KINETIC ENERGY, MASS AND CHARGE EQUILIBRATION IN FISSION

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A Fokker-Planck type of equation is applied to the simultaneous dynamic treatment of kinetic energy, mass and charge in the fission process of ^{236}U. Calculated results are compared with experimental values.

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Fission has for a long time been a point of interest and challenge to both experimental and theoretical physics. Recently heavy ion research has provided an additional impetus to the study of large scale collective motion where relative motion dynamics has been observed in connection to well known physical observables such as mass and charge. A first step is the choice of collective variables. Deformation or fission degrees of freedom have been recognized and extensively treated for quite a while. A skillful experiment [1] has pioneered the simultaneous extraction of the values of the kinetic energy, mass, and charge together with their variances. While previous data on kinetic energy and mass mean values and distributions have already been known, the obtained information about the mean value charge and variance has proved new and highly interesting. A constant value of the charge spread independent of the kinetic energy has been obtained. The specific value of σ_Z^2 equal, on the average, to 0.4 seems to substantiate the view that the charge degree of freedom evolves in time quantally. An obvious theoretical model that can be applied to the description of such a process is the Fokker-Planck type of equation. The latter describes both the mean values and spreading width of the relevant macroscopic degrees of freedom. Furthermore, the Fokker-Planck equation has been already applied

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[2] to the radial distance and mass ratio in fission. The detailed form of the Fokker-Planck equation and its solutionmethod is given in Ref. [3].

The purpose of this paper is to extend Ref. [2] by inclusion of the charge Z in the Fokker-Planck equation without the unnecessary introduction of additional phenomenological parameters in the scheme. It is also instructive to study the correlations between deformation and charge, or mass and charge within a dynamic model. Furthermore, as shown in [2] the above equation is identical to the equation for the Wigner transform of the quantal density operator in a locally harmonic approximation. Hence, the resulting set of ordinary differential equations is to be solved with the initial distributions of the physical variables different from δ-functions and equal to those of the minimal packet inside the first potential well. The latter might turn out to be of extreme importance for the charge degree of freedom.

Fission is at the moment far away from being a microscopically described phenomenon, since the large number of variables that enter the calculations: potential, inertia, friction and diffusion coefficients. The dynamic phenomenologic treatment is the natural extension of static considerations. Although one has to resort to some phenomenologic parameters, it is a necessary step that might hint at the range of compatible numerical values, which a microscopic theory should reproduce.

The calculation is performed for the ^{236}U nucleus studies experimentally [1]. The macroscopic degrees of freedom are the relative distance between the centres of mass, the weighed heavy fragment mass $x = N_1+Z_1/A$, and the neutron excess of the heavier fission product $y = N_1-Z_1/A$. Such a choice for the variables is very convenient, since it leads to a simple expression for the mass tenor when compared with the conventional parameter choice (c, h, α). The third variable Z observes a potential landscape as given by the liquid drop potential. The shell correction to the liquid drop energy is the sum of the original Myers and Swiatecki corrections for each of the fragments multiplied by a function of the Fermi-type [2]. The latter is zero at the saddle point and of the order of one around the scission. The microscopic calculation of the radial mass as function of distance is approximated by a function [4]

$$B_{rr}(r) = \mu - k(B_{rr}^{\text{hyd}} - \mu), \tag{1}$$

where μ is the reduced mass and $B_{rr}^{\text{hyd}}(r)$ is the hydrodynamical estimate of the collective inertia and $k = 11.5$. The inertias in the x- and y-direction are chosen equal to each other [5]:

$$B_{xx} = B_{yy} = 2000\ h^2/\text{Mev}. \tag{2}$$

We can get such an estimate of the inertias in the adiabatic approximation assuming that in the scission configuration the two tooching fragments are spherical. The Nilsson type potential is taken for describing of single particle levels in each fragment. The friction in the radial direction is proportional to the expression $B_{rr}(r)-\mu$. Such a choice of the friction parameter has good asymptotic behaviour, i.e. it vanishes for large distances.

The strength of the radial friction force is chosen so as to obtain optimal agreement between theory and experiment for the kinetic energy width. Friction forces in the x- and y-direction are taken simply proportional to the corresponding inertias.

A typical set of numerical results for energy, mass, and charge variances as a function of the relative distance R_{12} is displayed in Fig. 1. The radial motion is clearly decoupled from the other degrees of freedom. The variance σ_A^2 is found to be less steep around the scission as compared to the results of Ref. [2]. This is obviously due to the new independent degree of freedom employed in the present calculations. It is remarkable that the

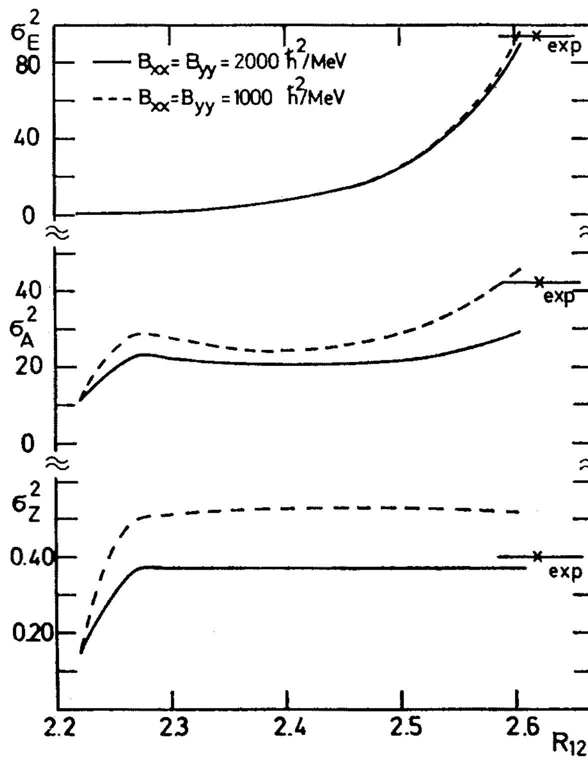

Fig. 1. Energy, mass, and charge variances as functions of the relative distance R_{12}. The latter is given in units of $r_0A^{1/3}$. The solid curves correspond to calculations with values of the mass in the x- and y-directions as estimated in [5]. Dashed curves correspond to arbitrarily taken twice smaller value of the x- and y-masses. The experimental results of the relevant quantities are also given

experimentally observed value of σ_Z^2 is reproduced fairly well. Note that we have used identical values for the inertias and friction foces in the x- and y-directions, i.e. no new parameters have been introduced since mass and charge are expected to have comparable inertias. All the displayed curves start on the left at the exit from the barrier point and end at the scission configuration. The latter is defined as the distance R_{12} where the separated half-density profiles touch but do not overlap. The initial widths of the distributions are taken to be equal to those of the minimal packet inside the barrier.

Fig. 2 shows calculations of σ_A^2 and σ_Z^2 at different initial values of the temperature. As expected, the variances become larger as the initial temperature increases. We have

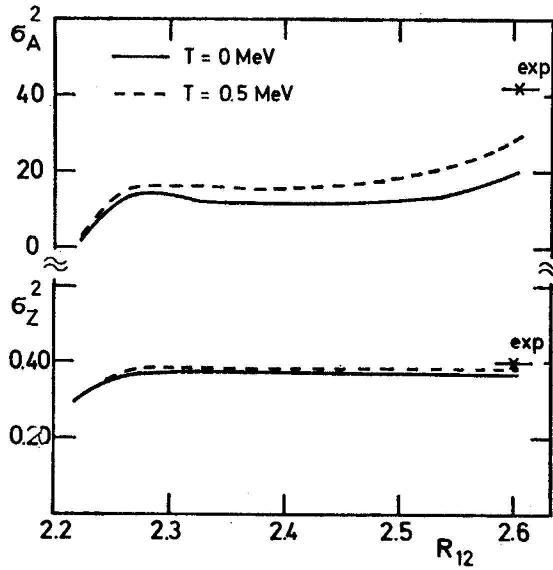

Fig. 2. Same as in Fig. 1 for σ_A^2 and σ_Z^2 for two different values of the initial temperature. The solid curves correspond to $T = 0$, and the dashed ones to $T = 0.5$ MeV

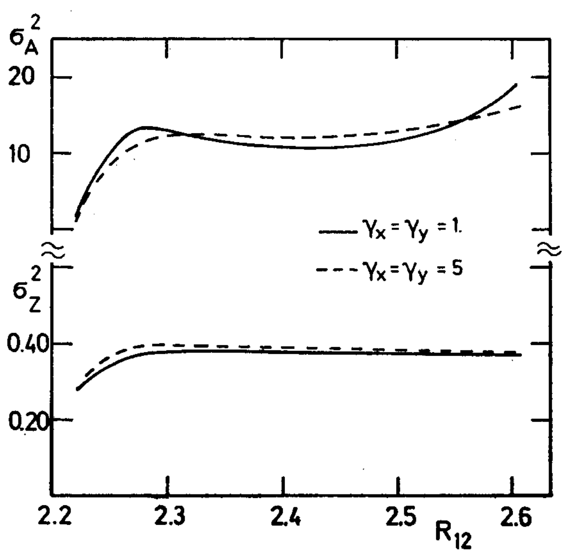

Fig. 3. Same as in Fig. 1 for σ_A^2 and σ_Z^2. The calculations have been performed for two different values of the proportionality factor between the friction strength and the mass in the x- and y-directions. The solid curves correspond to the case when friction is simply proportional to the magnitude of the mass. The dashed curves correspond to a calculation with the friction strength 5 times the mass value in the x- and y-degrees of freedom

used the generalized Einstein relation [2] for the friction and diffusion coefficients in the x- and y-directions.

Calculations of σ_A^2 and σ_Z^2 are given in Fig. 3 for different values of the friction force strength. It is seen that both quantities are hardly influenced by the strength of the friction force.

In conclusion we should say that the evolution of the charge excess in fission can be naturally incorporated in a Fokker-Planck equation dynamic model for the macroscopic degrees of freedom. A first guess choice for the charge excess degree of freedom inertial and friction parameters equating them to the corresponding values of the mass variable yield numerical results in good agreement with experiment.

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