SUPERASYMMETRIC FISSION OF ^{260}NO* FORMED IN THE REACTION ^{12}C+^{248}CM

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A possibility of the formation of superasymmetric fission fragments caused by the nuclear shells at Z = 20, 82 and N = 28, 126 is investigated. The mass-energy distributions of fission fragments of ^{260}No compound nucleus formed in the reaction ^{12}C + ^{248}Cm have been measured. The increase of fragment yields in the mass region around 52/208 u that corresponds to the formation of fissioning pair of two double magic nuclei Ca/Pb was observed. At excitation energy of 50 MeV the yield of these fragments is about 0,001%.

1. Introduction

Today the properties of spontaneous and low energy fission of nuclei up to the element with Z = 104 are well studied. It is known that at low excitation energies the asymmetric fission mode is observed in mass-energy distributions of fission fragments for all nuclei with mass from $A \approx 200$ up to $A \approx 256$. For the nuclei with A < (220 - 224) the symmetric mode corresponding to the liquid drop model prevails, while the contribution of the asymmetric component does not exceed 0.5% [1]. For actinide nuclei with Z = 90-102 and A = 226-256 the asymmetric mode predominates in spontaneous fission as well as in induced fission at excitation energies up to 30-40 MeV [2,3]. The nuclei in the region of Ra [4], Ac [5] and the light isotopes of Th [6] are the transitional cases between symmetric and asymmetric modes in fission. The mass distributions for these nuclei at low energy fission are a superposition of symmetric and asymmetric modes with comparable contributions.

Bimodal fission appears for Fm isotopes (Z=100) and more heavy elements [6] when two fission fragments are close to the spherical proton (Z=50) and/or neutron (N=82) shells.

Four main fission modes have been distinguished in theoretical calculations as well as experimentally. In accordance with the Brosa model [8], the modes are as follows: the Superlong symmetric mode S; the Standard I mode caused by the influence of proton Z = 50 and neutron N = 82 shells; the Standard II mode determined by deformed nuclear shells with Z ≈ 54-56 and N ≈ 86; and the Supershort mode, manifesting itself only when light and heavy fission fragments are close to the double magic tin with A≈132in their nucleon composition.

At intermediate energies the dynamics of large scale collective motion is determined by the interplay between the global liquid drop properties and nuclear shell effects, resulting in specific charge, mass and kinetic energy distributions of fission fragments. The competition between various fission modes and diminishing of shell effects with increasing projectile energy is still an open question. Mass yield in fission decreases exponentially for masses away from the symmetric region. The slope of the exponential drop of mass yield varies considerably for various systems. Moreover, the superasymmetric fission mode, connected with the influence of the nuclear shells at N = 50 and Z = 28, was found in neutron induced fission of actinides nuclei with yield of 10^{-4} %. In this case only the light fragment is close to the double magic ^{78}Ni.

The question about the possibility of superasymmetric fission with mass ratio A_H/A_L =208/48=4.3 when both fission fragments are close to the double magic ^{48}Ca and double magic ^{208}Pb arises. We may expect such specific fission channel in fission of ^{256}No (^{48}Ca+^{208}Pb). In order to remove quasifission process taken place in the reactions with heavy ions we have chosen the reaction with “light” heavy ion ^{12}C: $^{12}C+^{248}Cm\rightarrow^{260}No^{*}$.

2. Experiment

The experiments were carried out at the Flerov Laboratory of Nuclear Reactions using the beam of ^{12}C ions extracted from the U-400M cyclotron at energies around the Coulomb barrier. The energy resolution was ~2%. Beam intensities on targets were 1-2 pnA. Layer of ^{248}Cm 200 μg/cm2 thick, deposited on a titanium backing, was used as target. The enrichment was 99.99%.

Binary reaction products were detected in coincidence by the two-arm time-of-flight spectrometer CORSET [9]. Each arm of the spectrometer consists of a compact start detector and a position-sensitive stop detector, both based on microchannel plates. The arms of the spectrometer were positioned in an optimal way according to the kinematics of the reaction. Due to large correlation angles between the fragment pairs for the studied reaction the arms of the spectrometer were positioned asymmetrically at angles 40° and -125°. A typical mass resolution of the spectrometer in these conditions is ~2-3 u.

The data processing assumes standard two-body kinematics [9]. Primary masses, velocities, energies, and angles in the center-of-mass system of reaction products were calculated from measured velocities and angles in the laboratory system using the momentum and mass conservation laws with the assumption that the mass of the composite system is equal to $M_{target} + M_{projectile}$. Neutron evaporation before scission is not taken into account. This is justified by the fact that at this reaction energy not more than 2-3 neutrons could be emitted. Hence, considering that the spectrometer resolution is 2-3 u, the neutron emission will not lead to visible effects on the mass-energy distributions. Fragment energy losses in the target, backing, and the start detector foils were taken into account.

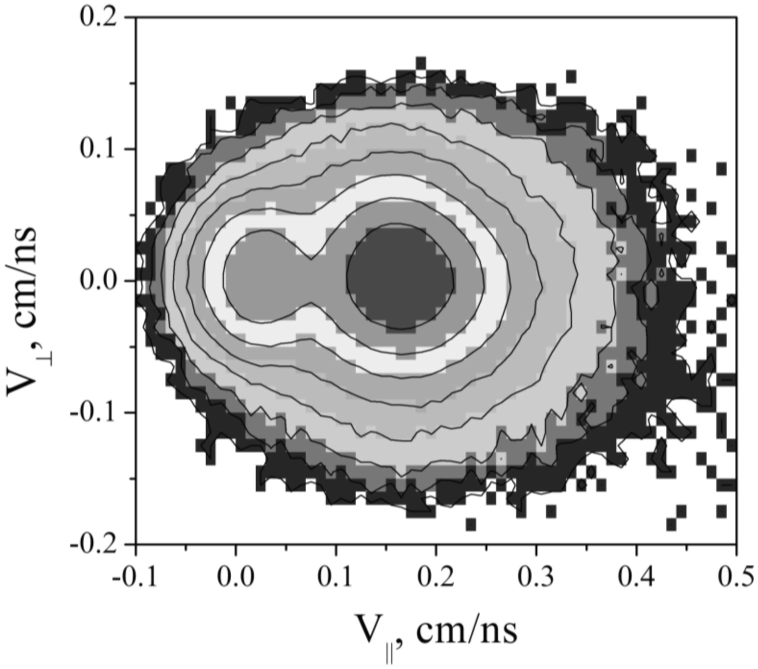

Figure 1. The distribution of velocity components $V_{||}$ and $V_\perp$ for the reaction $^{12}C + ^{248}Cm$ at beam energy of 80 MeV. $V_{||}$ is plotted relative to the calculated center-of-mass velocity $V_{c.m.}$.

The identification of the binary reaction channel with full momentum transfer (FMT) was based on the analysis of the kinematic diagram (the velocity vectors of two detected reaction products) in the center-of-mass system. For FMT events the distribution of the $V_{\perp}$ component of fragment velocity (projection of the fragment velocity vector onto the plane perpendicular to the beam) is expected to peak at zero, while the $V_{\|}$ (projection of the fragment velocity vector onto the beam axis) should be equal to the calculated center-of-mass velocity for the collision $V_{c.m.}$. Figure 1 illustrates the extraction of FMT events in the reaction $^{12}C + {}^{248}Cm$ at $E_{lab} = 80$ MeV. From this figure, it is apparent that the spectrometer detects two main groups of events. The events for which $V_{\|}$ is equal to $V_{c.m.} = 0.166$ cm/ns correspond to the binary products of the reaction $^{12}C + {}^{248}Cm$, while the group of events with $V_{\|}$ lower than $V_{c.m}$ corresponds to spontaneous fission of the target nucleus

3. Results and discussion

The mass-energy distributions of fission fragments of ^{260}No compound nucleus have been measured at the projectile energy of 80 MeV that corresponds to 50 MeV of excitation energy of the formed compound nucleus. The total amount of 2.5×10^{6} fission fragment events has been collected. In Fig. 2 the obtained mass distribution and average total kinetic energy (TKE) and its dispersion as a function of light fragment mass are shown.

Mass distribution is normalized to 200%. The mass distribution of the symmetric fragments has a nearly Gaussian shape and the <TKE> shows a parabolic dependence on mass typical for fission of excited compound nucleus, well described by the liquid drop model (LDM). Nevertheless, an increase of fragment yields in the mass region around 52/208u that corresponds to the formation of fissioning pair of two magic nuclei Ca/Pb, was observed. At an excitation energy of 50 MeV the yield of these fragments is about 0,001%. In addition the total kinetic energy for these fragments is found to be 20 MeV higher than predicted by the LDM. Since by far most of the final TKE is due to the Coulomb repulsion between fragments following scission, the shape elongation of the scission configuration determines the TKE. So, the configuration of fissioning nucleus ^{260}No at scission point at the formation of such superasymmetric fragments is more compact compare with normal fission.

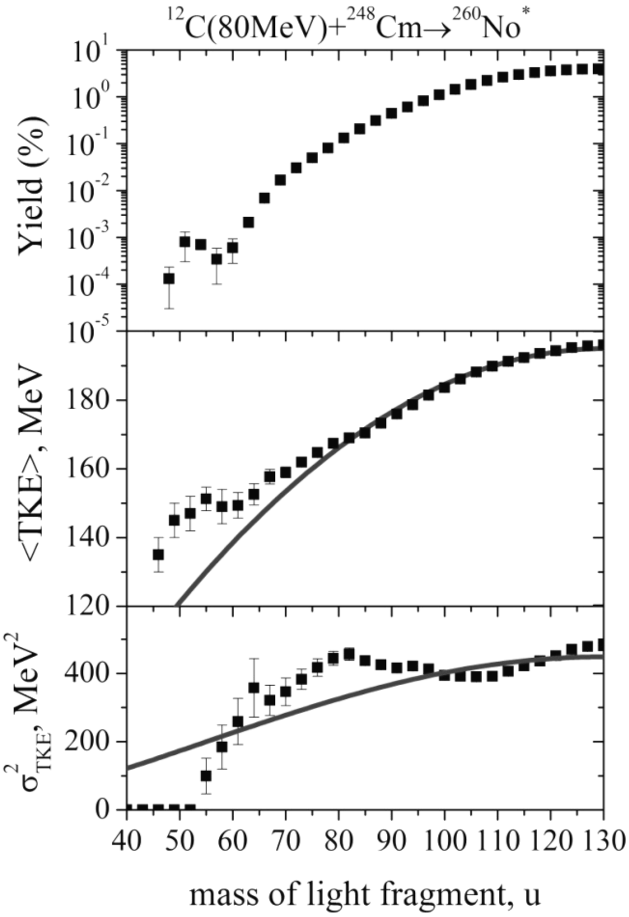

Figure 2. From top to bottom: mass distribution, average total kinetic energy and dispersion of the TKE as a function of mass of light fragment of the fission of ^{260}No* at excitation energy of about 50 MeV formed in the reaction ^{12}C + ^{248}Cm. The solid lines in the average TKE and dispersion of the TKE distributions delineate the expectation from the liquid drop model.

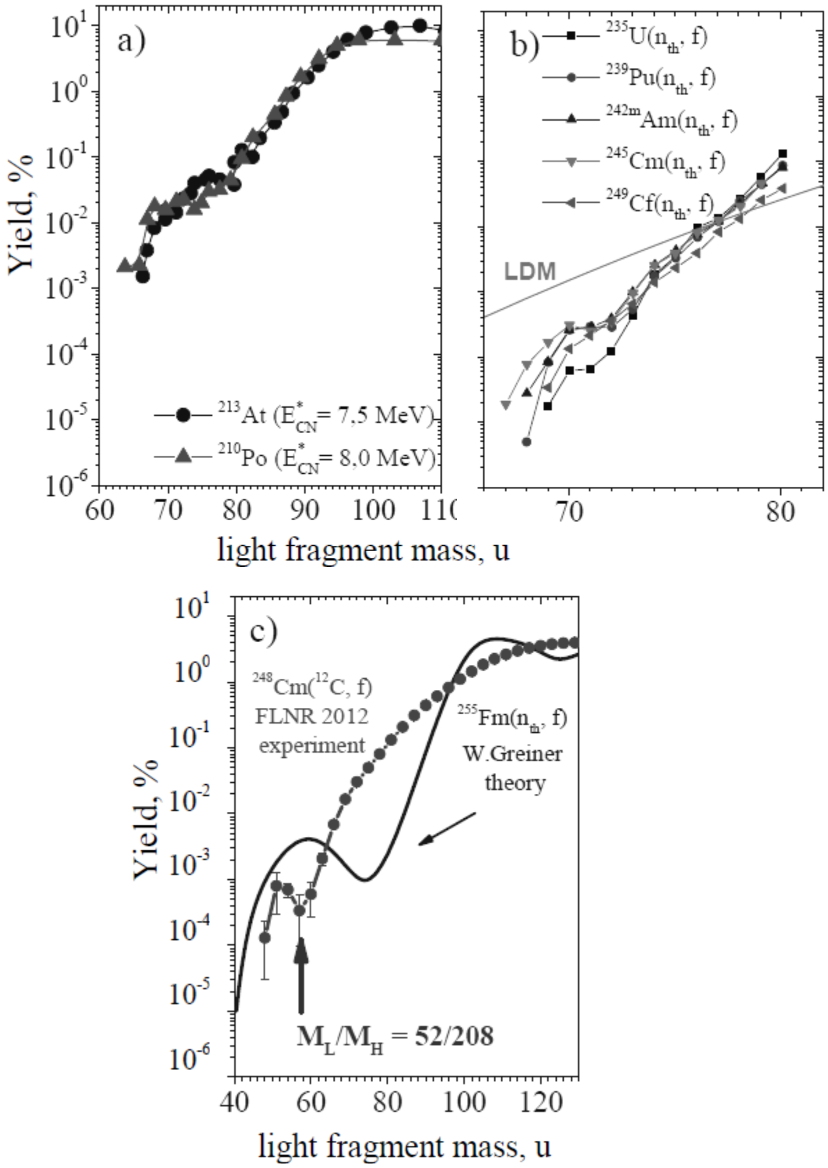

Figure 3. a) superasymmetric fission of nuclei around Pb region; b) superasymmetric fission in thermal neutron induced fission of actinide nuclei; c) superasymmetric fission of ^{260}No* compound nucleus observed in the present work.

For the first time the superasymmetric fission was observed in the fission of the compound nuclei in Pb region [10]. The enhancement of the mass yield in the region 65-75 u for the light fragment in the fission of ^{213}At and ^{210}Po compound nuclei is explained by the influence of double magic Ni ($Z = 28$, $N = 50$) and double magic Sn ($Z = 50$, $N = 82$). Notice that in this case the ratio $A_H/A_L \approx 2$, and the yield is around 10^{-2}%. (see Fig. 3 a).

In the thermal neutron-induced fission of actinide nuclei the superasymmetric mode with mass ratio of $A_H/A_L \approx 2.5$ caused by the shells in light fragment at $Z = 28$ and $N = 50$ was found [11]. In this case the yield of superasymmetric fission is around 10^{-4}% (see Fig. 3 b).

In present work the superasymmetric mode with ratio $A_H/A_L \approx 4.3$ caused by the influence of double magic Ca ($Z = 20$, $N = 28$) and double magic Pb ($Z = 82$, $N = 126$) has been observed in fission of excited ^{260}No compound nucleus. At excitation energy of 50 MeV the yield of these fragments is about 10^{-3}%. In Fig. 3c the experimental mass distribution obtained in the present investigation is shown in comparison with the predictions of Walter Greiner for thermal induced fission of ^{255}Fm. According to this calculation the yield of about 10^{-2}% is expected due to the influence of the closed shells, while for spontaneous fission of ^{255}Fm the yield of 10^{-4}% is expected for this superasymmetric mode [12].

4. Conclusion

In the present study of the $^{12}\mathrm{C} + {}^{248}\mathrm{Cm}$ reaction at $E_{lab} = 80$ MeV, the mass and energy distributions of fission fragments of ^{260}No ($E^* = 50$ MeV) have been measured aiming at search for the presence of superasymmetric fission mode with $\eta = 4.3$.

We observed the enhancement of fission fragment yields at $A_L/A_H \approx 52/208$ u. The total kinetic energy for these fragments is about 20 MeV higher than predicted by the LDM. Since the most of the final TKE is due to the Coulomb repulsion between fragments following fission, the shape at scission is more compact for this superasymmetric mode compare with the LDM.

The superasymmetric fission of ^{260}No was observed for the first time. The further investigations at lower excitation energies should be performed.

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