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Author
Myers, W.D.

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The Width of the Charge Distribution in Fission†

William D. Myers

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

The width of the charge distribution (for a fixed mass split) observed in nuclear fission can be estimated by assuming that it is associated with fluctuations in the collective coordinate corresponding to the flow of neutrons and protons back and forth through the neck connecting the nascent fragments [1,2]. This motion, which takes place between the two halves of the di-nuclear complex during the descent from saddle to scission, is analogous to the giant dipole resonance that is observed in nuclei throughout the periodic table.

The collective motion being considered here takes place inside a nuclear shape that is moving toward scission into two fragments. One way to determine the asymptotic charge dispersion is to solve numerically the corresponding Schrödinger equation with a time dependent effective mass that increases as the neck size decreases [2]. However, there is a simpler way available.

In ref. [3] an empirical criterion was established for determining when the ground state dispersion of an oscillator is no longer able to follow its adiabatic time development if the inertial mass has a particularly simple type of time dependence. This important quantity C is defined by the expression $C = (3/4)[(\dot{b}/b)^2/\omega^2] - 1$, where b is the inverse of the intertial mass, $\omega = \sqrt{bk}$ is the classical frequency of the oscillator, and k is the stiffness of the oscillator (assumed constant). Such an oscillator

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is expected to maintain its adiabatic ground state width so long as the first term on the right-hand side of the defining expression for C remains small, and C has a value near -1. When $(\dot{b}/b)$ becomes large enough compared to ω so that C changes sign, the system is expected to lose its ability to follow. In [3] we found that when b decreases linearly in time, the asymptotic width that remains when b has gone to zero is nearly the same as the adiabatic width calculated at the time when the value of C passes through 1.108. The width Γ (the full width at half maximum) is calculated from the expression $\Gamma = 2\sqrt{2\ln 2}\cdot(Ub/k)^{1/4}$, where $U = \hbar^2/4 = 10.8307\ \mathrm{MeV}^2\mathrm{dsec}^2$, the units of k are (MeV) and the units of b are $(\mathrm{MeV\ dsec}^2)^{-1}$ (1 dsec = 10^{-22} sec).

The methods developed in [3] can be applied to fluctuations in the charge distribution of separating fragments in strongly damped nuclear collisions or in fission. Since the asymptotic width of the charge distribution that is predicted depends on the time development of the system through C, we had hoped that we would not only be able to calculate the width of the charge distribution, but that we would also be able to distinguish between the different dynamical trajectories that have been proposed.

Figure 1 shows how the quantity b varies with time for two different saddle to scission trajectories proposed in ref. [4] for the fission of ^{236}U. As the neck between the fragments pinches off the inertia associated with flow between them goes to infinity and b goes to zero. For the curve labeled "viscous damping" the system moves rapidly toward scission with just enough classical hydrodynamical viscosity to give agreement with the observed asymptotic kinetic energies of the fragments. The curve labeled "one-body damping" is based on the ideas of ref. [5] and results in a much slower time development, but the predicted asymptotic kinetic energies are nearly the same as for the other trajectory.

Unfortunately, the freeze-out of the charge dispersion occurs so late in the process (see fig. 2) that there is almost no difference between the two predictions. In fig. 2 the last part of fig. 1 is shown on an expanded scale. In the lower half of the figure the quantity C is plotted for the case where the fission trajectory was calculated using viscous damping. (The calculation of C was based on $k = 3.1$ MeV.) C attains the critical value of 1.108 at $t_c = -1.11$ dsec and the corresponding inverse mass is $b_c = 0.0338$ (MeV dsec^2)$^{-1}$. This corresponds to a predicted charge dispersion of $\Gamma_f = 1.38$ which is somewhat smaller than the experimental value of 1.50. The quantity C for the case of the trajectory associated with one-body damping is not plotted since it lies nearly on top of the curve for viscous damping. Since the curves for b are so similar when freeze-out occurs, the predicted charge widths are nearly the same in the two cases. Consequently, we are forced to conclude that even though these considerations result in a predicted charge dispersion that is quite close to the observed value, they do not provide a means for choosing between the two fission trajectories.

Footnotes and References

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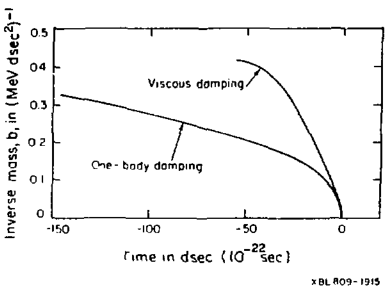

Fig. 1

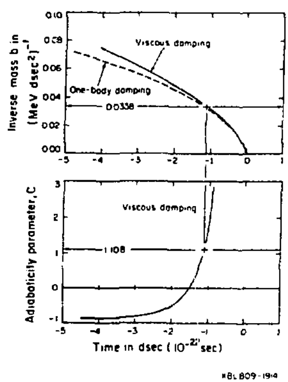

Fig. 2