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EVIDENCE FOR A SUPERSHORT FISSION MODE IN THE REACTIONS $^{242m}Am\ (n_{th},f)$ AND $^{244}Cm\ (sf)$

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Abstract

Evidence for a new fission mode has been found in the mass - energy distribution of fragments as from the thermal neutron induced fission of ^{242m}Am as from the spontaneous fission (sf) of ^{244}Cm. In both data sets, which were measured using different methods, a couple of events is grouped around the mass numbers $A_{LF} = 81 \div 82$ with total kinetic energies (TKE) near the Q - value of the reaction. The yield of these events amounts to several units times 10^{-5} of all fissions. The mass of this light fission fragment nearly corresponds to one third of the mass of the fissioning nucleus. An attempt is made to understand this mode in the framework of a cluster description of the fission process. Within this model, a strong influence of the magic neutron number N = 50 may cause a clusterization into three prefragments of nearly equal mass. One of them escapes and leads to the effect observed.

1. Introduction

The discovery of the cluster radioactivity /1/ as well as the observation of resonant phenomena in light "alpha - cluster" nuclei /2/ induced this search for possible clusterization effects in heavy nuclei. A traditional field for such an attempt is the ternary fission process where a cluster with mass larger than an alpha - particle is emitted. Furthermore, the search for a "real" ternary fission where the three fragments have nearly equal masses is of special interest.

Recent experiments were directed to register heavy clusters from the ternary fission of ^{243}Am /3/ or to find out the "real" ternary fission of ^{252}Cf /4/, but no clusters heavier than ^{34}Si had been found. For experimental reason, in the first case fragments with mass larger than 60 amu could not be registered. In ref. /4/ an upper limit for the probability of fission accompanied with the emission of a cluster of mass in the interval of $70 \div 90$ amu has been estimated to be $2 \cdot 10^{-9}$. The failure of heavy clusters in the experiments mentioned, however, does not mean that they fail in the fission of other nuclei too. Indeed, as has been found for light (^{24}Mg) as well as for heavy nuclei (^{258}Fm), clusterization occurs in a pretty small region of the excitation energy and at special nucleon compositions of the nuclei considered.

In analogy to the spontaneously fissioning nucleus ^{258}Fm which decays into two Sn fragments (Z = 50), some candidate nucleus undergoing "real" ternary fission might be such composed from nearly magic constituents. The magic neutron shell N = 50 (e.g. $^{82}_{32}Ge_{50}$) possibly should influence the low energy fission of the isotopes of Am or Cm. Furthermore, one should expect that an unusual three - cluster configuration of the fissioning nucleus also makes itself felt in the binary fission process.

2. Experiments

With the aim to proof the hypothesis made above, the mass - energy distributions of the fission fragments (FF) from the reactions ^{242m}Am(n_{th},f) and ^{244}Cm (sf) have been analyzed in detail. The data for the first reaction were obtained at the one - arm time - of - flight (TOF) spectrometer of the MEPHI /5/. The second experiment has been carried out at the FOBOS spectrometer of the FLNR of the JINR Dubna /6/.

The measurement of the velocities (v) of the FF from ^{242m}Am(n_{th},f) was performed at a TOF path of 120 cm using channel plate detectors with a time resolution of $\approx$100 ps /7/. The energy (E) was measured by a surface barrier detector with an energy resolution of 1.5 %. The mass - energy distribution of one of the FF was derived from the measured (v,E) - matrix. Applying the conservation law for the total linear momentum, the kinetic energy of the second fragment was calculated. Finally, the mass - TKE distribution of correlated FF has been obtained.

At the FOBOS spectrometer the mass ratio M_{LF} / M_{HF} of the primary FF pairs was measured applying the two - velocities (TOF - TOF) method. Position - sensitive avalanche counters delivered the time and coordinate information. A small transmission avalanche counter was used for the time reference. The mass resolution of the spectrometer amounted to $\leq$ 3 amu.

3. Results

In fig. 1 a contour - plot of part of the yield distribution Y(M,E*) of the FF of ^{243}Am is shown. The excitation energy (E*) of the fissioning nucleus at the scission point was calculated according to the expression $E^* = Q_{max} - TKE$. Q_{max} means the maximum possible Q - value of reaction (in dependence on the charge of the FF) for a given mass split M_{LF} / M_{HF} . It was calculated from the data of ref. /8/. As can be seen from fig. 1, at low E* within a cut of $\Delta E^* = 2 \div 3$ MeV, there are several peaks corresponding to the masses 81 amu, 82 amu and 83 amu. The statistics of these peaks exceeds the statistical fluctuations of the distribution in its vicinity by factors of $1 \div 3.5$.

Some evidence for similar peaks exists in ^{244}Cm(sf) too (fig. 2), although they are less conspicuous due to the low statistics. Therefore a quantitative evaluation is not possible. In fig. 2 part of the conditional probability distribution $P(M|E^*)$ for the formation of a fragment of mass M at E* is shown. This distribution has been derived from the yield distribution Y(M,E*) of the light primary fragment by normalizing each energy cut of the yield matrix to unity. As in the case of ^{243}Am, at low E* within a cut of $\Delta E^* = 10 \div 15$ MeV, there is a slight enhancement at the masses $81 \div 83$ amu.

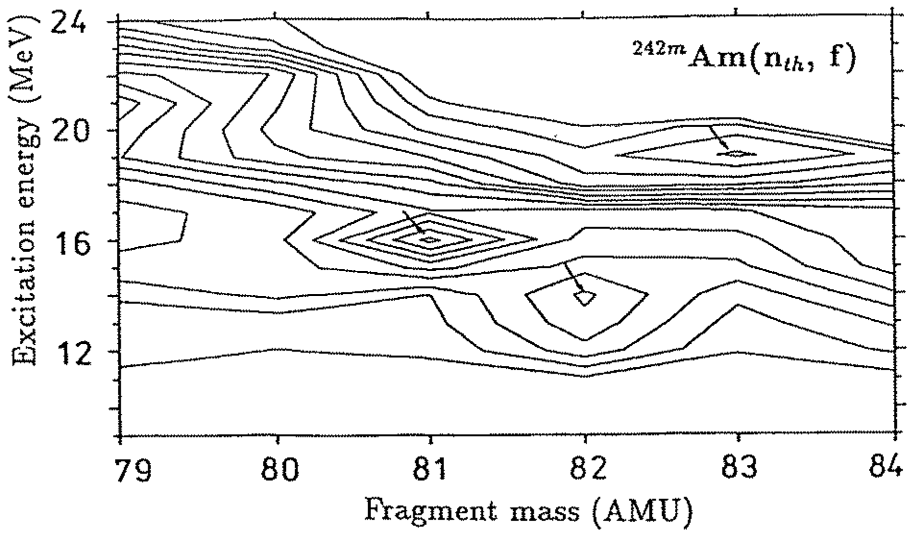

Fig. 1 Contour - plot Y(M,E*) of the yield distribution of FF for ^{242m}Am(n_{th},f). The maxima marked by arrows contain 18, 11 and 28 events (from left to right). The spacing of the contour lines corresponds to 4 counts.

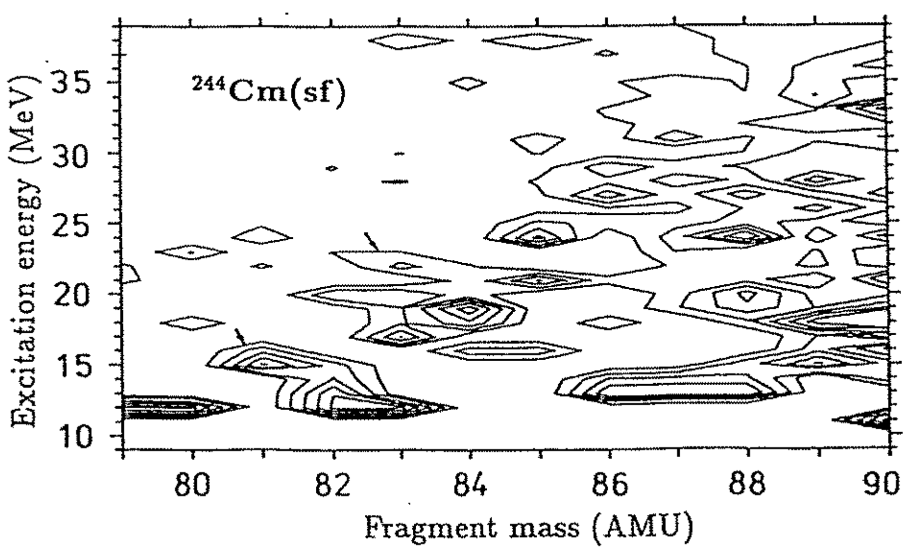

Fig. 2 Contour - plot of the probability distribution P(M | E*) for ^{244}Cm(sf) (see text !). The peaks considered are marked by arrows. The spacing of the contour lines is 1 %.

4. Discussion

We suppose an interpretation of the peculiarities found in the yield distributions of the FF quoting the cluster conception of the multi- modal fission model /9/. In the framework of this model, one can assume the following scenario.

At a certain stage of the fission process the fissioning nucleus reaches an elongated shape. Depending on spectroscopic and energetic conditions, there is some probability of preformation of three (strongly bound) clusters of nearly equal mass and charge $Z = 31 \div 32$. The "chain" of these clusters immediately ruptures due to the action of the Coulomb repulsion. This is the reason for the relatively small dispersion as of the mass of the FF (single mass peaks) as of the excitation energy E^* at scission in this process. If one cluster escaped, one observes the mentioned bumps in the mass - energy distribution characterized by a mass ratio of the FF being very near to 1 : 2. All other possible fission channels leading to a fragment in this mass region form the background underlying the bumps considered. As can be seen from fig.1 and fig. 2 , the structure of this background is different for ^{243}Am and ^{244}Cm. In a potential landscape of collective coordinates, e.g., the elongation of the nucleus and the mass asymmetry parameter, the fission path (valley) for this mode should be extremely short. Therefore, according to ref. /10/ , this fission mode can be named "supershort".

After one cluster escaped, the remaining two form an Eu or Gd nucleus in the cases of fission of ^{243}Am or ^{244}Cm, respectively. These nuclei have a relatively large ground state quadrupole deformation. This circumstance should support the rather cold fission at low E^*. It must be further noticed that for the realization of this compact mode (large TKE) a three - cluster stage before scission is essential. If only two prefragments are considered, the heavier one is a soft actinide nucleus. In this case one would expect a much larger mass - and TKE - dispersion of the FF.

From the mass - energy distribution of the FF of ^{243}Am an estimation for the amount of this three - cluster mode in the binary decay results in a value of $(2.1 \pm 0.7)\cdot 10^{-5}$. For ^{244}Cm(sf) this value seems to be a little bit higher.

Up to now it is a speculation to postulate a spontaneous "double neck rupture" after the preformation of three nearly equal clusters. This would lead to a "real" ternary fission. One further experiment is in preparation now to directly search for this possibly very rare process.

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