	4519	103	124	0.027±0.003
14—16	14.8	3738	100	120	0.032±0,003
17—19	17.7	1297	59	71	0,055±0.007
20—22	20,8	516	26	31	0,060±0.012
23—30	24.4	194	12	14	0.072±0.021
Total		15 724	358	428	

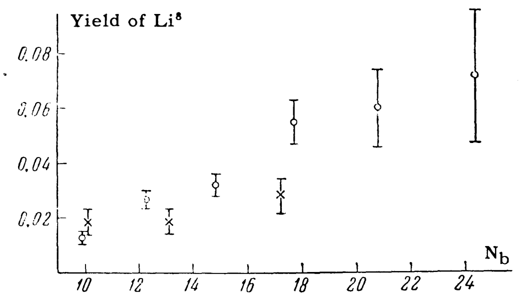

FIG. 1. Yield of Li^8 fragments per star as a function of the number of black prongs N$_b$: x – data of [3], o – present data.

on evaporation theory [5], then we find that over a wide range of excitation energies the experimental values of the yield exceed the calculated ones by approximately a factor of two. This difference was noticed also by Goldsack et al [3]. It must be noted that the expression given above for the energy U apparently becomes unsuitable for the calculation of the excitation energy in some interval of N$_b$, since, the energy U calculated with its aid exceeds the nucleon binding energy in the Ag and Br nuclei, for example, even for N$_b$ = 19. In large stars, an appreciable energy is carried away undoubtedly by the cascade particles, which, like the "evaporation" particles, produce black tracks. Consequently this expression for U can be used only if an exact calculation of the cascade is made.

The energy distribution of the Li^8 fragments is represented in Fig. 2. The Li^8 energy was determined from the range-energy relation given in the book by Demers [6]. The same figure shows the calculated curves calculated in accordance with the evaporation theory [7] and normalized to the same area, for the nucleus at rest and for a nucleus moving with velocity v = 0.015 c in the direction of the primary proton. Apparently the curve in which the motion of the nucleus is taken into account is in better agreement with the experimental histogram, since it covers a greater part of the high-energy particles. The energy distribution presented here does not differ much from the spectra obtained for Li^8 in disintegrations of silver and bromine by protons with energy 2.2 BeV [8], 5.7 BeV [3], and 24 BeV [9], by pions with energy 4.5 BeV, and by cosmic rays [10].

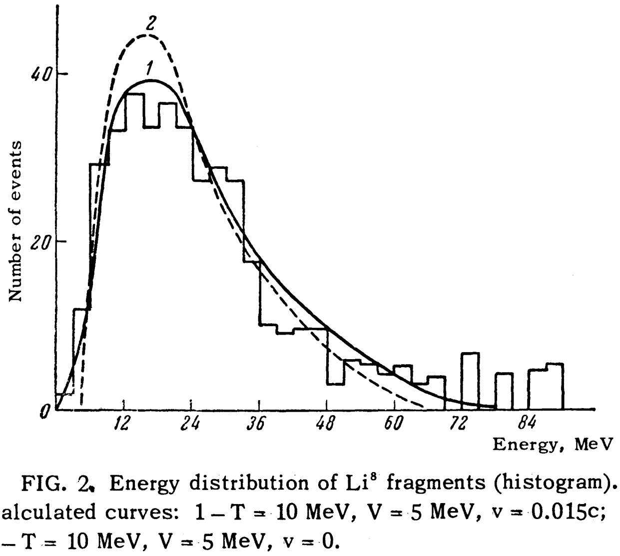

FIG. 2. Energy distribution of Li^8 fragments (histogram). Calculated curves: 1 – T = 10 MeV, V = 5 MeV, v = 0.015c; 2 – T = 10 MeV, V = 5 MeV, v = 0.

Figure 3 gives the energy distributions of the Li^8 fragments in stars having $8 \le N_b \le 12$ stars ($\bar{N}_b = 9.7$) and $N_b \ge 17$ stars ($\bar{N}_b = 18.6$), comprising 111 and 97 Li^8 tracks, respectively. These distributions are practically indistinguishable, in spite of the large difference in the excitation energy, if the latter is determined from the number of black prongs. The last fact does not contradict the evaporation theory, for from the point of view of this theory the identity of the two spectra for different excitation energies is due to the small influence of the energy U on the values of V + T and V + 2T (V is the Coulomb barrier and T the temperature of the nucleus), which determine the position of the maximum and the average energy in the spectrum, respectively.

Figure 4 shows the angular distribution of the

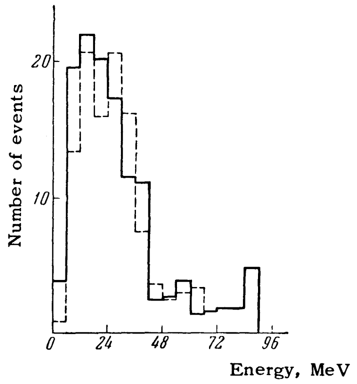

FIG. 3. Energy distribution of Li^8 fragments with different numbers of black prongs, N$_b$; solid line – $8 \le N_b \le 12$, dashed line – $N_b \ge 17$.

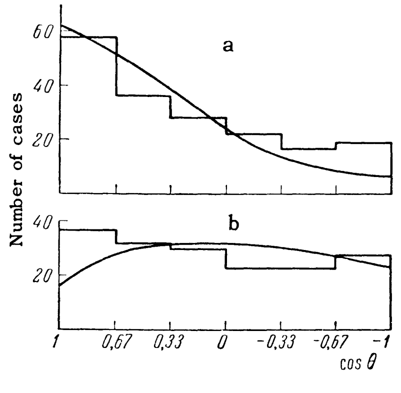

FIG. 4. Angular distribution of Li^8 fragments: a – E ≥ 21 MeV, b – E < 21 MeV.

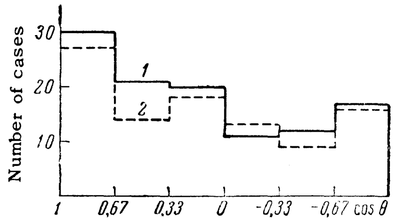

FIG. 5. Angular distribution of Li^8 fragments in stars with different number of black prongs N_b: 1 – $8 \leq N_b \leq 12$; 2 – $N_b \geq 17$.

Li^8 fragments for two parts of the energy spectrum with energies $E \geq 21$ MeV and $E < 21$ MeV. There is a pronounced tendency here toward forward emission (in the laboratory system) for particles of higher energy, whereas the slower fragments are emitted almost isotropically. The front-back ratios for fast and slow Li^8 are respectively equal to 2.18 ± 0.48 and 1.37 ± 0.30. The smooth curves in this figure show the angular distributions calculated assuming isotropic emission in the system of the resting nucleus at a nucleus velocity $v = 0.015c$. Comparison of the experimental histograms with the presented curves, calculated from evaporation-theory formulas [7], is apparently evidence of isotropic emission of the Li^8 in the system of the resting nucleus.

Figure 5 shows the angular distributions of the Li^8 fragments as a function of the number of black prongs N_b for the already indicated two groups of stars with $\bar{N}_b = 9.7$ and $\bar{N}_b = 18.6$. These distributions do not confirm the conclusion made by Goldsack et al [3] that the anisotropy in the angular distribution of Li^8 increases on going to stars with larger N_b. The histograms presented demonstrate that the angular distribution of Li^8 is practically independent of N_b. For these stars the ratio of the number of cases where Li^8 was emitted forward and backward was 1.8 ± 0.5 and 1.6 ± 0.5, respectively. This independence is maintained in any interval of values of N_b. For example, for stars with $8 \leq N_b \leq 10$ and $17 \leq N_b \leq 19$ the front-back ratio is 1.7 ± 0.7 and 1.6 ± 0.7, respectively.

To investigate the fragmentation process, it is also of interest to study multiple production of fragments, and in particular the formation of two Li^8 fragments in one disintegration. The latter process, however, is quite rare compared with the single emission of Li^8. The yield of two hammer tracks is only about 2 per cent of the number of single Li^8 tracks in the investigated disintegrations. An attempt to establish a connection between the two Li^8 fragments on the basis of the seven obtained cases has not led to success, for on the basis of such skimpy statistics one cannot say anything, for example, regarding the correlation between the fragment-emission angles or between the emission angles and the energy.

The foregoing characteristics of Li^8 fragment emission are compatible with the evaporation of Li^8 from a highly excited nucleus. However, the great width of the energy distribution, which leads to such high nuclear temperatures, when evaporation theory is known to become unsuitable, does not enable us to conclude that the only mechanism for the formation of Li^8 fragments in the investigated cases is evaporation. Apparently, as is indicated for example by Skjeggestad and Sorensen [7], who made a detailed analysis of the possible causes of broadening of the energy spectrum of Li^8, the emission of fragments is a more complicated phenomenon than pure evaporation.

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