# Kinetic energy distribution of ternary particles from the trajectory calculations

V. Gokula Lakshmi[1], K. R. Vijayaraghavan[2,*]
M. Balasubramaniam[3], and P. Prema[1]
[1]*Department of Sciences, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, Amrita University - 641112, INDIA*
[2]*Department of Physics, Alagappa Chettiar College of Engineering and Technology, Karaikudi - 630003, INDIA and*
[3]*Department of Physics, Bharathiar University, Coimbatore - 641046, INDIA*

## Introduction

In the present work, we have studied the trajectories of various possible ternary fragments in the spontaneous fission of $^{252}Cf$. In literature, there were numerous studies done regarding trajectories of alpha particles and other light particles. However, there is no much study done in the trajectories of heavy particle accompanied ternary fission.

Boneh and his collaborators [1], theoretically studied the alpha particle trajectories for long-range alpha particles emitted in the spontaneous fission of $^{252}Cf$, and the same is compared with the experimental results. From their theoretical studies and experimental analysis, they arrived best initial parameters such as initial position, initial energy and initial angle of alpha particle, and initial velocity of heavy fragments, mass ratio and initial distance between two main fission fragments for ternary fission. The position of third fragment is chosen in such a way that the net force experienced by the third fragment is zero. This position represents the saddle point in the potential energy surface.

We have used those parameters to study the trajectories of best possible ternary fragments in the fission of $^{252}Cf$. In one of the studies done by us, we reported the best possible combinations in different modes of ternary fission of $^{252}Cf$ [2]. Those combinations are obtained from the three cluster model which was proposed by Balasubramaniam and Manimaran [3]. Here, we assume that the fission mode is triangular that is the light third fragment is formed in the neck region of two main fragments. In addition to this, we assume that all the fragments are point charges, this will not affect our results since the initial distances are greater than the size of the fragments. Here, we consider Coulomb potential only, since the nuclear potential is negligible at such distances. Here, the response of the trajectory to different parameters were studied. Being a three body problem, it will be difficult to solve analytically and hence, we have done simulation for performing the calculation. We find the dynamics of the three fragments at small time interval $dt$ using Newton's equations (equation of motion) as given in Eqs. (1) and (2).

$$\frac{d\mathbf{X}_i}{dt} = \mathbf{U}_i \qquad (1)$$

$$m_i \frac{d\mathbf{U}_i}{dt} = \mathbf{F}_i \qquad (2)$$

where $\mathbf{X}_i$, $\mathbf{U}_i$ and $m_i$ are the position, velocity and mass of the $i^{th}$ fragment, and $\mathbf{F}_i$ is the net force experienced by the $i^{th}$ fragment due to other two fragments. This procedure is repeated until the Coulomb forces between the fragments become negligible.

## Results and Discussion

In general, after scission, the kinetic energy of fragments increases enormously and reaches a maximum value. The maximum value is attained when the Coulomb force becomes zero.

*Electronic address: vijayanphy@gmail.com

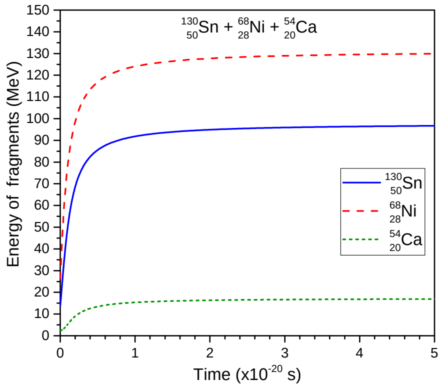


FIG. 1: Kinetic energies of fragments $^{130}_{50}Sn$, $^{68}_{28}Ni$ and $^{54}_{20}Ca$ with respect to time.

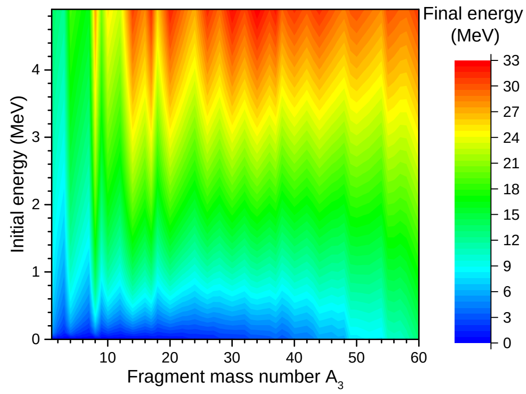


FIG. 2: Contour plot shows the final energy distribution of third fragments (A$_3$) with respect to initial energy and third fragment mass number.

To study the energy of ternary fragments, we have presented the kinetic energies of fission fragments with respect to time in Fig. 1 for one of the most probable combinations $^{130}_{50}Sn + ^{68}_{28}Ni + ^{54}_{20}Ca$ in the ternary fission of $^{252}Cf$. The initial energy of the third fragment is 3 MeV. The final energy of fragments is normalized to $Q$ value of the reaction. The final kinetic energies of fragments $^{130}_{50}Sn$, $^{68}_{28}Ni$ and $^{54}_{20}Ca$ are about 97 MeV, 130 MeV and 17 MeV respectively. To reach such saturated values, they take about $5 \times 10^{-20}$ $s$ after scission. However, within a short time of about $0.5{\times}10^{-20}$ $s$, the energy of fragments increases enormously and attains maximum fraction of energy.

To study the energy distribution of the third fragments, we have presented a contour plot in Fig. 2. $x$ - axis represents the mass number, $y$ - axis represents the initial kinetic energy and the colours represent the final energy of the third fragments, the colour scale is given at the right side of the plot. The study has been done for 60 different third fragments starting from mass number $A_3$ = 1 to 60. In addition to this, the initial energy of each third fragment varied from 0 MeV to 5 MeV. As a result, the third fragments had a range of final energies from 0 MeV to 33 MeV. From the Fig. 2, it is seen that the final energy of third fragment is increasing when its initial energy of third fragment is increased. Further, it is seen that for light fragments of mass number from $A_3 = 1$ to 12, the final energy is gradually increasing as the mass number increases at any given initial energy. However, for third fragments mass numbers with $A_3 > 12$, the final energy is almost same regardless of the mass number of the third fragment. For example, if the initial energy range is 4 MeV to 5 MeV, then the final energy can have distribution from 28 MeV to 33 MeV, and this range of energy is same for all third fragments with mass numbers $A_3 > 12$.

Further, we have studied the energy distribution of third fragments with respect to initial angle, initial energy, final energy and initial position of fission fragments. The angular distribution of third particle with respect to initial angle and final energy are also studied. These results will be presented elsewhere.

## References


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