Ternary potential energy surface of ^{56}Ni*

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Introduction

In low energy nuclear reactions leading to the formation and de-excitation of hot and rotating light mass nuclear system, light particle emission and binary fission channels have been reported within different theoretical models as well as experimental studies. These CN are shown to posses super and hyper-deformed shapes at higher angular momentum states. Recently, the component of ternary breakup and/or ternary clustering in such systems have been reported. In particular the systems ^{56}Ni and ^{60}Zn formed in low energy nuclear reaction are shown to have yields for the ternary breakup [1].

In this work, the three cluster model (TCM)developed by one of us [2] is extended by adding temperature and angular momentum effects. The extended TCM is applied to study the ternary fragmentation potential energies of ^{56}Ni* at a temperature of T=3 MeV. The moment of inertia governing the three body system is proposed.

Within TCM, the ternary fragmentation potential between three (spherical) fragments in collinear geometry with the incorporation of temperature effects is calculated as,

$$V_{tot} = \sum_{i=1}^{3}\sum_{j>i}^{3}(m_x^i(T) + V_{ij}(T)) + V_l(T), \quad (1)$$

where m_x^i are the mass excesses. For temperature dependence in the binding energy and/or mass excess we use the T-dependent liquid drop energy $V_{LDM}(T)$ of Krappe [3] with shell corrections $\delta U(T)$ of Myers and Swiatecki. Here,

$$V_{ij} = V_{Cij}(T) + V_{Nij}(T). \quad (2)$$

and V_l is the angular momentum dependent potential given as,

$$V_l = \frac{\hbar^2 l(l+1)}{2I_{CM}}. \quad (3)$$

$V_{Cij}(T)$ is the Coulomb interaction energy between the two interacting charges and $V_{Nij}(T)$ is the Yukawa plus exponential nuclear attractive potential. The three fragments are assumed to be aligned in the direction of the fission axis with the lightest fragment placed at the center as shown in Fig. 1. The separation distances for this configuration is

$$s_{ij} = s_{jk} = s; \qquad s_{ik} = 2(R_j + s) \quad (4)$$

with $s = 0$ corresponding to the touching configuration of three fragments. Here R_{ij} is j^{th} fragment distance from i^{th} fragment. R_{Ci}'s are the distances of the fragments from the

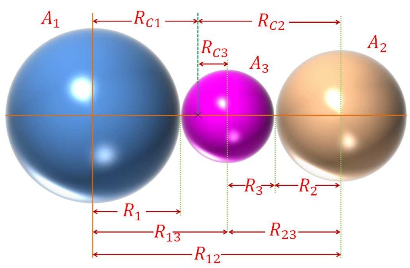

FIG. 1: Collinear arrangement of the fragments.

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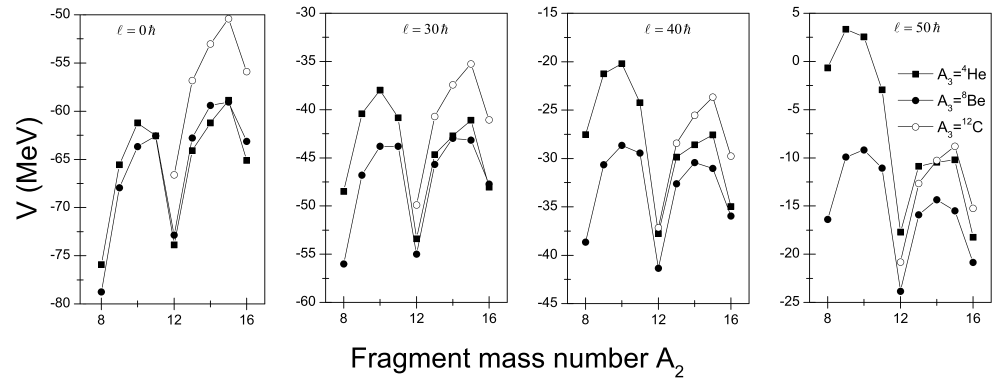

FIG. 2: Ternary fragmentation potential of $^{56}Ni^*$ as a function of A_3, A_2 (or A_1) and ℓ at T=3 MeV.

centre of mass and R_i's are the radius of respective fragments. Hence, center of mass of the three body system is,

$$R_{C1} = \frac{m_1(0) + m_2 R_{12} + m_3 R_{13}}{m_1 + m_2 + m_3}. \quad (5)$$

Where m_i's are masses of each fragments. The moment of inertia of this system about an axis which is perpendicular to $x-$axis and passing through center of mass can be written as,

$$I_{CM} = m_1 R_{C1}^2 + m_2 R_{C2}^2 + m_3 R_{C3}^2, \quad (6)$$

In order to avoid the repetition of fragments combination, we imposed a condition that $A_1 \geq A_2 \geq A_3$, hence the position of the center of mass will be in between fragments A_1 and A_3. Using this, we can impose two more conditions, to write the eq. (6) in terms of relative distances. The conditions are,

$$R_{C2} = R_{12} - R_{C1}; \quad R_{C3} = R_{13} - R_{C1} \quad (7)$$

With these conditions and from eq. (5) we have,

$$I_{CM} = \frac{m_1 m_2 m_3}{m_1 + m_2 + m_3} \left[\frac{R_{12}^2}{m_3} + \frac{R_{23}^2}{m_1} + \frac{R_{13}^2}{m_2} \right]$$

The rigid body moment of inertia is given as,

$$I_{CMR} = I_{CM} + \frac{2}{5} m_1 R_1^2 + \frac{2}{5} m_2 R_2^2 + \frac{2}{5} m_3 R_3^2$$

where $R_i's$ are radius of each fragments.

Results and discussions

Fig. 2 presents the ternary fragmentation potential as a function of fragment mass numbers A_3, A_2 (or A_1) and angular momentum values (as labelled) at T=3 MeV. The solid squares, solid circles and open circles corresponds to the third fragments A_3=^4He, ^8Be and ^{12}C respectively. In these panels there are 23 ternary possibilities. The increase in potential as ℓ increases is seen. When A_3=^8Be, the potential, lies the lowest even with the increase in ℓ values. When A_3=^{12}C, the potential at $\ell = 0$ lies highest but starts to compete with other cases with increase in ℓ. When A_3=^4He, the strong minima present (at A_2=8 and 12) becomes weaker as ℓ increases. At higher angular momentum values considered the possible ternary breakup could be ^{36}Ar+^8Be+^{12}C ; ^{32}S+^{12}C+^{12}C and ^{32}S+^8Be+^{16}O. The $^{56}Ni^*$ formed at higher excitation and rotation must possess clustering structure and the favoured ^8Be and ^{12}C at middle could be interpreted as a 2α and/or 3α structure as in experiments [1].

References

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[3] H. Krappe, PRC **59** (1999) 2640.