Fusion cross-section calculations in central and non-central collisions using classical and semi-classical formulae

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Introduction

Within the classical approximation, a *Classical rigid-body dynamical model* (CRBD-model) calculation [1-3] has been used to study the effect of Coulomb reorientation in a deformed+spherical system such as ^{24}Mg+ ^{208}Pb. In the dynamical simulation of collisions, barrier parameters are usually determined for central collisions and fusion cross-sections are calculated using the semi-classical Wong's formula [4].

$$\sigma(E_{c.m.}) = \left[\frac{R_B^2 \hbar\omega_0}{2E_{c.m.}}\right] \ln\left\{1+\exp\left(2\pi\frac{E_{c.m.}-V_B}{\hbar\omega_0}\right)\right\} \quad (1)$$

In the high energy limit, the Wong's formula (eq. 1) reduces to the classical formula,

$$\sigma_{fus}(E_{c.m.}) = \pi R_B^2\left[1-\frac{V_B}{E_{c.m.}}\right] \quad (2)$$

For non-central collisions, fusion cross-sections can be calculated using the critical impact parameter b_{cr} using the formula given below,

$$\sigma_{fus}(E_{c.m.}) = \pi b_{cr}^2 \quad (3)$$

A comparative study of fusion cross-sections of ^{24}Mg + ^{208}Pb system calculated using the barrier parameters in the case of central collisions (b=0) and barrier parameters corresponding to non-central collisions (b=b_{cr}) in the CRBD-model is presented. Calculational details of CRBD-model are given in ref. [1-3].

Results and discussion

Central collisions:

For ^{24}Mg + ^{208}Pb system, barrier parameters are dynamically determined corresponding to more than 500 initial random orientations for each collision energy $E_{c.m.}$. Using these barrier parameters in the Wong's formula (eq.1) average fusion cross-sections are determined for that particular energy only. Similarly, fusion cross-sections are determined for other energies also. Calculated fusion cross-sections are shown in the fig. 1 and are compared with the classical fusion cross-sections calculated with the classical formula (eq. 2).

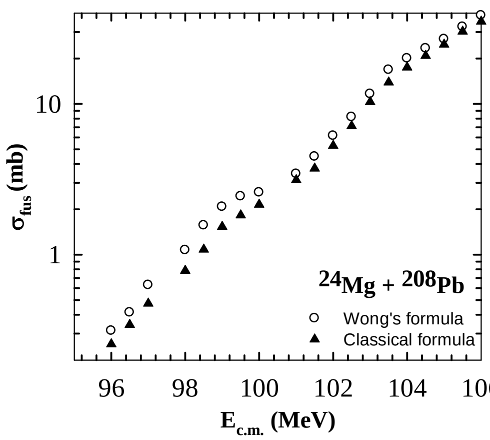

Fig.1 Fusion cross-sections calculated in the CRBD-model using the Wong's formula and classical formula.

At higher $E_{c.m.}$ fusion cross-sections calculated using the two formulae match closely. But at lower energies appreciable differences appear between the two calculations; fusion cross-sections calculated with the Wong's formula are higher than those obtained with the classical formula. Since the effect of reorientation is maximum at lower energies close to the barrier [3], the Wong's formula (eq. 1) which partially takes care of the penetrability of the barrier is more suitable for finding fusion cross-section compared to the classical approximation formula, (eq. 2).

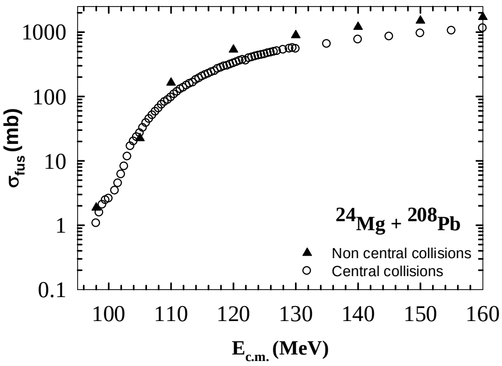

Fig. 2 Comparision of fusion cross-section calculated with CRBD-model for central and non-central collisions.

Non-central collisions:

By increasing the impact parameter for a given collision energy $E_{c.m.}$ and a given orientation we find the critical impact parameter (b_{cr}) which corresponds to just disappearance of the pocket in the ion-ion potential. The barrier parameters corresponding to b_{cr} are used in the Wong's formula (eq.1) instead of those corresponding to b = 0 to calculate fusion cross-sections. Fusion cross-sections at each collision energy are calculated by averaging over about 200 initially random orientations. Fusion cross-section calculations using the Wong's formula with barrier parameters for b=0 collisions and barrier parameters for b_{cr} (non-central) collisions are compared in fig. 2.

From the fig. 2 it is clear that fusion cross-sections for non-central collisions are higher than those for central collisions at higher energies while at lower energies they nearly match. This indicates that at lower energies contribution to fusion cross-sections due to higher ℓ values is negligible and hence $\ell = 0$ approximation made in the derivation of Wong's formula is justified. Since reorientation effect is prominent at energies close to or below the barrier, use of b = 0 barrier parameters in the Wong's formula is a good approximation.

We also calculate fusion cross-sections using the critical impact parameter values (b_{cr}) for different collision energies using the formula given in eq. 3. A comparison of fusion cross-sections calculated using eq.3 and Wong's formula (eq.1) with barrier parameters corresponding to critical impact parameters is shown in fig. 3.

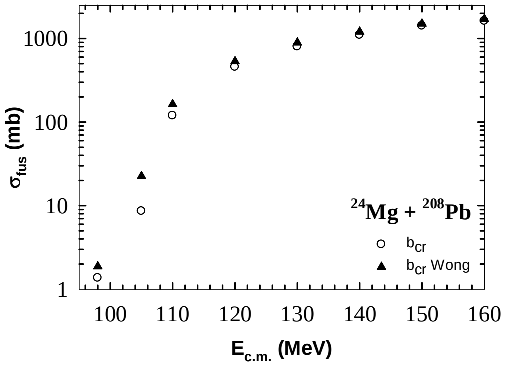

Fig. 3 Comparison of fusion cross-sections calculated using classical formula in eq. 3 and Wong's formula with barrier parameters corresponding to critical impact parameter.

It is clear from fig. 3 that at higher collision energies fusion cross-sections using eq. 3 nearly agree with those obtained from the Wong's formula. It means that at higher collision energies the Wong's formula approaches the classical limit because of the contribution of higher ℓ values. But at lower energies where contribution from the higher ℓ values is small, fusion cross-sections using the Wong's formula are higher because Wong's formula partially takes care of the penetrability of the barrier.

References

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