Search for spontaneous collinear tripartition of ^{252}Cf nuclei

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Double arm spectrometer SAVEC has been used to identify spontaneous collinear tripartition of ^{252}Cf nuclei: ${}^{M_0}Z_0 \to {}^{M_1}Z_1 + {}^{M_3}Z_3 + {}^{M_2}Z_2$. No effect has been observed for $M_3 > 75$ u at the level of 7.5×10^{-6} with respect to the probability of the binary fission process. [S0556-2813(99)00807-9]

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When studying disintegrations of ^{238}U nuclei induced by relativistic protons [1,2] a noticeable part ($\sim$1%) of the events could be treated as a collinear tripartition

$$ {}^{M_0}Z_0 \to {}^{M_1}Z_1 + {}^{M_3}Z_3 + {}^{M_2}Z_2 \tag{1}$$

with the formation of a slowly moving fragment ${}^{M_3}Z_3$. Comparing the results of the two experiments, in which disintegrations were induced by protons with energies 1 GeV and 11.5 GeV [3], one could come to the conclusion that the probability of the collinear tripartition increases with the increasing energy of the beam. The question still open is whether this process is specific only for disintegration of highly excited heavy nuclei. In general one could assume such a process to proceed in a spontaneous disintegration of a heavy nucleus.

A very simple kinematic analysis of the one-dimensional motion of the three positive charges [1] shows that the condition for the third (inner) fragment ${}^{M_3}Z_3$ to be at rest for $Z_3 \neq 0$ is

$$M_1/M_2 = \sqrt{Z_2/Z_1}. \tag{2}$$

Used straightforwardly, this expression means that both neutron-rich and neutron-deficient fragments should appear simultaneously as a result of the process, while in the experiment the latter were observed only in disintegrations induced by relativistic protons. For spontaneous disintegration, where only neutron-rich fragments were detected, the only possibility to satisfy Eq. (2) is

$$M_1 = M_2, \quad Z_1 = Z_2, \tag{3}$$

which means a symmetric (both in masses and in charges) collinear tripartition with a slowly moving third fragment ${}^{M_3}Z_3$. Considering all available experimental results on the symmetric spontaneous fission of heavy nuclei, one may come to the conclusion that the most promising nucleus for search for the collinear tripartition is a spontaneously fissioning isotope ^{258}Fm. As known from the experiment, the fission of this nucleus is mainly symmetric in masses, so $M_1 = M_2$. The charges of the fragments Z_1 and Z_2 are usually considered to be equal to $50e$, though it has never been proved experimentally. It might well be that they are equal to each other ($Z_1 = Z_2$), but differ from $50e$. That would be an evidence for existence of the collinear tripartition process.

Unfortunately we do not have the source of the ^{258}Fm. When studying disintegrations of ^{238}U nuclei induced by relativistic protons [1,2], a source of spontaneously fissioning ^{252}Cf was used for energy and time calibrations. A part of the calibration data is used here to search for the spontaneous collinear tripartition. The mass of the third fragment is limited by the condition $M_3 > 75$ u, which corresponds to the events of collinear tripartition, found in the disintegrations of ^{238}U induced by 1 GeV protons.

The main idea is to find the events of the spontaneous disintegration with equal momenta of fragments

$$P_1 = P_2 \tag{4}$$

for sufficiently large missing mass

$$\Delta M = M_3 = M_0 - (M_1 + M_2). \tag{5}$$

We have used (2E,2V) measurements performed with the help of the spectrometer of the angular-velocity-energy correlations (SAVEC). The usefulness of that kind of an instrument is obvious, though such devices are not used frequently. The detailed analysis of the (2E,2V) method is given in [4]. Here we confine ourselves to a short description of the device, schematically shown in Fig. 1.

The SAVEC comprised a vacuum chamber with two time-of-flight tubes. At the end of each tube at the distance 70 cm a mosaic of eight semiconductor surface-barrier detectors (SSBD) was placed. The detectors were manufactured of *n*-type silicon with the specific resistivity of 250 Ohm cm, and a 50 μg/cm^2 layer of gold. The area of each detector amounted to 4.5 cm^2. One of the arms of the spectrometer was fixed, the other could be turned in the hori-

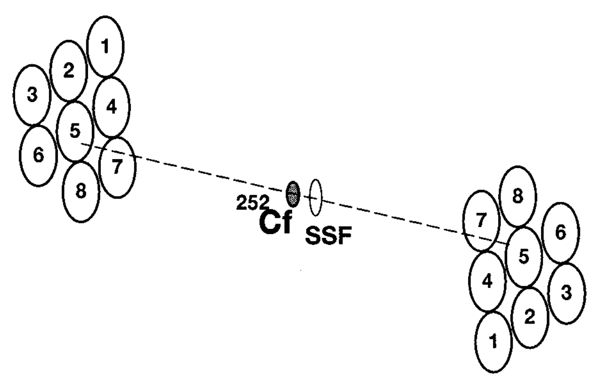

FIG. 1. Scheme of the spectrometer of the angular-velocity-energy correlations (SAVEC).

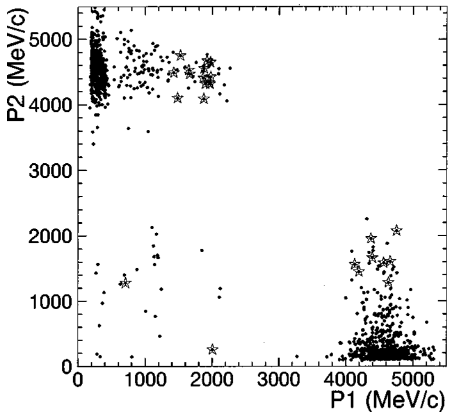

FIG. 2. Two-dimensional plot P_2 versus P_1 for events selected from the total statistics of 1.33×10^5 spontaneous disintegrations of ^{252}Cf by the condition $M_3>75$ u. The events which have a fragment mass in the range 55 u$\leqslant M_i \leqslant$65 u are marked by stars.

zontal plane. The weightless ^{252}Cf source with α-particle activity of 20 μCi on the nickel backing of 90 μg/cm^2 was placed in the middle of the chamber.[1] The source spot diameter amounted to 1 cm. The detectors in each mosaic were numbered so that the pair of fragments detected by the cells with equal numbers corresponded to maximum collinearity, i.e., minimal deviation (1.25°) from 180°. The maximum deviation for the whole mosaic amounted to 7°.

An independent time-start device for time-of-flight measurements was located at the distance of 3.7 cm to the source in the fixed arm of the spectrometer. Secondary electrons from the fragment interaction with a 85 μg/cm^2 thick start-signal nickel foil were detected in a thin scintillator by a fast photomultiplier. The nickel backing of the source was located on the side of the movable arm, so every detected fragment should pass through either backing foil or time-start foil.

If kinetic energies E_i and times-of-flight T_i of two massive complementary fragments are measured simultaneously, one can determine their masses $M_i \sim E_i T_i^2$ and momenta $P_i \sim E_i T_i$. The latter, together with appropriate angular resolution, allows one to make a two-dimensional plot P_2 versus P_1. Figure 2 shows such a plot (P_1, P_2) for the events selected from the total statistics of 1.33×10^5 spontaneous disintegrations by the condition $M_3>75$ u.

Almost all the points in Fig. 2 correspond to the binary fission events in which at least one of the two momenta P_i is underestimated with respect to the average momentum of the fragment $P_0=4575\pm50$ MeV/c. Independent determination [5] of the fragment kinetic energy by the time-of-flight method and by the ionization loss measurement with the SSBD has proved the existence of the pulse-height defect in the latter method. Its value is rather small, but it manifests itself for all the detected fragments. For the events shown in Fig. 2 the distortion of the fragment momentum is very large, but these events represent a small part of the total statistics. A special analysis showed, that the sizable distortions of the kinetic energy values are twice more frequent for heavy fragment group than for light one. This circumstance allows one to suggest that the distortion is caused by a Rutherford scattering of the fragment in the material of details of the SAVEC construction, comprising nickel foils of the backing of the ^{252}Cf source and start-signal device, gold layer on the inlet windows of the SSBD, and the bulk material of the detector, silicon. The scattering on nickel nuclei, located at a large distance from the SSBD, can be selected by the mass value of the detected fragment. The events which have a fragment mass in the range 55 u$\leqslant M_i \leqslant$65 u, corresponding to the natural nickel isotopes, are shown by stars in Fig. 2. As seen from Fig. 2, the scatterings on the nickel films represent only a small part of the events with underestimated momentum and energy. The main part of the events should be ascribed to the fragment scattering on silicon nuclei, forming the lattice of the SSBD material.[2] The points concentrating near the axes in Fig. 2 originate from the events in which one of the fragments hits an insensitive spot (relatively small) of the SSBD. These points comprise also the random coincidences of the fragments with numerous 6.12 MeV α-particles from the ^{252}Cf decay.

According to Eq. (3), the hypothetical collinear tripartition process (1) could also be detected by the SAVEC. One may assume for example the process

$$^{252}_{98}\mathrm{Cf}\rightarrow{}^{72}_{28}\mathrm{Ni}+{}^{108}_{42}\mathrm{Mo}+{}^{72}_{28}\mathrm{Ni} \tag{6}$$

similar to the earlier considered hypothetical disintegrations

$$^{236}_{92}\mathrm{U}\rightarrow{}^{72}_{28}\mathrm{Ni}+{}^{92}_{36}\mathrm{Kr}+{}^{72}_{28}\mathrm{Ni} \tag{7}$$

and

$$^{258}_{100}\mathrm{Fm}\rightarrow{}^{72}_{28}\mathrm{Ni}+{}^{114}_{44}\mathrm{Ru}+{}^{72}_{28}\mathrm{Ni}. \tag{8}$$

Taking into account the available experimental data on kinetic energies of the fragments, one can estimate the average values of the momenta of separating nickel nuclei as $P_{\mathrm{Ni}}=3550$ MeV/c [2] in reaction (7) and $P_{\mathrm{Ni}}=3940$ MeV/c [7] in reaction (8). Assuming that the momenta P_{Ni} in reaction (6) should be between these values and taking into account that the momenta of nickel nuclei, knocked out of the nickel films do not exceed 2000 MeV/c, we may choose a range from 2000 to 4000 MeV/c in each arm of the SAVEC. The condition for observation of the spontaneous collinear tripartition events in this momentum range is the equality of the measured momenta, that is a grouping of the points near the diagonal, given by Eq. (4). The absence of such events means that we do not observe process (6) in this experiment. We do not observe any disintegration of the type (1) for $M_3>75$ u at the level 7.5×10^{-6} of the probability of

[1]The ^{252}Cf source was made at the Kurchatov Institute of Atomic Energy in Moscow.

[2]The important role of the nuclear collisions for the fission fragments penetrating a certain thickness of matter was illustrated by a fission fragment track registered holographically in a cloud chamber filled with the air-argon-helium mixture [6].

the spontaneous binary fission of ^{252}Cf nuclei. If one takes into account the events close to the diagonal in the momentum range 1000–2000 MeV/c, one can specify more accurately 75 u$<M_3<$152 u.

One should specially note the absence of any trace of the double α-decay

$$^{252}_{98}\mathrm{Cf}\rightarrow\alpha+^{244}_{94}\mathrm{Pu}+\alpha, \tag{9}$$

in which each α-particle should have the momentum $P_\alpha=291$ MeV/c.

Summing up, we state that (2E,2V) measurements of two separating fragments are quite promising for the search for the spontaneous as well as induced collinear tripartition of heavy nuclei. Such a search for the disintegration of ^{252}Cf nuclei allowed to obtain the upper limit for the process with the formation of slowly moving massive fragments.

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