

Current Density and Angular Distribution of Neutrons Emitted During Scission

N. Carjan^{1,2,*} and M. Rizea¹

¹*National Institute of Physics and Nuclear Engineering,
PO Box MG-6, 077125 Bucharest-Magurele, Romania*

²*Centre d'Etudes Nucleaires de Bordeaux-Gradignan,
Université Bordeaux 1, BP 120, 33175 Gradignan Cedex, France*

A time-dependent approach to the angular distribution of the scission neutrons with respect to the fission axis based on a recently developed dynamical scission model is presented. It implies the numerical solution of the bi-dimensional time-dependent Schrödinger equation with time-dependent potential for the motion of a neutron inside a nucleus that undergoes fission. The time evolution is calculated from the configuration with a minimum neck radius (α_i), the start of the scission process, to the configuration of two just-separated fragments (α_f), the end of the scission process. The resulting neutron wave packets are then propagated further in time but with the configuration of the fissioning system frozen at α_f . The numerical solutions at a given time t are used to calculate the current density $\bar{D}_{em}(\rho, z, t)$, a key quantity in the angular distribution evaluation. We investigate the nucleus ^{236}U at two mass asymmetries defined by the light fragment mass $A_L = 70$ and 96. The number of neutrons that leave a sphere of radius $R = 30$ fm (a test is done with $R = 40$ fm) around the fissioning nucleus in a solid angle $d\Omega$ and in a time interval dt , $d\nu_{sc}/d\Omega$, is calculated. The integration in time of this quantity from 0 to ∞ gives the angular distribution. In practice we could only reach $T_{max} = 4 \times 10^{-21}$ sec. At this time however the majority of the scission neutrons left the sphere. The scission neutron emission is found to take place mainly along the fission axis with a small preference for the light fragment similar with what is experimentally observed for all prompt neutrons. A ratio ν_L/ν_H close to the experimental value (1.41) is obtained. We concluded that the distinction between scission and evaporated neutrons, based on their angular distribution, is more challenging than expected.

I. INTRODUCTION

It is well established experimentally that the emission of prompt neutrons in low energy fission is strongly focused in the direction of motion of the fission fragments, hence along the fission axis [1–3]. From this feature a rapid conclusion about the origin of these neutrons was drawn: they are isotropically evaporated in the moving frame of the fully accelerated fission fragments, the observed anisotropy being a trivial effect of the transformation into the laboratory system (kinematic anisotropy). The possibility that a much earlier emission (around scission) could be intrinsically very anisotropic has been ignored mainly due to the difficulty in tackling such a phenomenon. The dynamical, microscopic and quantum mechanical scission model developed recently [4, 5] allows to calculate, for the first time, the angular distribution of the neutrons released during the transition of the fissioning nucleus at scission (i.e., during the neck rupture).

The purpose of the present paper is to present the results of such calculations.

II. DYNAMICAL SCISSION MODEL

The dynamical scission model [4, 5] calculates the time evolution of each neutron state $|\hat{\Psi}^i(t)\rangle$ in a nucleus that undergoes scission using the time-dependent, two-dimensional Schrödinger equation (TDSE2D) with a time-dependent potential (TDP). More precisely, this evolution is followed from the moment when the neck cracks (α_i) until the neck is completely absorbed by the nascent fragments (α_f). The duration ΔT of this transition is unknown and it is a parameter of the model. The TDSE2D is solved numerically by an algorithm of Crank-Nicolson type that is unconditionally stable

$$\left(1 + \frac{i\Delta t}{2\hbar}\hat{\mathcal{H}} + \frac{i\Delta t^2}{4\hbar}\hat{\mathcal{H}}'\right)\hat{\Psi}(t + \Delta t) =$$

$$\left(1 - \frac{i\Delta t}{2\hbar}\hat{\mathcal{H}} - \frac{i\Delta t^2}{4\hbar}\hat{\mathcal{H}}'\right)\hat{\Psi}(t).$$

*Corresponding author: carjan@theory.nipne.ro

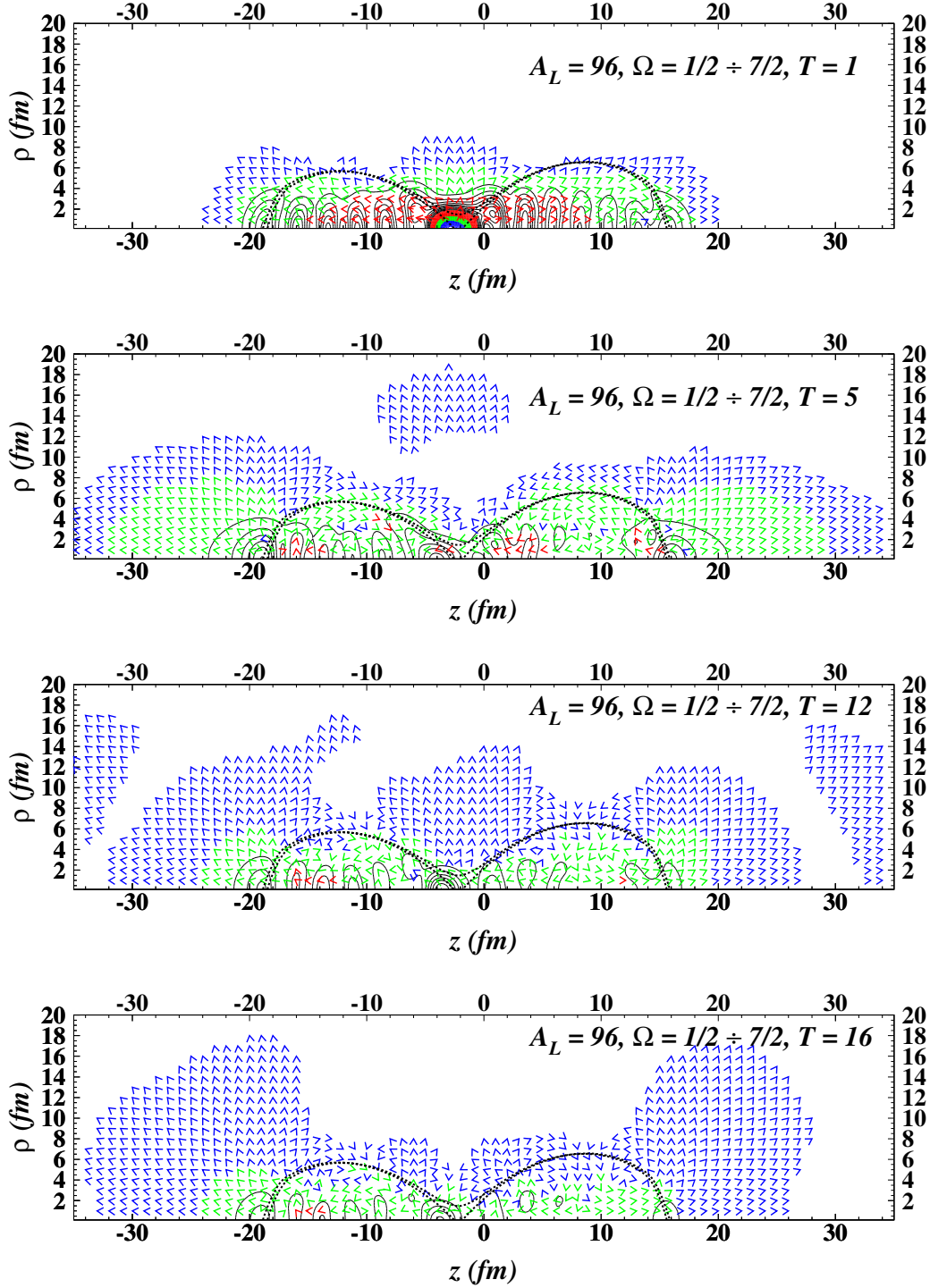


FIG. 1: Spatial distribution of average emission directions (arrows) for the most probable mass division ($A_L=96$) of ^{236}U at four successive times T (in 10^{-22} sec) after scission. The just-before and immediately-after scission shapes are indicated by dotted lines. The corresponding probability densities are also shown (contour lines). Bound states with $\Omega=1/2, 3/2, 5/2$ and $7/2$ are included in these calculations.

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