Fragment-spin-bearing modes in fission

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Introduction

Nuclear processes that influence the final fission fragment spins and excitation energies are important from a nuclear technology view-point because they determine the partition and energy release through prompt neutrons and gamma rays. From a fundamental view-point too they are very important and they still constitute a widely open problem in collective nuclear dynamics. These processes are caused by motions of nucleons governed by the changing one-body mean field. Keeping this in mind, the present work examine the fragment spin bearing modes that are active during the final phases of the fission process.

Notable works in spontaneous and thermal neutron fissions have been reported recently which suggest that the 'spin bearing collective modes' can be replaced almost entirely by the quantal fluctuations that arise from Heisenberg uncertainty[1]. However the axial alignment of the nascent or just separated fragments is a pre-requisite for this mechanism to operate and precisely how this 'collective' spatial alignment is achieved by the fragments is not made clear[1]. Another level of assumption is that the system at scission is represented by a wave function, a pure case with no temperature[1]. However numerous studies show that nuclear fission is a typical example of damped collective motion.

Model

Rotational motions in a progressively necking-in pre-scission nucleus can be understood on the basis of collective modes induced by the fast elementary nucleon transfer processes[2]. In the final phases, the volume from which the nucleons finally recede to pre-fragments is spatially confined (on the average) to the neck region. Here we attempt a tentative study of one-body dissipation mechanism of such nucleon recess and the possible consequences for the dynamics of fragment spin bearing modes. The generalized wall formula [3] is used as a basis for this study. The nucleon recess is treated as pair of drifts in the nucleon gas. A schematic representation for such nucleon drifts from neck region is given in Fig. 1 of Ref.[4] (and also in Fig.1 below in some bare details) and it is explained qualitatively how such pairs of drifts excites the spin-bearing modes. Depending on the directions of (*a1, R1*) and (*a2, R2*), there can, not only be angular momentum imparted with direction perpendicular to symmetry axis as in the wriggling mode, but also components parallel to symmetry axis as in the twisting mode[4,5].

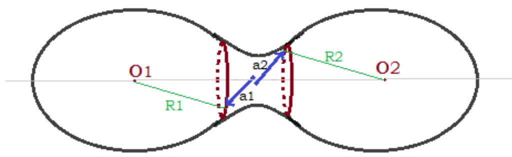

Fig. 1 Schematic diagram illustrating the nucleon drifts from the neck region in a pre-scission nucleus. a1 and a2 are the pair of drift vectors and R1 and R2 are the radius vectors connecting the respective surface elements and the centers of masses O1 and O2 of the pre-fragments.

Although it is not necessary that the nucleon transfers occur simultaneously and they are of exactly opposite momenta, these qualities are to be maintained on the average over a reasonable short time period. According to the present work, Heisenberg uncertainty and Pauli exclusion principles play their essential roles in maintaining the nucleon pair drifts from neck region. Let the joint probability that a pair drift occur be $P_1(a1,R1)P_2(a2,R2)f_{12}(a1,R1,a2,R2)$ where f_{12} is the joint distribution that satisfies above criteria, at least in an approximate way. A particularly difficult task is to design a reliable numerical algorithm to calculate different contributions to f_{12}. Having obtained f_{12}, the joint probability is calculated by statistical (Monte Carlo) integration [6].

Pre-fragments

The pre-scission configurations at which above model can be applied need careful considerations as one is dealing with an overall out-of-equilibrium process. This problem involves not just one property of the system like its potential energy surface but also the formation dynamics of pre-fragments and their interactions. A two-stage description has been proposed in the microscopic study of nuclear scission and quantum localization in [7]. According to this work, from the onset, as one approach the scission point, the pre-fragments emerge into existence, and as a result, the values of the global constraints split into the contributions from these pre-fragments. It is expected that the correct description of the system will rely on separate collective coordinates for these individual pre-fragments. For one-body dissipation the scission shapes are compact and they are the same for the fission of light nuclei as for the fission of heavy nuclei. In the present work two-sets of shape parameters, the 'funny hills' [8] and the 'five-parameter dumbbell' [9] have been used as alternative sets of shape parameters for pre-fragments, that bearing the above one-body criterion.

One-body dissipation

The exchange, back and forth, of nucleons between two nuclei connected by a narrow neck has been treated in the window formula for heavy ion collisions[3]. Pairs of drifts from the neck region in pre-scission nucleus, which are in a more organized form, has not been treated before. These drifts can set in highly correlated type of motions of the surface elements and these motions can survive as rotations. In general, the work done by surface displacements δn proceeding at a rate $\dot{n}$ should be written as[3]

$$\boldsymbol{\delta E = \rho \bar{v} \oint (\dot{n} - D) \delta n \, d\sigma} \qquad (1)$$

or

$$\boldsymbol{\dot{E} = \rho \bar{v} \oint (\dot{n} - D) \dot{n} \, d\sigma} \,,$$

where D specifies the normal component of the drift velocity of the particles about to strike the surface element $d\sigma$. In the case of a rigid container endowed with a steady translation with velocity V and a steady rotation about an origin O with angular velocity Ω the dissipation would cease if the drift became such that

$$\boldsymbol{D = (V + \Omega \times R).\breve{n}} \,, \qquad (2)$$

since this is just the normal velocity $\dot{n}$ of a surface element of the rigidly moving container (R is the radius vector from O to the surface element in question). A relevant question has been asked in [3]that what is the drift distribution D to be used in Eq. (1) when the 'container' is translating, rotating *and* slowly changing its shape. A solution has been provided in [3] by seeking a function D that (a) has as little spatial structure as possible and (b) satisfies a self-consistency constraint and the resulting conservation conditions on linear and angular momentum. The present work adopt this approach of self-consistency and implement it for the pairs of drifts from the neck region. The numerical results obtained with the above formalism will be presented.

Author is grateful to Dr. D.C.Biswas for useful comments and discussions.

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