Kinetic energy distributions of ternary fragments in the fission of ^{252}Cf

K. R. Vijayaraghavan[1]* and M. Balasubramaniam[2]
[1]*Department of Physics, Alagappa Chettiar Government College of Engineering and Technology, Karaikudi - 630 003, INDIA and*
[2]*Department of Physics, Bharathiar University, Coimbatore - 641 046, INDIA*

Introduction

Ternary fission is the process of splitting of a heavy radioactive nucleus into three fragments. The ternary fission can happen in two different ways *viz* direct ternary fission and cascade fission. In direct ternary fission, the heavy radioactive nucleus splits into three fragments simultaneously. Cascade fission is a two-step process. In the first step, the heavy radioactive nucleus splits into two fragments, then, in the second step, any one of the fragments again splits into two fragments.

In Ref. [1], we reported the kinetic energies of most probable combinations by assuming the fission mode as cascade. In cascade fission, each fragments produced in the second step, has two possible velocities, due to positive and negative solutions. The results of positive solutions are presented in Ref. [1]. From the results, it is seen that the lightest fragment has very low kinetic energy in comparison to other two fragments.

Inorder to study the isotopic effects on kinetic energies of fission fragments, we have presented in Ref. [2] the results of the ternary decay of $^{252}\text{Cf} \rightarrow {}^{A_1}\text{Sn} + {}^{A_3}\text{Ca} + {}^{A_2}\text{Ni}$, where A_1, A_2 and A_3 are the fragment mass numbers. In this work, the charge numbers are fixed and mass numbers are varied. It is found that the kinetic energies of the third fragment are very low compared with other two fragments. Further, it is found that the kinetic energy of third fragment decreases as the excitation energy of the intermediate fragment (A_{ij}) was increased. This fact explains why the direct detection of true ternary fission with three fragments heavier than $A > 40$ has escaped from the experimental observation.

In the present work, we have calculated the minimum and maximum kinetic energies of all fission fragments that can be studied in a cascade mode picture. The kinetic energies of fission fragments are obtained by solving the conservation equations for the fission process. The energies obtained in such a way are asymptotic in nature.

In general, ^{252}Cf can break into 1.5 lakhs different ternary combinations. Repetition of fragment combination is avoided by considering that $A_1 \geq A_2 \geq A_3$. Each possible combination can be obtained in three different ways of fission in cascade mode. They are,

$$A \rightarrow A_1 + A_{23} \rightarrow A_1 + A_2 + A_3$$
$$A \rightarrow A_2 + A_{31} \rightarrow A_2 + A_3 + A_1$$
$$A \rightarrow A_3 + A_{12} \rightarrow A_3 + A_1 + A_2$$

Though the final fragments in the above three ways are same, the intermediate process is different. Hence, the kinetic energies of fragments produced in one way may not be same as the kinetic energies of fragments produced in the other way. Hence, effectively, there are more than 4.5 lakhs of possible combinations in the ternary breakup of ^{252}Cf. All these possibilities are considered in this study.

Being a cascade (two-step) process, two Q-values involved in the decay however, the overall Q-value is equal to the sum of the Q-values in each step. Further, the cascade process will be forbidden if the overall Q-value is negative and for some combinations, the overall Q-value may be positive, but any one of the Q-values may be negative, hence, such combinations are also considered as forbidden.

*Electronic address: `vijayanphy@gmail.com`

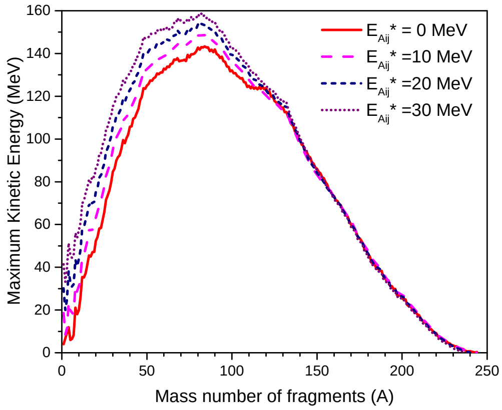

FIG. 1: Maximum kinetic energies of fragments with respect to their mass numbers in the ternary fission of ^{252}Cf for the excitation energies $E^*_{A_{ij}} =$ 0, 10 MeV, 20 MeV and 30 MeV.

Results

We have calculated the kinetic energies of all possible fission fragments by considering that the ternary fragments are produced in their ground state. We have studied the minimum and maximum kinetic energies of fragments with respect to their charge numbers and mass numbers in the ternary fission of ^{252}Cf for various excitation energy of intermediate fragment (A_{ij}) that is produced in the first step of cascade process. The maximum kinetic energies of fragments with respect to their mass numbers are presented in Fig. 1 for the excitation energies $E^*_{A_{ij}} = 0$, 10 MeV, 20 MeV and 30 MeV.

From the results, it is seen that the minimum energy of each fragment is almost zero or few electron volts. However, the maximum energy increases as the mass number or charge number of the fragment increases and reaches maximum value of 143.3 MeV when $A = 84$ and $Z = 34$ for $E^*_{A_{ij}} = 0$. For further increase in the mass number and charge number, the kinetic energy of fragments decreases and reaches almost zero kinetic energy. Also, the kinetic energy is found to increase as the excitation energy of A_{ij} is increased for fragments upto mass numbers $A = 150$. It is seen that the excitation energy has no influence on the kinetic energy of heaviest fragments ($A > 150$).

Summary

Minimum and maximum kinetic energies of ternary fragments are calculated for various excitation energies of intermediate fragments by assuming that the ternary fission mode is cascade fission. It is found that the lightest and heaviest fragments have less kinetic energy compared with the intermediate size fragments. Further, it is shown that the excitation energy of intermediate fragment does not affect the kinetic energy of heaviest fragments. The emitted fragments have high velocity, hence, this model needs to be modified further by incorporating the relativistic equations.

References

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