Fragments kinetic energies in the ternary split up of ^{252}Cf

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Introduction

In ternary fission process a heavy radioactive nucleus breaks into three fragments. If one of the fragment is very light compared to the other two, it is referred to as light charged particle accompanied fission. The most viable light charged particle observed experimentally is ^{4}He, which comes out in a direction perpendicular to the main fission fragments. However a ternary breakup involving three fragments of exactly equal size has not been observed but it has been studied theoretically. But recently [1], using the missing mass method (with a double time of flight spectrometer) the ternary breakup involving three fragments of comparable masses is measured and is termed as true ternary fission and/or collinear cluster tri-partition (CCT).

Velocities and kinetic energies

In this work we present the kinematics of the emitted fragments corresponding to favourable breakups (in collinear geometry) for all possible third fragments. In this study we assume a two step fission process and in step-I the parent radioactive nucleus A fissions into fragments A_i and A_{jk} and then in step-II the composite fragment A_{jk} breaks into fragments A_j and A_k. The subscripts i, j and k takes the values from 1 to 3. The Q-value for the ternary decay is,

$$Q = M_x - [m_x^i + m_x^j + m_x^k] \tag{1}$$

where M_x is the mass excess of the decaying nucleus and m_x are the mass excesses of the product nuclei, expressed in MeV . Since the breakup is considered to happen in two steps, the Q-value in the first step is

$$Q_I = M_x(A) - [m_x(A_i) + m_x(A_{jk})] \tag{2}$$

and in the second step the Q value is

$$Q_{II} = m_x(A_{jk}) - [m_x(A_j) + m_x(A_k)] \tag{3}$$

If the momentum and energy of the fragments are conserved in the two steps then the final result will comply with the expectations of the asymptotic values independent of the decay mechanisms. The momentum conservation in the first step is given by,

$$m_{A_i} v_{A_i} + m_{A_{jk}} v_{A_{jk}} = 0 \tag{4}$$

where m_{A_i}, $m_{A_{jk}}$, v_{A_i} and $v_{A_{jk}}$ are the masses and velocities of the fragments A_i and A_{jk} respectively.

The conservation of energy in step-I is

$$Q_I = \frac{1}{2} m_{A_i} v_{A_i}^2 + \frac{1}{2} m_{A_{jk}} v_{A_{jk}}^2$$

From the above conservation equations, the velocities of the fragments A_{jk} and A_i can be written as

$$v_{A_{jk}} = (+)\sqrt{\left(\frac{2m_{A_i}}{m_{A_i} + m_{A_{jk}}}\right)\frac{Q_I}{m_{A_{jk}}}} \tag{5}$$

$$v_{A_i} = (-)\sqrt{\left(\frac{2m_{A_{jk}}}{m_{A_i} + m_{A_{jk}}}\right)\frac{Q_I}{m_{A_i}}} \tag{6}$$

Here we assumed a cold process (excitation energies of the parent and fragments are not considered). In the second step of the process, the composite fragment A_{jk} is assumed to break into two fragments A_j and A_k whose kinetic energies and velocities will be obtained

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from the momentum and energy conservation equations as described below. The momentum conservations leads to the following equation,

$$m_{A_{jk}} v_{A_{jk}} = m_{A_j} v_{A_j} + m_{A_k} v_{A_k} \tag{7}$$

m_{A_j} and m_{A_k} are the masses of the fragments A_j and A_k. The energy conservation in this step II is given as

$$Q_{II} + \frac{1}{2} m_{A_{jk}} v^2_{A_{jk}} = \frac{1}{2} m_{A_j} v^2_{A_j} + \frac{1}{2} m_{A_k} v^2_{A_k}$$

In addition to the Q-value Q_{II}, the kinetic energy of the composite fragment is also added and which is shared as kinetic energies of the fragments A_j and A_k.

The velocities of the fragment A_k and A_j can be obtained by solving the above conservation equations which results in,

$$v_{A_k} = \frac{m_{A_k} m_{A_{jk}} v_{A_{jk}} \pm \sqrt{\xi^2}}{m^2_{A_k} + m_{A_j} m_{A_k}} \tag{8}$$

$$v_{A_j} = -\left[\frac{m_{A_k} v_{A_k} - m_{A_{jk}} v_{A_{jk}}}{m_{A_j}}\right] \tag{9}$$

Kinetic energies of all the three fission fragments (for all possible third fragments) are obtained from their velocities as,

$$E_{A_x} = \frac{1}{2} m_{A_x} v^2_{A_x} \tag{10}$$

where, x takes any one of the values of i, j and k. Thus, the kinetic energies of all the three fragments are obtained.

Results

There are two possible velocities for fragments A_j and A_k due to $\pm$ term in Eq.(8) and correspondingly two possible kinetic energies. Here we present the results of + term in Fig.(1). The possible combinations are obtained by minimising their total potential in the configuration $A_i + A_k + A_j$ with $i = 1$, $k = 3$ and $j = 2$. The other possibilities and detailed results with general derivation including excitation energies will be presented in [2].

Due to negative Q-values, the ternary breakup for third fragment (A_k) mass numbers from 1 to 32 , is not possible. For other third fragments the kinetic energies are far lower than the other two fission fragments. The kinetic energy of third fragments upto mass number 50 is around 20 MeV and it increases upto mass number 60 then drastically decreases for other third fragments. This sudden variation is due to the fact that, upto third fragment mass number 60, the heavy fragment(A_1) is associated with proton closed shell with Z=50 and after that it changes to neutron closed shell with N=50 of the fragment (A_2). The heavy fragment mass number also changes from around 130 to 108. Similar result is seen in the potential energy surface also. The detailed results will be presented.

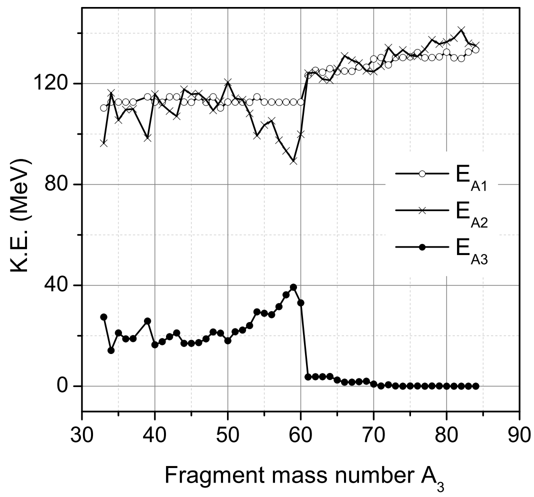

FIG. 1: Kinetic energies of the fission fragments (for all possible third fragments) of ^{252}Cf .

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References

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