UGC – MAJOR RESEARCH PROJECT | EXECUTIVE SUMMARY

"A STUDY OF HEAVY ION COLLISIONS IN THE HEAVY AND SUPERHEAVY MASS REGION AND THE RELATED PHENOMENA"

PRINCIPAL INVESTIGATOR

Dr. M. BALASUBRAMANIAM

ASSISTANT PROFESSOR, DEPARTMENT OF PHYSICS

BHARATHIAR UNIVERSITY, COIMBATORE

SUBMITTED TO

UNIVERSITY GRANTS COMMISION

NEW DELHI

JANUARY – 2013

This project aims at further developing the Dynamical Cluster decay Model to explain the de-excitation process of excited compound nuclei formed in low energy reactions in heavy and superheavy mass region. This model would serve as an alternate to the existing statistical model. The prime objectives of the model are to study the role of different temperature dependent mass formulae in the calculation of the observables such as kinetic energies of the fragments, fission cross section over the entire mass spectrum, calculation of excitation functions etc.,. Apart from this the role of different interaction potentials in DCM and its effects in the observables also the entrance channel effects in the formation of compound system and incident energy effects are studied.

Most of the objectives of this project are covered and the executive summary of the findings is given below.

In Dynamical Cluster decay Model (DCM), one of the important ingredients is the temperature dependent binding energies. Initially temperature dependence due to Davidson et al. is used in DCM. The results indicate that the two nucleon transfer mechanism is prevalent in low mass systems whereas the experimental signature indicates a four nucleon transfer mechanism as seen from the observed cross sections. In literature, there are different binding energy expressions available. As a first we have analyzed the role of temperature dependent binding energy forms due to Krappe and Guet et al's instead of Davidson is used in DCM. The reformulated DCM was applied to study the decay of hot and rotating ^{56}Ni compound system formed in ^{32}S+^{24}Mg reaction at $E_{c.m.}$=51.6 and 60.5 MeV. The use of Krappe's formula results in the explicit preference of a four-nucleon transfer, indicating strong minima in the potential energies corresponding to α-structured nuclei as well as exhibiting structural effects in the preformation calculations favoring α-structured nuclei. The overall cross sections for the light particles and intermediate mass fragments are nicely reproduced by the use of Krappe's formula. However, the individual channel cross-sections exhibit a strong distribution only for α-nuclei, and for other fragments the results are lower by a factor of 2 to 3. The use of Guet et al.'s formula though does not show any explicit structure effects in the potential energy calculations or the preformation calculations; the overall cross sections calculated for light particles and intermediate mass fragments compare well with the experimental data. The results of individual channel cross-sections, however, do not exhibit any explicit preference for theα-structured nuclei; rather, the individual channel cross sections decreases with an increase in the mass number of the fragments. The calculated average kinetic energies using both formulas for the favored α-fragments compares well with experimental values. Without any refitting of the coefficients of the temperature-dependent binding energies, the DCM works out well and the explicit preference ofαstructure depends mainly on the choice of formula used. This work is published in Physical Review C 86, 014613 (2012).

In addition to this, we have also analyzed the effect of shell corrections in DCM. In Earlier calculations, analytical expression of Myers and Swiatecki is used for calculating shell corrections with 14 (N=Z=14) as a magic number. For this case, we have also analyzed the role of 14 and 20 alone, 14 and 20 both as magic numbers in the magic number sequence in shell correction calculation. Though the shell corrections will vanish at the temperature we considered, it has pronounced effect when different sequences of magic numbers are considered. Initial results due to Krappe's temperature dependence and its role of shell corrections due to Myers and Swiatecki were presented in the 56^{th} National level DAE-Symposium on Nuclear Physics, pp No. 608 (2011).

Later in a work, we have studied the effect of temperature dependent Wigner and pairing energies explicitly in the binary fragmentation of ^{59}Cu. The light odd mass compound system of ^{59}Cu is first studied in DCM. The effect of T-dependent Wigner and pairing energies in the fragmentation potentials is discussed by considering three different temperatures, T= 0.5. 1.0, and 4.1898 MeV. It is seen that for low temperatures both pairing and Wigner terms contribute significantly in the structure of the fragmentation potential. However, for the temperature corresponding to E_{lab} =275 MeV for the reaction under consideration, the pairing term vanishes and the resulting structure arises only due to the Wigner term. The roles of temperature-dependent Wigner term and Wigner term at T=0 MeV are also analyzed. In addition to this, we have also analyzed a factor α-appearing in the calculation of hydrodynamical masses defining the radius of the cylinder assumed in the total nuclear volume of the two spherical fragments for the mass transfer. It is seen that this factor has a significant effect in the preformation values. For lower values of α-for near symmetric fragments, the characteristic four-nucleon structure is seen (for ℓ=0ħ), which diminishes and vanishes completely with increase in α-values. In general, the preformation probabilities for the fragments beyond A_2 > 12 increase with increase in the α-values.

However, this scenario changes at higher ℓ-values. At higher ℓ -values, for 4n nuclei, the preformation value is maximum for lower α-value and decreases with increase in α-value. However, for other fragment combinations, the preformation probability increases with increase in α-values. This significant change in the preformation results also in the cross-section calculations. For different α-values, the experimental data are fitted by varying the free parameter ΔR and a linear relation is obtained between ΔR and α-values. Our calculated cross sections for the charge distribution of the measured fission fragments are reasonably closer to the experimental data. In this work, we have not tried for exact fitting. It is just an attempt to see any correlation between only one parameter of the model, namely ΔR and the value of α (dictating the nucleon transfer in the inertia part) as a function of energy so as to make the dynamical cluster-decay model a parameter-independent model, which would account for all the fusion-fission reactions of the low-energy domain. This is also published in Physical Review C 87, 024608 (2013).

Further, we have also studied the effect of different entrance channel effects and incident energies of the compound system of ^{59}Cu formed in $^{35}Cl+^{24}Mg$, $^{19}F+^{40}Ca$ and $^{32}S+^{27}Al$. In this work, we have calculated the excitation functions for the light particle productions for the $^{19}F+^{40}Ca$ and $^{32}S+^{27}Al$ reactions. By varying ΔR, we have calculated the excitation functions for $^{19}F+^{40}Ca$ reaction and a polynomial relation obtained between ΔR and $E_{c.m.}$. Using this relation we have calculated the excitation functions for $^{32}S+^{27}Al$ reaction. The obtained results are compared with the experimental results. This work is presented in International Conference on Recent Trends of Nuclear Physics as a poster presentation and it is published in AIP conference proceedings 1524, 159-162 (2013).

Further the role of incident energies of the compound systems is also studied for $^{56,60}Ni$ formed in $^{16}O+^{40,44}Ca$ reaction. Here we have calculated the temperature binding energies with the use of Guet et al's form. The results are presented as a poster in the 57^{th} National level DAE-symposium on Nuclear Physics pp. No. 484 (2012).

The model is further refined by incorporating deformation effects of the fragments and is applied to the decay of ^{56}Ni formed in $^{32}S+^{24}Mg$ reaction at $E_{c.m.}$=51.6 MeV. The effect of deformation is clearly reflecting in the potentials, mass parameters and preformation probabilities. This will reflect in cross section values. This work was submitted to International Nuclear Physics Conference (INPC) 2013.

The fully temperature dependent DCM with the use of Krappe's binding energy formula applied to the even-mass and α-structured ^{56}Ni compound system formed in ^{32}S+^{24}Mg reaction at $E_{c.m.}$=60.5 MeV. In this work we have achieved the better fit of our calculated results with the experimental values. For this purpose, we have tuned the neck length parameter ΔR for individual fragments from A_2=12 to 28 (Heavy mass fragments, HMFs). For light particles (LPs, A_2=1-4) and light mass fragments (LMFs, A_2=5-11) is also varied but not individual. Here, our calculated overall cross section values of the light particles and intermediate mass fragments and as well as the individual fragments cross section values are in good agreement with the experimental data than the earlier work on DCM and also the other model results. This is achieved first in DCM, for this reaction. A detailed manuscript is under preparation for its submission to peer reviewed journal.

The existing codes are established and modified for its various calculations like kinetic energies of the fragments and individual fragment cross sections, plotting purpose and etc.,. Further, these codes are integrated and generalized for its use in both environments of Windows and Linux.

The preformation probability which is the main ingredient of the DCM is so far calculated based on quantum mechanical fragmentation theory (QMFT). In this project an attempt is made to calculate preformation probability as a function of hydrodynamical masses and reduced mass. The obtained results are tested for different mass regions from low to superheavy via ^{56}Ni, ^{116}Ba, ^{226}Ra, ^{256}Fm and ^{286}X. The obtained results are published in European Physical Journal A, 47, 126 (2011)

Further in the superheavy mass, the role of proximity potential is tested for α-decay studies with an intention to extend the ideas to DCM. The half-lives of known α-emitters and wide range of elements in superheavy mass region are predicted. The results are published in Journal of Physics G: Nuclear and Particle Physics, 40, 035104 (2013).

LIST OF PUBLICATIONS OUT OF THE PROJECT

International journals:

1. Decay studies of $^{59}Cu^*$ formed in the $^{35}Cl+^{24}Mg$ reaction using the dynamical cluster-decay model

   C. Karthikraj and M. Balasubramaniam, Phys. Rev. C **87**, 024608 (2013).

2. Nuclear surface energy coefficients in α-decay

   N. S. Rajeswari and M. Balasubramaniam, J. Phys. G: Nucl. Part. Phys. **40**, 035104 (2013).

3. Temperature-dependent binding energies in a dynamical cluster-decay model applied to the decay of hot and rotating $^{56}Ni^*$

   C. Karthikraj, N. S. Rajeswari, and M. Balasubramaniam, Phys. Rev. C **86**, 014613 (2012).

4. Cluster pre-existence probability

   N.S. Rajeswari, K.R. Vijayaraghavan and M. Balasubramaniam, Eur. Phys. J. A **47**, 126 (2011).

International conference proceedings:

1. Effects of deformation in the decay of $^{56}Ni^*$ formed in $^{32}S+^{24}Mg$ reaction

   C. Karthikraj and M. Balasubramaniam

   Contributed to International Nuclear Physics Conference (INPC2013), 2-7 June 2013, Italy.

2. De-excitation studies of ^{59}Cu formed in different entrance channel reactions

   C. Karthikraj and M. Balasubramaniam, AIP Conf. Proc. **1524**, 159 (2013).

National symposium proceedings:

1. Fission of $^{59}Cu^*$ formed in $^{35}Cl+^{24}Mg$ reaction

   C. Karthikraj and M. Balasubramaniam, Proc. of the DAE Symp. on Nucl. Phys. **57**, 486 (2012).

2. Decay of $^{56}Ni^*$ system formed in $^{16}O+^{40}Ca$ reaction

   N. S. Rajeswari, C. Karthikraj, and M. Balasubramaniam

   Proc. of the DAE Symp. on Nucl. Phys. **57**, 484 (2012).

3. Role of shell corrections in the temperature dependent binding energies applied to the decay of $^{56}Ni^*$

   C. Karthikraj, N. S. Rajeswari, and M. Balasubramaniam

   Proc. of the DAE Symp. on Nucl. Phys. **56**, 608 (2011).

4. Cluster pre-existence probability from WKB integral

   N.S. Rajeswari and M. Balasubramaniam

   Proc. of the DAE Symp. on Nucl. Phys. **55**, 186 (2010).