Statistical and Dynamical Aspects in the Study of Compound nucleaus and Nuclear Fission

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In nuclear physics, study of excitation and decay of nuclei in the two dimensional space of excitation energy (E_X) and angular momentum (J) provides insight into the behavior of not only the microscopic nuclear many body quantum systems but also the macroscopic stars. Using the heavy-ion collisions, it is now possible to study the excited nuclei of a variety of choices in a wide range of E_X and J. The fusion reactions which leads to compound nucleus (CN) formation are suitable for this purpose. The CN decays to the ground state by sequential emission of several particles and γ-rays, which are governed by the statistical properties of nuclei in the decay process. In case of heavier CN, where fission decay competes with particle emission, the dynamical effects play an important role along with the statistical ones in understanding the gross properties of the decay process. In the present thesis work, the statistical aspects in the decay of medium heavy compound nuclei, in particular the spin dependence of the nuclear level-density and the dynamical aspects involved in the nuclear fission have been investigated.

The nuclear level density (NLD) is one of the basic statistical parameters which plays crucial role in determining the decay channels of the excited nucleus. It is a key ingredient in the calculation of reaction cross sections using the framework of Hauser-Feshbach (HF) theory of compound nuclear reactions [1]. Applications of HF theory require global knowledge of nuclear level densities as a function of E_X and J. This is best served by using a phenomenological level density function, known in the literature as back-shifted Fermi-gas formula (BSFG) [2, 3]. There are two fundamental parameters in the BSFG formula which are tuned to reproduce the experimental data and they are the level density parameter, 'a' and the spin cut-off parameter, σ^2 [2, 3]. Information about the parameter 'a' at high E_X and J are crucial in phenomenological descriptions. The excitation energy dependence of the parameter 'a' has been investigated earlier from particle evaporation measurements for a wide variety of excited nuclei [4]. The level-density parameter 'a' determined from these measurements is an averaged quantity over a range of excitation energies and angular momenta. The studies of the level-density parameter 'a' with angular momentum selection are very few and as a result the value of 'a' is essentially unknown in high angular momentum domains for a great majority of nuclei.

In this thesis work, measurements of γ-ray multiplicity fold gated α-particle evaporation spectra in heavy-ion fusion reactions are carried out. Inverse level density parameter ($K = A/a$) is obtained as a function of angular momentum at an average excitation energy around 35 MeV from statistical model analysis of the measured α-particle spectra for a number of nuclei in the shell region of $Z \sim 50$ and in the mid-shell region of $Z \sim 70$. Around the the shell closure region of Z=50, the 'gross' K value (summed over all J) is seen to be in the range 9.0 - 10.5 MeV, which is within liquid drop model estimate [5]. The variation of K as a function of angular momentum in the range of 5 to 30$\hbar$ for the shell closure region, shows interesting features not accounted by the shell and angular momentum corrected values of K used in the statistical model [5]. However, in the mid-shell region the average value of K is 8.2 ± 1.1 MeV [6], and remains essentially constant around the average value

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in the angular momentum range of 15 to 30$\hbar$ [6]. Present results for nuclei in the shell closure region and in the mid-shell region would serve as important inputs for microscopic theories to understand the statistical properties of nuclei in different mass regions.

In case of heavy compound systems ($Z \simeq 80$ and $A \simeq 200$), nuclear fission competes with particle emission and the dynamical effects become important along with the statistical ones. The fission dynamics between saddle to scission has been of continued interest. It is still debated whether fission is an adiabatic (fast) or dissipative (slow) process. Various probes such as neutrons, charged particle, GDR γ-rays, and FF kinetic energies have been employed to address the above question. These experimental observations indicate that nuclear motion from compound nucleus to the scission point is over damped and energy dissipation during fission is essential to understand the fission dynamics. However, at the time of scission the actual tearing up of the neck joining the two nascent fission fragments is still not clearly understood. Moreover, the temperature dependence of the nuclear viscosity could not be determined using above mentioned probes in a wide energy range from spontaneous fission to the heavy-ion fission.

The near-scission emission (ternary fission) of the α-particles presents a good choice to understand the scission mechanism in the wide energy range . Measurements of α-particle energy spectra in coincidence with fission fragments are carried out for the systems of ^{11}B (62 MeV) + ^{232}Th (Z^2/A=37.13) and ^{12}C (69 MeV) + ^{232}Th (Z^2/A=37.73) in a wide range of relative angles with respect to FF emission direction [7, 8]. CsI(Tl-Si(PIN) detectors used in these experiments for charged particle measurements are characterized for various aspects [9].

The measured spectra are fitted with moving source model calculations to extract the α-particle multiplicities corresponding to different emission stages of the fusion-fission process. In case of ^{12}C (69 MeV) + ^{232}Th reaction an extra source of α-particle emission other than pre-, post-, and near-scission emission is observed which is attributed to ^{8}Be breakup in α-transfer induced fission reactions [8]. The obtained results have been analyzed along with data from literature over a wide range of excitation energy (E_{CN}) and fissility of the compound system to develop the systematic features of pre-fission and near-scission emission as a function of α-particle emission Q-value and Z^2/A of the compound system.

It is seen that pre-scission α-particle multiplicity (α_{pre}) normalized to $E_{CN}^{2.3}$ show a systematic linearly increasing trend with α-particle emission Q-value [7]. The fraction of near-scission multiplicity (α_{nse}) is observed to be nearly same at around 10% of the total pre-scission multiplicity ($\alpha_{pre} + \alpha_{nse}$) for various systems over a wide range of Z^2/A and excitation energy suggesting that the near scission emission of α-particles in heavy-ion induced fission is a statistical process [7]. This is in contrast to low energy and spontaneous fission where the neck-emission is a dynamical or fast process. Therefore, it can be inferred that nuclear collective motion during scission exhibits a changeover from super-fluid to viscous nature with increasing excitation energy.

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