Decay of hot and rotating nuclei formed in heavy ion reactions at low energies

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Introduction

The decay of hot (E≠0) and rotating ($\ell \neq 0$) nuclei formed in heavy ion reactions provide an interesting topic of research in nuclear physics. This study helps to carry-out comprehensive analysis of reaction dynamics along with relevant information about the nuclear structure and associated properties. Depending upon the mass of parent compound system, various emissions possibilities may arise. Generally, light particles or evaporation residue (ER) is dominant for the light mass systems and fission fragments starts competing as the mass of the composite system increases. The intermediate mass fragment (IMF) and heavy mass fragment (HMF) contribution is also seen in light, intermediate and heavy mass region. In addition to compound nucleus process, non compound nucleus mechanism also play significant role in the dynamics of a nuclear reactions.

In the present work, dynamical cluster decay model (DCM) [1]has been applied to study the decay behavior of a variety of nuclear systems lying in the mass range A=110-255. The effect of static or dynamic deformations, orientations, angular momentum, entrance channel, different versions of proximity, pairing strength, anisotropy, level density etc. have been explored and phenomena like ER, fission, quasi fission, fusion hindrance and incomplete fusion (ICF) have been addressed and investigated within DCM.

It is worth mentioning here that DCM is a reformulation of preformed cluster decay model (PCM) [2] which is based on the well known quantum mechanical fragmentation theory (QMFT) [3] where the fragments are asummed to be preborn in the nucleus before penetration through the barrier. The temperature dependence along with the deformation and orientation effects are duly included in the formalism used.

The experimental data is achieved nicely within one parameter fitting, the neck length parameter (ΔR) of the model whose value remains within the range of proximity interaction.

Calculations and results

As a first application, DCM has been used to study the decay of ^{254}Fm* formed in boron induced reaction [4]. The deformation and orientation effects are observed to play a significant role. The nice comparison of DCM calculations with the experimental data at all energies suggests that the contribution of competing non-compound nucleus quasi-fission (qf) component is quite small. The mass distribution changes from symmetric to asymmetric while moving from heavy ion induced reaction to spontaneous decay. The effect of static and dynamic deformation is explored. The fission fragment anisotropies are explored nicely using DCM based parameters.

Besides, the usual compound nucleus decay, DCM has been applied to study the incomplete fusion phenomenon in reference to ^{12}C+^{208}Pb and ^{13}C+^{207}Pb reaction channels by fitting the neck length parameter, different possible decay mechanisms are explored and analysed. The entrance channel independence is observed on the basis of fragmentation, preformation etc.. In addition to this, the fragment mass distribution is worked out by colliding ^{13}C weakly bound stable projectile with a variety of target nuclei resulting in

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^{13}C+^{159}Tb, ^{13}C+^{181}Ta and ^{13}C+^{207}Pb reactions, which shows that the fragment distribution changes significantly with increase in the mass of the target. The ICF systematics is nicely explored within DCM and is observed to be large for the asymmetric channel in agreement with morgestern systematics.

Next, the decay of preactinide nuclear system ^{204}Po* formed via ^{16}O + ^{188}Os and ^{28}Si +^{176}Yb reaction channel is investigated [5]. Here the cross sections are calculated by simultaneously fitting the neck length parameter for the ER and fission process. The deformations are seen to play an important role in the decay of ^{204}Po*. With the deformed choice of fragmentation the calculated evaporation residue cross-sections and fission cross-sections find excellent agreement with the available data at all incident center of mass energies, except at one highest energy for the channel ^{28}Si +^{176}Yb in case of fission process. This indicates the presence of some amount of nCN contribution at this energy. The fission fragment anisotropies calculated within SSPM approach using DCM based ℓ_{max} values for the non sticking limit of moment of inertia, show reasonable comparison with the experimental data, therefore the contribution of nCN component is not confirmed in agreement with the experimental predictions. The isotopic effect is worked out by studying the decay of ^{202}Po* and ^{204}Po* nuclei, which imparts important information regarding sub structure of fission fragments in decay of Po isotopes.

In addition to ER and total fission cross sections, independent fragment cross sections are also worked out in the decay of ^{118,122}Ba* formed in ^{78,82}Kr+^{40}Ca reactions [6]. The DCM results present nice agreement with the experimental data except for a narrow heavy mass fragment (HMF) window. To account for this unfitted region, we have attempted different versions of proximity potential, level density parameter, non zero pairing strength but the valley remains unfitted. However the inclusion of non compound nucleus component in the form of quasi fission resulted into the fitting of HMF window. DCM calculated results are compared with BUSCO, GEMINI and DNS codes where the overall comparison of the data with DCM is better than the others. The N/Z behavior of Ba isotopes is analysed where neutron deficient isotope seems to give more α-structure.

Along with the data at near and above barrier energies the sub barrier data is also worked out by studying the decay of medium mass nuclear system ^{112}Xe* across the Coulomb barrier. The neck length parameter gives barrier modification in a straight forward way for the best fitted fusion-evaporation cross sections in DCM. This barrier modification allow us to account for the data at sub barrier energies i.e to address the fusion hindrance phenomenon. The effect of diffuseness coefficient is also analysed which gives larger value of cross sections for smaller diffuseness coefficient which can be justified by significant modification in penetrability of decaying fragments. The fission as well as intermediate mass fragment cross sections are predicted and found to be negligibly small in agreement with the experiment.

Acknowledgments

I am thankful to Dr. Manoj K. Sharma and Prof. Raj K. Gupta for their guidance and support, and financial support from UGC, New Delhi is gratefully acknowledged.

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