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# Non-Equilibrium Aspects of Fission Dynamics within the Time Dependent Density Functional Theory

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In the first microscopic description of induced fission, based on a full implementation of the Time-Dependent Density Functional Theory (TDDFT) extended to superfluid fermion system, using only 8 well known parameters (energy and density of symmetric nuclear matter, nuclear surface tension, symmetry energy and its density dependence, strength of the spin-orbit and pairing interactions, and proton charge), without any fitting or unchecked assumptions, and with controlled approximations, it was demonstrated that the fission dynamics from saddle-to-scission has a strongly non-equilibrium character. This is the apparent behavior of a viscous fluid and the use of the widely used adiabatic hypothesis is invalid. Within this theoretical framework the need for a collective potential energy surface and for a collective inertia become both superfluous and irrelevant and the role of the pairing correlations is crucial. A very good agreement was obtained with the experimental data for total kinetic energy of the fission fragments, their average masses, charges, excitation energies, intrinsic fission fragment angular momenta and their correlations. The dependence of these properties with excitation energy of the formed compound nucleus was studied and general features observed in experiments were also observed.

In more recent developments we have shown that the fission dynamics is unexpectedly non-Markovian in character, an aspect at odds with many phenomenological treatments of various aspects of fission dynamics such as Langevin, Smoluchowski, Brosa, Fokker-Planck, Boltzmann-Uehling-Uhlenbeck/Boltzmann-Nordheim frameworks. The solution of the TDDFT equation for superfluid systems is identical to the exact solution of the time dependent Gorkov equations for a superconductor in non-equilibrium. A theoretical prediction by Bohr and Wheeler in 1939, almost as old as Meitner and Frisch's nuclear liquid drop fission model from 1939, that a nucleus at scission should produce smaller droplets, now identified as scission neutrons, remained an unsolved problem both theoretically and experimentally. The clear evidence of non-equilibrium scission neutrons has been demonstrated now and their number and wide energy spectrum have been predicted within the TDDFT framework. In another demonstration of the power of TDDFT we have simulated the induced fission of odd-mass and odd-odd nuclei within TDDFT, a process notorious for its theoretical complexity and difficulty of accurate treatment due to the presence of time-symmetry breaking terms in the density functional. All these developments became possible now due to the availability of very powerful supercomputers.

**Primary author:** BULGAC, Aurel

**Presenter:** BULGAC, Aurel

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