Long range alpha trajectory with proximity potential

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Introduction

The term 'long range alpha' is used to distinguish the high energy alpha particle emitted in cold ternary fission compared to other alpha emissions. Ternary fission in which fragments are produced in the ground state is called cold ternary fission, which was first observed in 1998 by using triple gamma coincidence technique [1]. Such cold ternary decays produce all the three fragments with very low or zero internal excitation energy and consequently with very high kinetic energies. The fact that the light charged particles(LCP's), usually alpha particles, emitted in cold ternary fission are focused mainly into the equatorial plane perpendicular to the fission axis indicates that most of the ternary clusters originate from the region of the neck between the two heavier fragment [2]. Accordingly in equatorial emission at close to the scission configuration a few of the nucleons form a short neck and at a given value of the neck radius a double scission takes place and a third light fragment is emitted orthogonally [3]. On the other hand in polar emission LCP's are emitted at angles close to 0 or 180 degree and considered as cluster emission from the heavy fragment and is a very rare phenomenon.

The trajectory calculation of long range alpha particle in cold ternary fission is expected to give more details of scission configuration than in normal ternary fission. This is because initial conditions are better known due to the fact that fragments are of compact shape and produced in ground state. Misicu et al [4] suggested a method for computing initial energy and the location of LCP in terms of inter-fragment distance for the alpha particle in cold ternary fission and calculated the trajectory taking Coulomb force alone.

Since the tip distance is much lower in cold fission than in hot ternary fission, the contribution of nuclear force is expected to be relevant. Therefore for a proper reconstruction of the scission configuration it is indispensable to take in to account the nuclear force for cold ternary fission. The finite size of fragments is also considered since the same will affect the effective distance. The nuclear force here we used is that of the proximity potential proposed by Blocki et al [5]. The position and velocity of the alpha particle can be calculated using the following equations

$$V_{x\alpha}(t) = V_{x\alpha}(t_0) + a_{x\alpha}(t')dt \quad (1)$$

$$V_{y\alpha}(t) = V_{y\alpha}(t_0) + a_{y\alpha}(t')dt \quad (2)$$

$$X_\alpha(t) = X_\alpha(t_0) + V_{x\alpha}(t')dt + \frac{1}{2}a_{x\alpha}(t')dt^2 \quad (3)$$

$$Y_\alpha(t) = Y_\alpha(t_0) + V_{y\alpha}(t')dt + \frac{1}{2}a_{y\alpha}(t')dt^2 \quad (4)$$

with $$a_{x\alpha} = \sum_j \frac{F_{\alpha j}}{m}\left(\frac{X_j - X_\alpha}{r_{\alpha j}}\right) \quad (5)$$

and $$a_{y\alpha} = \sum_j \frac{F_{\alpha j}}{m}\left(\frac{Y_j - Y_\alpha}{r_{\alpha j}}\right) \quad (6)$$

The total force acting on the alpha will be

$$F_{\alpha j} = F_{coul.} + F_{nucl.} \quad (7)$$

with $$F_{coul.} = \frac{eZ_\alpha Z_j}{r_{\alpha j}^2} \quad (8)$$

where $$r_{\alpha j} = \sqrt{(X_\alpha - X_j)^2 + (Y_\alpha - Y_j)^2} \quad (9)$$

Here $j = H, L$ for heavy and light fragments respectively. The nuclear force F_{nucl} is taken as negative gradient of the proximity potential.

Results and discussion

The values of final energy, asymptotic angle emitted in long range alpha emission and the location of alpha particle is a rich source of information on the fragment configuration at scission. The direction of the alpha particle is determined by the electrostatic repulsion of fragments due to Coulomb force and is found modified by the attractive nuclear force. We have done the calculation for the splitting of ^{252}Cf in to ^{156}Nd+^{92}Kr+^{4}He for a tip distance from 6 to 8fm with step of 0.2fm. It is assumed that in the range 6-8fm the light particle has the possibility to escape by tunneling or by the disappearance of the barrier [4]. The variation of the final energy and asymptotic angle obtained in the absence and presence of nuclear force is shown in Table 1.

Table. 1 Asymptotic angle (in degrees) and final energy (in MeV) for various tip distances

Tip dista -nce (fm)	Initial. energy (MeV)	Coulomb force		Coulomb+Nuclear	
		Asymp. Angle	Final energy	Asymp. Angle	Final energy
6.0	2.71	85.35	22.16	78.15	21.35
6.2	2.49	85.22	21.26	78.05	20.41
6.4	2.30	85.11	20.39	77.99	19.50
6.6	2.08	84.95	19.52	77.92	18.44
6.8	1.89	84.79	18.69	77.88	17.45
7.0	1.72	84.65	17.95	77.86	16.47
7.2	1.51	84.45	17.12	77.87	15.36
7.4	1.34	84.28	16.37	77.92	14.37
7.6	1.18	84.08	15.75	78.01	13.42
7.8	1.02	83.84	15.12	78.16	12.41
8.0	0.85	83.79	14.48	78.30	11.23

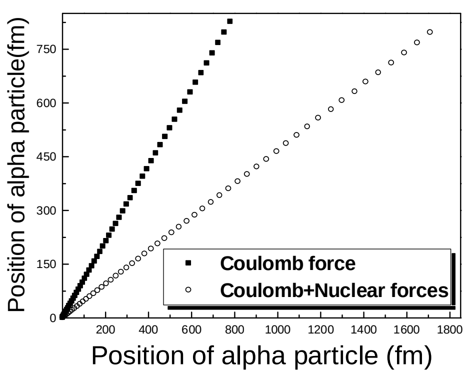

Fig. 1 Trajectory of alpha particle

For increasing tip distance the kinetic energy of the alpha particle is found to decrease as in normal ternary fission [6]. The final value of emission angle and energy of the alpha particle is found modified by the presence of nuclear force by reducing the asymptotic angle and final energy. Hence we have to conclude that the scission point configuration is altered due to the presence of nuclear force. The kinetic energy of alpha particle coincides with the experimentally measured value [7] of 16MeV at a tip distance of nearly 7.2fm. There is a lowering of final energy observed due to the attractive nature of the nuclear force and it is found that due to the presence of the nuclear force the alpha particle trajectory is shifted towards the light fragment and this shift per tip distance varies with tip distances. Sensitivity of the trajectory to initial energy and position of the alpha particle is the other feature observed.

A comparison of computation approach in hot and cold ternary fission in the case of ^{252} Cf is made in the following . In hot ternary fission the initial conditions of the different combinations must be varied to get the final physical quantities. On the other hand initial conditions in cold case are better known. An inter-fragment distance of 17 to 28fm and an initial alpha kinetic energy 0.125 to 4.35MeV were used to reproduce the experimental energy of 15.6MeV for hot ternary fission [7]. Whereas the range of parameters used in cold ternary fission is much reduced. In order to get the experimentally measured alpha kinetic energy of 16MeV a tip distance around 7fermi and initial alpha energy around 2MeV is sufficient.

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