Fusion-fission of ^{219,220}Ra* using the Dynamical Cluster-decay Model

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Introduction

The decay of ^{219,220}Ra* formed in ^{10,11}B + ^{209}Bi reactions, at different incident energies is studied by using the Dynamical Cluster-decay Model (DCM) of Gupta and collaborators [1], extended to include the deformations and orientations of nuclei. The formation and decay of an equilibrated compound nucleus (CN) has been a topic of great interest and is supposed to impart important information in context of reaction mechanism at low energies. The CN can decay in number of ways depending on the incident energy of projectile and shape orientations of target nucleus, etc. Thus for a compound nucleus reaction, the complete fusion (CF) cross-section σ_{CF} is defined as the sum of the cross-section due to the emission of light particles (LP's), the so-called evaporation residue σ_{ER} and the fission cross section due to the decay of compound nucleus into symmetric and/or near symmetric fragments, the so-called fusion-fission component σ_{ff}. Thus, in general $\sigma_{CF}= \sigma_{ER}+\sigma_{ff}$, and different compound nucleus reactions show preference for either of the two as a dominant decay mode. Some other competing non compound nucleus (NCN) processes like quasifission (qf), incomplete fusion (ICF) etc also compete with equilibrated compound states, the NCN component being more probable in weakly bound projectile reactions.

In this paper, we have used the Dynamical Cluster-decay Model (DCM) to estimate the complete fusion cross-section for ^{219,220}Ra compound systems formed in ^{10,11}B + ^{209}Bi reactions in reference to recent work [2]. In [2], the data for fission and α-active heavy reaction products is made available for ^{10,11}B + ^{209}Bi reactions and CF suppression (15% for ^{10}B and 7% for ^{11}B channel) is predicted. However in present work we concentrate only on the complete fusion (CF) process and tried to fit $\sigma_{CF}(=\sigma_{ER}+\sigma_{Fiss})$ cross-sections in the framework of DCM. The calculations are made for quadrupole (β_2) deformed fragments having "optimum" orientations θ_i^{opt} of hot (compact) configurations for the decaying fragments [3].

The Model

The DCM is based on the collective coordinates of mass (and charge) asymmetries, the relative separation R, the multipole deformations $\beta_{\lambda i}$ (λ=2, 3, 4), and orientations θ_i (i=1,2) of two nuclei or fragments. In terms of ℓ-partial waves, the DCM defines the compound-nucleus decay cross-section for oriented nuclei as

$$\sigma = \frac{\pi}{k^2}\sum_{l=0}^{l_{max}}(2l+1)P_0P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}}. \tag{1}$$

Here μ is the nucleon mass and ℓ_{max} is the maximum angular momentum, which is fixed at point where the light particle cross-section become negligible. P_0, the preformation probability, is the solution of stationary Schrödinger equation in mass asymmetry coordinate η and P is the WKB penetrability of preformed fragments or clusters in R-motion. The only parameter of the model is the temperature dependent neck length parameter ΔR(T), defining the first turning point $R_a = R_1(\alpha_1,T)+R_2(\alpha_2,T)+\Delta R(T)$ for the penetration of preformed fragment.

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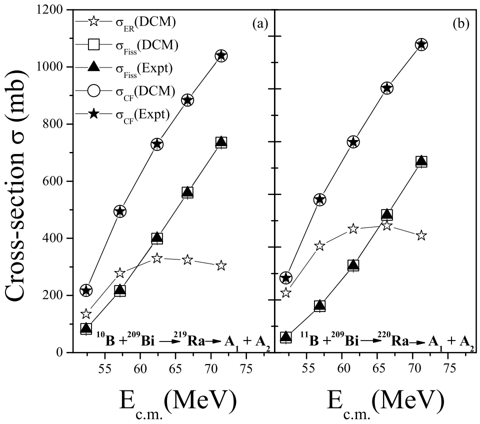

FIG. 1: The DCM based fission (σ_{Fiss}) and complete fusion cross-section (σ_{CF}) for ^{10,11}B + ^{209}Bi reactions, compared with data of [2].

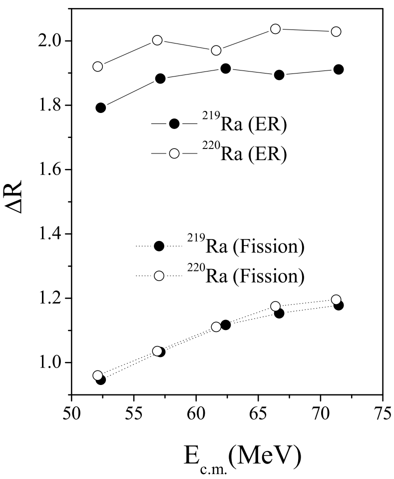

FIG. 2: The variation of neck length parameter ΔR with $E_{c.m.}$ for ER and fission processes in decaying ^{219,220}Ra nuclear systems.

Calculations and discussion

Fig.1 show DCM calculated cross-sections for fission (σ_{Fiss}) and complete fusion (σ_{CF}) over a wide range of c.m. energies (52 - 72 MeV), compared with available experimental data [2]. Here ER data is taken empirically from the complete fusion cross-section, as σ_{ER}=σ_{CF}^{Expt}-σ_{fiss}^{Expt} and the same is fitted in the framework of DCM. The calculated FF and CF cross-sections show excellent comparison with the available data for ^{10,11}B + ^{209}Bi reactions, using the quadrupole (β_2) deformations having "optimum" orientations θ_i^{opt} in DCM. It is important to note that the decay cross-sections are controlled by only one parameter of the model, the neck length parameter ΔR. This is depicted in Fig.2, where we observe that ER occurs first since ΔR for this process is large for both the systems and thus two processes i.e. ER and fission occur in different time scales. We find that ΔR varies smoothly over a range of incident energies for both the cases of evaporation residues and fission processes. One may see that main contribution to complete fusion cross-section comes from the fission cross-section at higher energies and evaporation residues contributes more at energies near the barrier. The evaporation residue cross-sections consist of significant contribution from the neutron evaporation cross-sections along with smaller contribution from other charged particle evaporation residues produced through the αxn and pxn (x=2,3,4) emission channels in ^{219}Ra and ^{220}Ra reactions [2]. We are in the process of applying DCM to study the subsequent decay process chains and ICF contribution in ^{10,11}B + ^{209}Bi reaction.

References

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