Nuclear many-body dynamics through barriers

Cédric Simenel*
Australian National University

Denis Lacroix†
IJCLab, Orsay

David Regnier‡
CEA, DAM, DIF

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I. SUMMARY OF THE SCIENTIFIC ISSUE

Although quantum tunneling led arguably to some of the best predictions in physics, as in $\alpha-$decay, a complete understanding of the role of the internal structure of composite systems on overcoming potential energy barriers is still lacking so far. Advances in theoretical modeling of the dynamics of the many-body wave-function through a potential energy barrier are required to improve our description of nuclear reactions such as fusion and fission at low energy.

Fusion via tunneling is effectively a powerful microscope, magnifying quantum effects in nuclear collisions through the exponential dependence of tunneling probability on the potential, which is modified by quantum coherent effects. High-precision experiments at energies well below this fusion barrier have demonstrated the failure of standard coupled-channels models of fusion. This so-called sub-barrier fusion hindrance remains a puzzle with interest in astrophysics, where changed quantum tunneling rates can have drastic effects. Various interpretations are currently debated, including couplings to non-collective states, interplay with transfer channels, quantum dissipation and decoherence, and Pauli repulsion.

The case of fission is even more complex. Several paths exploring various regions of the potential energy surface are often competing with each other, leading to fission modes that affect fragment properties such as mass, charge, and kinetic energy. Ultimately, a complete description should account for large amplitude (non-adiabatic) collective dynamics, excitation, dissipation, equilibration, fluctuation, shell effects, particle emission, coupling to the electromagnetic field, entanglement (between the fragments), and many-body tunneling.

Unfortunately, the Schrödinger equation cannot be solved exactly for many-particle systems and most approaches are based on the mean-field approximation. However, the price to pay for such a simplification is often to remove completely the possibility for quantum tunneling of the many-body wave-function. Nevertheless, several approaches are under development that are expected to overcome these limitations, such as the stochastic mean-field method and the imaginary-time-dependent mean-field theory. Dynamical evolution of a collective wave-function is also possible with the time-dependent generator coordinate method (TDGCM) and recent improvements in the construction of the underlying potential energy surfaces (PES) to avoid discontinuities open interesting perspectives in applying TDGCM without the Gaussian Overlap Approximation.

*Electronic address: `cedric.simenel@anu.edu.au`
†Electronic address: `denis.lacroix@ijclab.in2p3.fr`
‡Electronic address: `david.regnier@cea.fr`

II. GOALS OF THE PROJECT

In summary, the goals of the project are to encourage discussions and new collaborations in the following areas :

1. The description of quantum tunneling using beyond real-time-dependent mean-field techniques
2. The phenomenology of deep sub-barrier fusion and the ability of current models to predict experimental data
3. Phenomenology of PES topology and the role of shell effects
4. Production of improved PES for TDGCM calculations
5. Towards TDGCM calculations without the Gaussian Overlap Approximation
6. Interplay between internal excitations and tunneling.
7. Description and interpretation of observables.

III. LIST OF INVITED SPEAKERS

— Rémi Bernard, CEA, Cadarache, *PES topology and interplay with shell effects*
— George Bertsch, University of Washington, *Nuclear Fission Theory and EDF methods*
— Sandrine Courtin, IPHC, Strasbourg, *Measurement of fusion cross-sections at astrophysical energies*
— Thomas Czuba, IJCLab, *Exploring Phase-Space methods and beyond for tunneling*
— Denis Lacroix, IPN, Orsay, *Stochastic Mean-Field method for fusion*
— Raphaël-David Lasseri, ENS-Paris-Saclay, *Nuclear discontinuities through the prism of Machine Learning*
— Petar Marevic, ENS-Paris-Saclay, *Fission with symmetry restored energy density functional*
— Patrick McGlynn, ANU, Canberra, *Imaginary-time-dependent mean-field method to many-body tunneling*
— Florian Mercier, IJCLab, *New alpha particle radioactivity*
— Nathalie Pillet, CEA-DAM-DIF, *Role of the tensor force in fission*
— David Regnier, CEA-DAM-DIF, *Microscopic calculation of fission product yields with particle-number projection*
— Christelle Schmitt, IPHC, Strasbourg, *Experimental Evidence for Common Driving Effects in Low-Energy Fission from Sublead to Actinides*
— Cédric Simenel, ANU, Canberra, *Effect of Pauli principle in nucleus-nucleus potentials in deep sub-barrier fusion*
— Anna Zdeb, CEA-DAM-DIF and CEA Saclay, *Multidimensional PES in fission of* ^{252}Cf *and* ^{258}No.

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