ESTIMATES OF LIFETIME AND PRODUCTION RATE OF MASSIVE NUCLEAR-UNSTABLE FRAGMENTS IN DISINTEGRATIONS OF ^{238}U NUCLEI INDUCED BY 1 GeV PROTONS

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In the study with the help of a double-arm time-of-flight spectrometer of nuclear fission induced by 1 *GeV* protons in heavy nuclei, events which at the time were attributed to an explosion of the nucleus were observed. These events were characterized by large nucleon losses and the presence of two massive fragments whose kinematics differed markedly from the two-body case. The subsequent investigations of the disintegration of heavy nuclei induced by relativistic protons which were performed using different experimental methods [1] led to the conclusion that massive nuclear-unstable fragments are formed. A nuclear reaction in which the two-body kinematics breaks down appears to be a process where the nucleus is disintegrated into three fragments of comparable mass. At the stage of separation of the fragments under the Coulomb repulsion the nuclear-unstable fragment decays into several minor fragments, thereby justifying the use of the notion "nuclear explosion". An important consequence of the proposed reaction mechanism is that the degree of unbalance of the momenta of the two detected nuclear-stable fragments depends on the lifetime of the moving nuclear-unstable fragment. It was expected that this effect should manifest itself in the measurement of momentum spectra of pair fragments that have different separation angles.

The experiments with pair fragments, formed during the irradiation of ^{238}U nuclei by 1 *GeV* protons, were carried out with the help of a double-arm time-of-flight spectrometer with collinear (180°) and noncollinear (170°) arrangements of the spectrometer arms. The axis of the stationary arm in each case was orthogonal to the direction of the primary beam. The basic configuration of the experiment is shown in fig.1, and the procedural details were published elsewhere [2]. Disintegration events were selected where nucleon losses

$$\Delta M = A_o - (M_1 + M_2) \qquad (1)$$

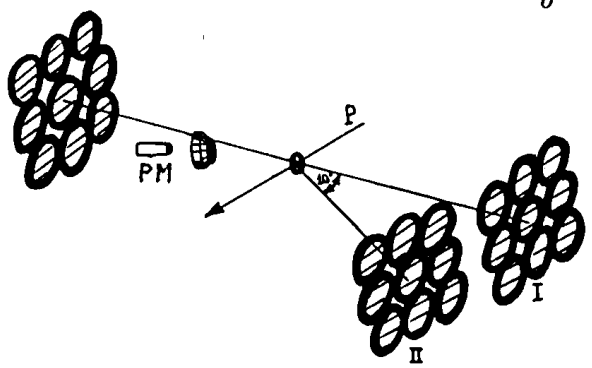

Fig.1. Schematic diagram of the arrangement of the semiconductor detectors in the double-arm time-of-flight spectrometer. The elements of the independent start-signal device are indicated. I — collinear geometry, II — noncollinear geometry

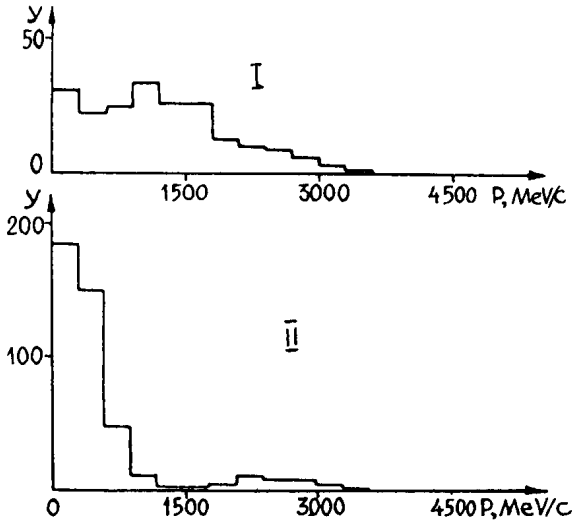

Fig.2. Spectra of projections of the momentum transfer in experiments with collinear (I) and noncollinear (II) geometry for events with nucleon losses $\Delta M \geq 75$ *amu*

were larger than 75 *amu*. These events were employed to construct distributions along the projections

$$P = /P_1 - P_2 / \tag{2}$$

of the total momentum transferred to the two fragments onto the axis perpendicular to the direction of the primary beam. Momentum spectra are shown in fig.2. The both spectra were analyzed in an identical manner under the assumption that they are the sum of two distributions. The first distribution is a normal distribution with zero mean and $\sigma_p = 449$ *MeV/c* and the second distribution complements the normal distribution. The quantity $\sigma_p = 449 \pm 17$ *MeV/c* corresponds best to the momentum distribution measured in the noncollinear geometry. The analysis showed that the relative probability of the complementary distribution changes from $Y_I = 93.6^{+6.4}_{-13.2}\%$ to $Y_{II} = 10.6 \pm 1.6\%$ on going from the collinear to the noncollinear geometry. At the same time the average value of the projection of the transferred momentum increases from $P_I = 980 \pm 390$ *MeV/c* to $P_{11} = 2530 \pm 100$ *MeV/c*. The experiments in the collinear and noncollinear geometries thus attribute the decrease in the number of the events in the complementary distribution to the increase in the average value of the momentum transfer. The decrease in the fraction of events is a natural consequence of radioactive decay

$$N(t) = N_0 e^{-\lambda t}, \tag{3}$$

while the average value of the momentum transfer increases as a result of the longer lifetime of the nuclear-unstable fragment at the Coulomb repulsion stage. It was found that events in which the nuclear-unstable fragments decayed in the intervals between the final time t_f and initial time t_i of acceleration were recorded in each of the two experimental distributions. They were estimated with the help of the analytical expression

$$t = \tau \left\{ 1/2 \ln \frac{1+x}{1-x} + \frac{x}{1-x^2} \right\}, \tag{4}$$

which was obtained for the motion of two bodies under the action of the Coulomb repulsion. In this formula $x = P/P_0$, where P is the time-dependent momentum, and P_0 is the maximum possible momentum acquired by a fragment as a result of acceleration. The temporal parameter is

$$\tau = 2 e^2 Z_1 Z_2 \cdot \mu^2 P_0^{-3}. \tag{5}$$

In this expression $Z_1 Z_2$ and μ which are, respectively, the product of the charges and the reduced mass of the separating fragments, relatively little affect the value of τ. The momentum P_0, for which the experimentally measured value of the average momentum of the nuclear-stable massive fragment $P_0 = 3000 \pm 20$ *MeV/c* was taken, is the determining factor. Ultimately, for the splitting of the ^{238}U nucleus by 1 *GeV* protons the temporal parameter τ was found to be $2 \cdot 10^{-21}$ *s*. The normalized experimental data

for the collinear and noncollinear geometries lead to a system of two equations containing the constant λ and the quantity N_0 of the total number of massive nuclear-unstable fragments produced in the nuclear reaction

$$N_I = N_0 (e^{-\lambda t_{iI}} - e^{-\lambda t_{fI}}), \qquad (6)$$
$$N_{II} = N_0 (e^{-\lambda t_{iII}} - e^{-\lambda t_{fII}}).$$

The system of equations was solved, and it was found that $\lambda = (5.7 \pm 0.5) \cdot 10^{20} s^{-1}$ and $W_{3*}/W_2 = (9 \pm 2) \cdot 10^{-3}$. The obtained quantities are referred to processes of production and decay of nuclear-unstable fragments with masses larger than 45 *amu*. The first one corresponds to the mean lifetime $\lambda^{-1} = (1.8 \pm 0.2) \cdot 10^{-21}$ *s*, while the second one describes the production rate of massive nuclear-unstable fragments relatively to binary fission probability [3,4].

References

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