Exploring the role of target deformation on the dynamics of pre-equilibrium emission in alpha-induced reactions

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Introduction

Recent studies on the systematics of pre-equilibrium (PE) nuclear reactions have attracted researchers working in the field of nuclear reactions using light-heavy ions at energies well above the Coulomb barrier. [1]. If a projectile is scattered with moderate energies, its energy spectrum consists of a smooth structureless region at low energies and sharp structures towards the higher energy region. The former part of the energy spectrum is attributed to the well-established reaction dynamics that proceed via the compound nucleus emission process, whereas, later on consisting of the sharp structure belongs to more simple modes of motion excited via direct reaction process. In between these two extremes a complex process is likely to occur that is called pre-equilibrium (PEQ) reaction.

Frequently the term 'pre-equilibrium' is used for nuclear reactions that occur well and just before the establishment of the compound nucleus during 10^{-16}-10^{-22} seconds. Pre-equilibrium and equilibrium reactions practically never occur purely, but always in admixture form and their contribution depends on the type of incident particle and energy, the reaction channel and the structural properties of the target nucleus.

Though, a series of experiments and theories are available in the literature to understand the basic mechanism and existence of pre-equilibrium reaction dynamics for both nucleon and alpha-induced reactions. Our group has also been involved for a couple of decades in probing this reaction dynamics by measuring the excitation functions(EFs) of various reaction products for proton and alpha-induced reactions using VECC accelerator facility. The measurement and analysis of EFs are not only of paramount importance as these successfully explain the direct characteristics of the deexcitation process but also used to make a strong database for testing various nuclear reaction models. To have a comprehensive understanding of PEQ reaction dynamics, more and more investigations, exploring the structural effects are significantly needed.

Model calculations and pre-equilibrium fraction

The energy dependence of pre-equilibrium fraction has been explored in recent years and is found to increase with projectile energy for all projectile target systems. In the present work, an attempt has been made to investigate the role of target deformation on PEQ nuclear reaction dynamics. The cross-sections for alpha-induced reactions for various isotopes of Samarium (^{144,149,152,152,154}Sm), Nihonium($^{142, 143,145,146,148}$Nd) and Gadolinium (^{154,156,157,158,160}Gd) have been obtained theoretically using the statistical model with and without the inclusion of preequilibrium emission of particles using the nuclear reaction model code ALICE-91 [2]. The code ALICE-91 employs the Weisskopf-Ewing model for the statistical component and hybrid model as well as the geometry-dependent hybrid model of Blann for the pre-equilibrium emission. Level densities of residual nuclei play an important role in deciding the shapes and absolute value of the excitation functions while in preequilibrium reactions, the initial exciton configuration is a crucial quantity. The optimized set of input parameters like level density parameter, exciton number and others are taken the same as used in our earlier studies [3,4].

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Results and Discussion

The relative strength of the pre-equilibrium emission process may be determined in terms of pre-equilibrium fraction, F_{PEQ} (%) which may be defined as $F_{PEQ}(\%) = \left\{ {}^{\sigma_{PEQ}}/_{\sigma_{Total}} \right\} \times 100$. Here the symbols have their usual meanings. The deduced F_{PEQ} (%) is plotted as a function of the target deformation parameter (β_2). In Fig. 1 the variation of F_{PEQ} (%) for different natural isotopes of Sm (Z=62) and Gd (Z=64) are presented. It can be seen from Fig. 1(a) and (b) that for even-even nuclei, F_{PEQ} (%) increases with β_2 of target and mass number of target nuclei. For even-odd nuclei, the F_{PEQ} (%) show an abrupt increase as compared to its nearby even-even nuclei.

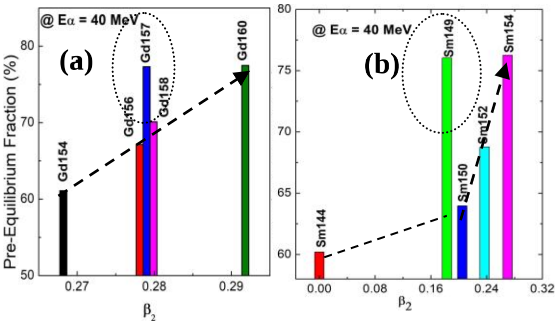

Fig.1 The deduced F_{PEQ} (%) as a function of target deformation parameter for Sm and Gd

The calculated values of F_{PEQ} (%) as a function of β_2 of target nuclei Nd are plotted in Fig.2. As can be seen from the figure that F_{PEQ} (%) is increasing with β_2, except for ^{148}Nd, where it does not follow the trend of even-even nuclei. For even-odd nuclei, the value of F_{PEQ} (%) is much larger than even-even nuclei, as expected. The relatively smaller values of F_{PEQ} (%) for ^{144}Sm and ^{150}Sm in Fig.1(a) may be explained in terms of magic numbers and special numbers. The conventional magic numbers are {2, 8, 20, 28, 50, 82, 126}. A stronger suggestion of the magicality of a number can be understood in terms of the Incremental Binding Energies (IBE) [5]. The examination of the incremental binding energies reveals the magicality of the conventional nuclear magic numbers. It is perfectly plausible that there could be substructures called subshells within the shell. When a subshell is filled the energies of the next subshell may or may not be sufficiently different to produce a change in the pattern of the incremental binding energies. For the shell containing the 83rd through 126th nucleons, the special numbers appear to be 84, 88, 96 and 114 [5]. The number of neutrons for ^{144}Sm is 82, a magic number and for ^{150}Sm, the number of neutrons is 88, a special number, where a reduced value F_{PEQ} (%) is observed.

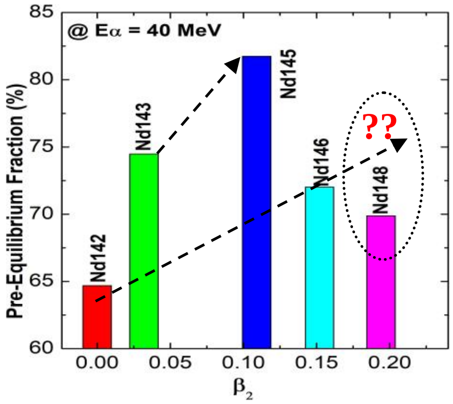

Fig.2 The deduced F_{PEQ} (%) as a function of target deformation parameter for Nd

Also, for ^{148}Nd, as shown in Fig.2 the number of neutrons is 88, again special and at that number, the F_{PEQ} (%) is less than ^{148}Nd, which must be larger than it. It may be concluded that PEQ process strongly depends on the deformation (shape) of the target nucleus and the neutron magic numbers/special numbers also play an important role in fixing the contribution of PEQ. The present results are rather preliminary and need to be established with further studies by considering a large number of systems and experimental data.

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