LA-UR -81-302

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SUBMITTED TO: International Workshop IX on Gross Properties of Nuclei and Nuclear Excitations, Kleinwalsertal, Austria, January 1981

MASTER

University of California

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LARGE-AMPLITUDE DYNAMICAL MOTION AND FLUCTUATIONS IN NUCLEAR FISSION AND HEAVY-ION REACTIONS

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When studying the dynamics of large-amplitude nuclear motion such as occurs in fission and heavy-ion reactions, a useful starting point is the separation of the total degrees of freedom into two types: (1) a few collective degrees of freedom describing the shape of the nuclear surface that are treated explicitly and (2) the remaining relatively large number of internal degrees of freedom that are treated implicitly. Once such a separation has been made, it is necessary to describe the transfer of energy between the collective and internal degrees of freedom, as well as the Brownian fluctuations in the collective degrees of freedom arising from an implicit treatment of the internal degrees of freedom.

This problem has been studied previously at various levels of approximation by means of classical generalized Hamilton equations of motion[1,2] at one extreme and Fokker-Planck equations[3-6] at the other. In the former case the Brownian fluctuations have been neglected, and in the latter case all the terms affecting the average dynamical motion have not been included. The goal of the present work is to describe simultaneously both the average dynamical motion and the Brownian fluctuations in terms of quantities that are calculated from specified nuclear models.

For this purpose we have derived the generalized Liouville-Fokker-Planck-Chandrasekhar equation

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$$\frac{\partial f}{\partial t} + (M^{-1})_{ij} p_j \frac{\partial f}{\partial q_i} - \left[\frac{\partial V}{\partial q_i} + \frac{1}{2}\frac{\partial (M^{-1})_{jk}}{\partial q_i} p_j p_k\right]\frac{\partial f}{\partial p_i}$$

$$- \eta_{ij}(M^{-1})_{jk}\frac{\partial}{\partial p_i}(p_k f) = \tau \eta_{ij}\frac{\partial^2 f}{\partial p_i \partial p_j} \quad , \qquad (1)$$

where repeated indices are to be summed over from 1 to N, for the distribution function f in phase space of nuclear collective coordinates $q_1, \ldots, q_N$ and momenta $p_1, \ldots, p_N$. We have incorporated Brownian fluctuations under the assumption that they are a Markov process and are restricting our considerations to nuclei at high excitation energy, where classical statistical mechanics is valid and single-particle effects are negligible. We are calculating the nuclear potential energy of deformation V in terms of a Coulomb energy and a double volume integral of a Yukawa-plus-exponential folding function[7,8], the inertia tensor M by means of the Werner-Wheeler approximation to incompressible irrotational flow,[1,2] the dissipation tensor η for both ordinary two-body viscosity and wall-and-window one-body dissipation[2], and the nuclear temperature τ by use of the Fermi-gas model. It is our hope that the calculated widths of distributions in fission and heavy-ion reactions will prove sensitive to the dissipation mechanism.

Because of the practical difficulty of solving the generalized Liouville-Fokker-Planck-Chandrasekhar equation (1) exactly, we have transformed it into a system of coupled nonlinear first-order differential equations for the average values and variances of the collective coordinates and momenta and the average excitation energy, at two different levels of approximation. At the higher level we retain all terms through first order in the variances that appear in the equations for both the average values and variances, whereas at the lower level we neglect the variances in the equations for the average values of the collective coordinates and momenta. At both levels we retain all relevant derivatives of the potential energy, inertia tensor, and dissipation tensor, as well as all terms in the average momenta.

As a first application, we have solved these equations numerically for initial conditions that are obtained by applying the transition-state method at the fission saddle point for ^{236}U. At both levels of approximation the calculated variances diverge to infinity before the system has moved appreciably from the saddle point, presumably because the system is on a potential-energy surface with negative curvature in the fission direction. We are currently trying to understand whether this divergence in the variances represents a fundamental deficiency in the theory, or alternatively whether it places an important upper limit on the magnitude of nuclear dissipation and the time spent from saddle to scission.

This work was supported by the Alexander von Humboldt Foundation and the U. S. Energy Research and Development Administration.

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