



Contribution ID: 150

Type: **Contributed Oral**

A new time-dependent approach to modeling nuclear fusion

Monday 1 December 2025 14:00 (15 minutes)

Nuclear fusion not only promises carbon-free energy but also drives deeper insights into fundamental quantum dynamics under extreme conditions. Non-relativistic quantum scattering theory informs our broad understanding of nuclear collision processes. However, detailed theoretical insights remain elusive with conventional approaches.

In this work, we investigate a new time-dependent (coupled channels) formulation that treats nuclear fusion as formation and decay of quasi-bound states of the interaction potential, thereby avoiding artificial boundary conditions that can obscure critical details of the process. With this, we aim to better understand and predict fusion probabilities for a wide range of collision energies and nuclei pairs, which remains challenging for current theoretical approaches. While focused on fusion, the theory can be extended to any non-relativistic potential scattering problem where such an analysis would be beneficial, for example, atomic and molecular collisions.

The scattering (S)-matrix captures all the details of a scattering process. This work extends the application of the time-correlation formalism for calculating the energy-resolved S -matrix (developed in quantum chemistry) to nuclear physics, where the presence of the long-range Coulomb potential needs to be accounted for. A novel time-domain analysis on separability of the contributions to the S -matrix from resonances (which, in our case, models fusion) in the potential has been performed. We demonstrate how this new perspective can enable us to gain first theoretical insights into Bohr's (1936) independence hypothesis. Furthermore, we lay the foundations for examining the consequences of the experimentally observed interactions at larger distances (before fusion is initiated) in case of heavier nuclei, which can aid in the synthesis of the next super-heavy element.

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Session Classification: Theoretical Physics

Track Classification: Topical Groups: Theoretical Physics