Study of reaction mechanisms for the synthesis of super-heavy elements

Doctorant·e

DONGLO Hope

Direction de thèse

ACKERMANN DIETER (Directeur·trice de thèse)
BOILLEY David (Co-encadrant·e de thèse)

Date de la soutenance

04/12/2024 à 10:00

Lieu de la soutenance

Université Caen Normandie, Salle des thèses, Campus 2 Caen

Rapporteurs de la thèse

ANTALIC STANISLAV Comenius University Bratislava
SHEN CAIWAN Huzhou University

Membres du jurys

ACKERMANN DIETER, Directeur de recherche, 14 GANIL de CAEN
ANTALIC STANISLAV, , Comenius University Bratislava
BOILLEY David, Maître de conférences, Université de Caen Normandie (UCN)
EVEN JULIA, , GRONINGEN - UNIVERSITY OF GRONINGEN
GULMINELLI Francesca, , Université de Caen Normandie (UCN)
SHEN CAIWAN, , Huzhou University

Abstract

This thesis investigates the mechanism of synthesising super-heavy elements (SHE) via fusion evaporation reactions. These are nuclei with atomic numbers $Z \ge 104$ and do not exist in nature due to their vanishing macroscopic fission barriers. They are stabilised by quantum shell correction. The search for new SHE pushes the boundaries of nuclear physics, furthering our understanding of their formation, stability, and structure. However, synthesising SHE is challenging due to decreasing production cross sections as the atomic charge increases, necessitating theoretical simulations to guide experiments and identify optimal reaction conditions. This work focuses on improving the predictive power of the Kewpie2 model, designed for fusion evaporation simulation. Fusion evaporation is modelled as a three-stage process: capture, formation, and survival. While Kewpie2 independently simulates the capture cross section and survival probability, it has relied on external calculations for formation probability. This thesis implements the formation step in the Kewpie2 code for the first time using both the overdamped and full Langevin formalisms. The injection point distance (describing projectile-target nuclei starting configuration) is optimised for cold and hot fusion reaction datasets in both cases. An improved injection point distance parametrisation, consistent with the Langevin formalism, reproduces measured evaporation residue cross sections for hot fusion reactions, typically with accuracy better than an order of magnitude. For cold fusion reactions, multiple neutron emission channels are explained by introducing an additional structural term, achieving good agreement with experimental data. In this case, the 1n channel data are described as having a factor deviation from the experimental data, while the 2n and 3n channels are within an order of magnitude. The thesis also investigates survival probability modelling using the latest data for SHE. Both the formation and survival steps are extensively tested and compared with the Fusion-by-Diffusion (FbD) model for sets of 27 cold and 24 hot fusion reactions. Analysis of the reduced friction coefficients within the overdamped Langevin approach suggests that the dynamic is not fully damped. Therefore, a full one-dimensional Langevin formalism is investigated and implemented in Kewpie2. The formalism is applied to hot fusion reaction data. The fitting coefficients of the model are optimised using a so-called systematic fitting technique, and the results confirm that the dynamic is not fully damped. In this approach, the model predictions are within an order of magnitude deviations from the experimental data. Predictions for the synthesis of elements with atomic numbers $Z_{\text{CN}} =$ 119 and 120 align with results from other codes. Additionally, a method for studying ratios of formation probabilities is proposed and discussed for the synthesis of ^{258}No and ^{259}Db. In conclusion, this work significantly enhances Kewpie2, making it a self-contained tool for studying SHE synthesis and guiding future experimental efforts