Quasifission dynamics in ^{48}Ca+^{232}Th, ^{238}U, ^{244}Pu, ^{248}Cm reactions using the dynamical cluster-decay model

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Introduction

The dynamics of fission fragments in heavy-ion reactions are typically influenced by the shell closures of the fragments and can be categorized into three types: asymmetric quasifission (QF_{asym}) (driven by shell closures at Z=28, 82, and N=50, 126), symmetric quasifission (QF_{sym}) (due to shell closures at Z=50 and N=82), and fusion-fission (FF) when the resulting fragments are of nearly equal masses [1]. In general, reactions involving actinide targets exhibit a broad peak in the binary mass yield, centered around ^{208}Pb, which is attributed to shell closures at Z=82 and N=126 in ^{208}Pb, corresponds to QF_{asym}. The mass distribution of fission fragments in the reactions ^{48}Ca+^{232}Th, ^{238}U, ^{244}Pu, and ^{248}Cm at energies near the Coulomb barrier, measured at the Flerov Laboratory for Nuclear Reactions of the JINR, revealed that the double magic lead influences QF_{asym} only in the first two reactions. The peak position of the heavy QF_{asym} fragment shifts from mass numbers 206−208 in the ^{48}Ca+^{232}Th reaction to 210−212 in the ^{48}Ca+^{248}Cm reaction. This shift suggests that the doubly magic lead may not be the sole factor governing QF_{asym} in heavy-ion reactions involving actinide targets. Theoretically, this shift has been attributed to changes in the position of the potential energy minima or valley [2]. However, Fig. (3) in ref. [2] shows that the potential energy valley for symmetric mass combinations is at lower energy than the asymmetric ones and hence the most probable process should be QF_{sym}, but the observed one is QF_{asym}. This indicates that the reaction yield is not directly linked to the potential energy valleys of ref. [2]. So, an investigation for the correlation of the energy valleys with fission yields using the dynamical cluster-decay model would be of interest.

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Methodology

The dynamical cluster-decay model [3, 4] is worked out in terms of the collective coordinates of mass [η=(A_H-A_L)/(A_H+A_L)] or charge [η_Z=(Z_H-Z_L)/(Z_H+Z_L)] asymmetry, internuclear separation R, the deformation parameters $\beta_{\lambda i}$ (λ=2, 3, 4; quadrupole, octupole, and hexadecapole defromations) and orientations θ_i of the interacting nuclei; i=L, H; being light and heavy fragments. The fragment cross-section within the model is defined as

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \quad k=\sqrt{\frac{2\mu E_{cm}}{\hbar^2}} \quad (1)$$

where P_0, the fragment preformation probability, is obtained from the solution of the stationary Schrödinger equation in η-coordinate with fragmentation potential at fixed interaction distance.The fragments are quadrupole deformed and oriented to their optimum hot-compact configurations. The penetration probability P is related to the R-motion of the fragments. In other words, the production of the fragments is considered as the dynamical mass motion of the preformed fragments through the interaction potential.

Results and discussion

Fig. (1) (a) shows that the fragmentation potential of the reaction ^{48}Ca+^{232}Th has a valley around the fragment combination of masses (135, 145) with neutron shell closure

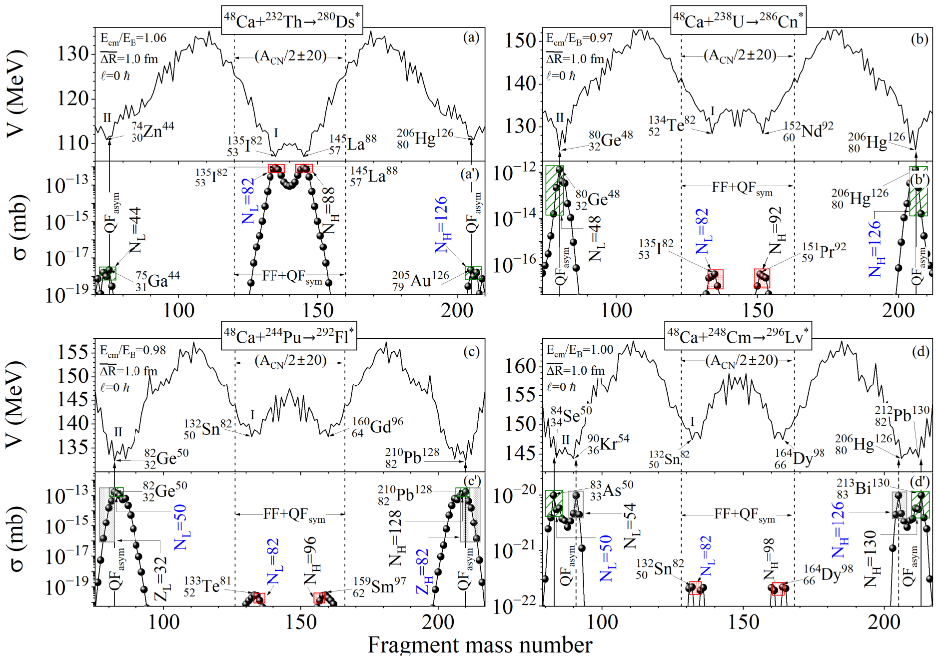

FIG. 1: (a-d) Fragmentation potential and (a′-d′) fission fragment cross-section as a function of fragment mass number for the reactions ^{48}Ca+^{232}Th, ^{238}U,^{244}Pu, and ^{248}Cm, respectively. The symmetric and asymmetric quasifission energy valleys are designated as I and II, respectively.

(N_L) at 82. This means that a large mass transfer should occur toward this energy valley and leads to a significant energy release, thereby resulting in a higher probability of the process. The high probability is observed as peaks around masses (135, 145) in the symmetric mass region ($A_{CN}/2 \pm 20$) of the mass distribution, as shown in Fig. (1) (a′), and corresponds to QF_{sym}. Another mass transfer to the potential valley around masses (74, 206) with shell closure around N_H=126 is possible, although relatively less favorable due to its higher potential energy. It corresponds to the QF_{asym} process. In this reaction, the QF_{sym} is the most probable process followed by the FF and QF_{asym}. Fig. (1) (b-d) shows that the large mass transfer should occur to the valley of the fragmentation potentials corresponding to the shell closures around N_H=126 along with N_L=50 and Z_H=82 which corresponds to the QF_{asym}, see Fig. (1) (b′-d′). For these reactions, QF_{asym} is the dominating process followed by QF_{sym} and FF. The calculated shift in the position of the QF_{asym} peak from A_H=205 to 213 with heavier actinide target is in agreement with the observed shift, given in ref. [2]. It may be noted that the QF_{sym} is governed by shell closure at N_L=82 for all the reactions.

Conclusion

The energy valleys in the fragmentation potentials of our calculations are directly linked to the fission yield. The most probable process for these reactions is asymmetric quasifission, which matches with the observed results, except for the first reaction.

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