Production of light fragments in the interaction of 1-GeV protons with silver nuclei

E. N. Vol'nin, A. A. Vorob'ev, and D. M. Seliverstov

Leningrad Institute of Nuclear Physics, USSR Academy of Sciences
(Submitted April 17, 1974)
ZhETF Pis. Red. 19, 691–694 (June 5, 1974)

We measured the energy spectra of light fragments with $2 \leq z \leq 5$ produced when 1-GeV protons interact with silver nuclei, and determined their production cross section. The results are analyzed on the basis of the evaporation model.

The production of isotopes of light nuclei following bombardment of silver with protons of energy $T_p = 5.5$ GeV was investigated in[1].

The present paper is devoted to a study of the energy spectra of the isotopes of helium, lithium, beryllium, and boron at $T_p = 1$ GeV. The use of a fragment identification system based on $\Delta E - E - B\rho$ measurements, which has a lower energy registration threshold than that given in[1] (2 MeV for α particles), has made it possible to measure the spectra of light nuclei in a wide range of energies.

The experiment was performed with a target 5 mg/cm² thick bombarded by protons at an intensity 3×10^5 sec^{-1} cm^{-2} and at two angles, $\theta = 60°$ and $\theta = 120°$, relative to the direction of the proton beam. The obtained spectra are shown in the figure. The cross sections for fragment production and the angular anisotropies (the ratios of the number of particles emitted in the front and rear hemispheres) are listed in the table.

The energy spectra were analyzed on the basis of the evaporation model in functional form, used in[1]:

$$P(E) \sim \int_{k=\langle k\rangle-\Delta}^{k=\langle k\rangle+\Delta} (E - kB)\exp\left(-\frac{E - kB}{T}\right)dk, \quad (1)$$

where E is the energy released upon production of the particle in the evaporating-nucleus system, C is the temperature of the nucleus, kB is the effective Coulomb barrier. The nominal barrier was calculated under the assumption that the nucleus produced after the fast cascade was $^{102}_{44}$Ru.[3] We used the value $r_0 = 1.44$ F. The introduction of the parameter Δ to take into account the distribution over the Coulomb barrier, and also allowance for the correlation between the velocity of the evaporating nucleus and the velocity of the fragment, make this calculation method close to the cascade-model calculation. The correlation was introduced in the form

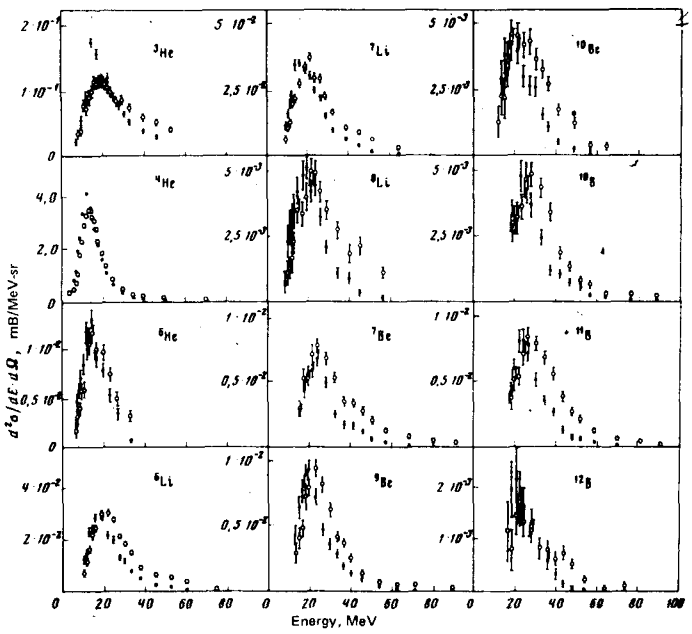
$$\frac{v - \langle v\rangle}{\langle v\rangle} = n\frac{V - \langle V\rangle}{V}, \quad (2)$$

where v, $\langle v\rangle$, V, and $\langle V\rangle$ are the velocities and the mean velocities of the evaporating nucleus and of the fragment. The parameters for the approximation of the experimental data are listed in the table. The value of n was 0.5—1.0 in all cases, with the exception of the

Fragment production cross sections, angular anisotropies ($\sigma, F/B$), and parameters for the approximation of the experimental data with calculated spectra.

Fragment	σ,¹⁾ mb	F/B	$\langle k\rangle$	T, MeV	Velocity of nucleus $v/c \cdot 10^{-3}$
^{3}He	54 ± 10	1.16 ± 0.13	0.5 ± 0.02	11.2 ± 0.2	6 ± 1
^{4}He	610 ± 100	1.07 ± 0.09	0.59 ± 0.01	4.6 ± 0.1	3 ± 0.1
^{6}He	2.7 ± 0.5	1.18 ± 0.19	0.59 ± 0.02	6.9 ± 0.3	5 ± 1
^{6}Li	8.5 ± 1.6	1.34 ± 0.2	0.52 ± 0.01	8.5 ± 0.1	7 ± 1
^{7}Li	9.9 ± 1.8	1.29 ± 0.17	0.54 ± 0.01	8.2 ± 0.1	6 ± 1
^{8}Li	1.5 ± 0.3	1.45 ± 0.25	0.57 ± 0.03	8.7 ± 0.4	7 ± 2
^{9}Li	0.3 ± 0.08	1.70 ± 0.63	0.60 ± 0.06	9.6 ± 1.2	10 ± 3
^{7}Be	2.2 ± 0.4	1.65 ± 0.22	0.55 ± 0.02	10.0 ± 0.3	4 ± 1
^{9}Be	2.3 ± 0.4	1.33 ± 0.19	0.55 ± 0.02	7.7 ± 0.2	6 ± 1
^{10}Be	1.3 ± 0.3	1.52 ± 0.26	0.53 ± 0.03	8.8 ± 0.4	5 ± 2
^{11}Be	0.13 ± 0.05	1.60 ± 0.62	0.54 ± 0.10	5.2 ± 1.0	8 ± 5
^{10}B	1.3 ± 0.2	1.34 ± 0.23	0.57 ± 0.03	8.7 ± 0.3	6 ± 2
^{11}B	2.4 ± 0.4	1.50 ± 0.20	0.61 ± 0.02	8.7 ± 0.3	5 ± 1
^{12}B	0.4 ± 0.11	1.52 ± 0.55	0.61 ± 0.05	7.3 ± 0.5	5 ± 3

¹⁾The cross-section errors include the statistical errors, the monitoring errors, and the errors in the normalization of the ^{7}Be production cross section at $T_p = 1$ GeV.[2]



Energy spectra of light fragments produced by interaction of 1-GeV protons with silver nuclei. The spectra were corrected for the absorption of the particle energy in the target: ○—θ = 60°, ●—θ = 120°.

neutron-deficient isotopes ^{3}He and ^{7}Be ($n=2.5$). The parameter Δ ranges from 0.18 to 0.22.

On the basis of the obtained data and of a comparison with the results of[1] we can draw the following conclusion: When the energy of the incident proton is varied from 1 to 5.5 GeV, the form of the fragment mass distributions changes little, whereas the fragment production cross sections increase appreciably. The energy spectra are much harder at $T_p=5.5$ GeV, whereas the Coulomb barriers change little. At a proton energy $T_p=1$ GeV, the parameter $\langle k \rangle$, which determines the effective Coulomb barrier, remains constant for all the isotopes. The obtained temperatures are also close to each other for most fragments, with the exception of ^{4}He and the neutron-deficient nuclei ^{3}He and ^{7}Be. The velocities of the evaporating nucleus coincide in most cases with the values obtained from calculations[3] by the cascade-evaporation mode ($v/c=0.0055$).

From the aggregate of data given in the table it follows that angular anisotropies and the spectrum-approximation parameters in agreement with the evaporation model can be obtained only for ^{4}He. Even in this case, however, the distribution (1) is incapable of decribing the high-energy part of the ^{4}He spectra, even when correlation is introduced. For all the remaining fragments, the temperature is an "unphysical" parameter. The particularly large values obtained for the temperature and correlation parameter of the neutron-deficient fragments ^{3}He and ^{7}Be may indicate that these nuclei are produced by a unique mechanism connected with large energy transfer. It appears that both mechanisms play a role in the production of the remaining isotopes.

1. E. K. Hyde, G. W. Butler, and A. M. Poskanzer, Phys. Rev. 4C, 1759 (1971).
2. E. Baker, G. Friedlander, and J. Hudis, Phys. Rev. 112, 1319 (1958).
3. V. S. Barashenkov, K. K. Gudima, A. S. Il'inov, and V. D. Toneev, JINR Preprint R2-5118, Dubna, 1970.