Light Charge Particle and Intermediate Mass Fragment Emission from Excited Compound Nuclei Formed in Heavy-ion Reaction

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Introduction

Nuclear reactions induced by heavy ions have now become a major tool in the field of nuclear physics research. A deep understanding of fusion-fission process of the compound nucleus that are formed in heavy ion reaction is essential for studying the formation of heavy nuclei. The studies in the field of heavy ion induced reactions have been targeting toward this aim. There have been extensive experimental studies on collision involving deformed nuclei that can have many orientations in the ground state. In low energy heavy ion reactions, both the light (A ~ 60) and medium mass (A ~ 110) compound systems emit Intermediate mass fragments (IMFs) with mass lighter than A ~ 20 and they arise as multiple clusters and are accompanied by the production of multiple light particles ($Z \leq 2$). Light compound nuclei (CN) with mass number $A_{CN} < 44$ that are formed in low energy (E/A < 15MeV/nuclei) heavy ion reactions are highly excited and carry large angular momenta. It was found that the decay process must depend on temperature and angular momentum dependent potential barriers. Theoretically the de-excitation of the compound systems formed in low energy nuclear reactions were studied using different models. The cluster decay studies of $^{112-122}$Ba as a ground and excited system was done within the model. In the present study the decay of excited compound nuclei like ^{48}Cr, ^{56}Ni, ^{44}Ti, and $^{26-29}$Al with and without incorporating the deformation effects has been investigated. Also, the studies were extended to the excited state decay of heavy elements. In all cases, the study has been extended and the cross sections for entrance channels and E_{CM} values other than the available experimental values have been evaluated, which can help future experimental studies in this field.

Within the Coulomb and proximity potential model (CPPM) [1] and the Coulomb and proximity potential model for deformed nuclei (CPPMDN) [2], a wide range of studies have been performed on the alpha decay of heavy and SHN, cluster decay of heavy and SHN and also on the decay of excited compound nuclei. The modified version of CPPM for excited nuclei with temperature effects included [3] was used to study the decay properties of various even-even isotopes of barium in the range $112 \leq A \leq 122$ using recent mass tables for both the ground and excited state decays.

The decay cross section

An extensive study on the decay of light nuclei in excited state has been done within the one-dimensional barrier penetration model by taking the scattering potential as the sum of the Coulomb and nuclear proximity potential. The total cross section, the intermediate mass fragment (IMF) production cross section, and the cross section for the formation of light charged particle (LP) for both the spherical as well as deformed nuclei have been calculated using the formulae of Wong for small values for E and for large values of *E*, and the Glas and Mosel formula and compared with the available experimental data.

Results and discussion

The details on the results obtained through the studies are given below.

(a) Cluster Decay of $^{112-122}$Ba Isotopes from Ground State and an Excited Compound System

Cluster radioactivity is a natural radioactivity process which is accompanied by the emission of particle that is heavier than alpha particle but lighter than a fission fragment, without being accompanied by the emission of any neutron. Within the Coulomb and Proximity Potential Model (CPPM), the ground state and excited state decay properties of various isotopes of Ba with A = 112 - 122 emitting clusters with mass A_2 = 4 – 56 have been studied. The logarithmic half life time values are also computed using Universal formula (UNIV) and Universal Decay Law (UDL) and are compared with those values calculated using CPPM. In cluster decay process, the role of doubly magic daughter Sn nuclei is evident from our study. A comparison of $\log_{10}$ ($T_{1/2}$) value reveals the fact that the exotic cluster decay process gets slow down due to the presence of neutron excess in the parent nuclei. A comparison of half-life time for ground and excited system shows that the decay probability increases with a rise in temperature i.e., inclusion of excitation energy decreases $T_{1/2}$ values. Also, there is a good agreement between the half-life values calculated using CPPM and those values computed using UNIV and UDL.

(b) Investigation on Excited State Decay of Light Nuclei

Our initial study on the decay of excited light nuclei was on ^{48}Cr* [4] nuclei formed through the entrance channels ^{24}Mg+^{24}Mg, ^{36}Ar+^{12}C and ^{20}Ne+^{28}Si. The light charged particle formation cross section, intermediate mass fragment cross section and the total cross section for E_{CM} values other than the experimental values have been calculated. The calculations have been done within the barrier penetration model using the Wong's formula, approximated Wong's formula and Glas and Mosel formula. The present study provides a good agreement with the experimental data when compared to other theoretical studies on the same excited state nuclei. As an extension of the above work, the decay of excited state nuclei ^{56}Ni* [5] formed in ^{32}S+^{24}Mg, ^{36}Ar+^{20}Ne, ^{40}Ca+^{16}O and ^{28}Si+^{28}Si reactions has been considered. A similar study was done within the barrier penetration model, taking the scattering potential as the sum of Coulomb and nuclear proximity potential, and the decay cross sections of both the spherical and deformed $^{26-29}$Al* formed through the entrance channels ^{16}O+^{10}B, ^{16}O+^{11}B, ^{18}O+^{10}B, and ^{18}O+^{11}B respectively, for various E_{CM} values have been computed. The calculated values have been compared with the available experimental data.

The decay studies of compound system ^{44}Ti* [6] formed in reactions ^{32}S+^{12}C and ^{28}Si+^{16}O have been done within the same model for both the spherical and deformed nuclei. The obtained results of fragment cross section corresponding Z=6 fragment and the available experimental data at E_{CM} = 60 MeV for the entrance channel ^{32}S+^{12}C are found to be in agreement.

(c) Study on excited state decay of heavy nuclei

In this part of the study, as an extension of our earlier work, the decay of excited heavy nuclei formed through various channels has been studied. As our initial step into the field of study of heavy nuclei, the decay of ^{118,122}Ba* formed in ^{78,82}Kr + ^{40}Ca reactions at the relatively low laboratory energy of 5.5 MeV/nucleon (E_{cm} = 145.42 and 147.87 MeV respectively) is studied using the CPPM using the barrier penetration model, taking the scattering potential as the sum of Coulomb and nuclear proximity potential. The experimental data for the complete charge spectrum along with evaporation residue and fission cross sections are available for the nuclear systems ^{118,122}Ba*. Thus, the evaporation residue cross section and total fission cross sections, have been evaluated with the spherical choice of fragmentation. The calculations are also done by including the role of deformation.

References

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