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Executive Summary

Applications of Shell Models in Nuclear Astrophysics

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It is generally agreed upon that the best way for describing medium-mass nuclei is the interacting shell model, which takes into consideration correlations outside of the mean-field in a valence space. Such nuclei are essential to the dynamics of astrophysical objects and the nucleosynthesis that underlies them. Due to the harsh astrophysical environment's temperature, density, and proton-to-neutron ratio, direct experimental identification of the necessary input is frequently not possible; as a result, the data must be modelled.

This study provides an overview of some of the advancements made using shell model research. Here, the diagonalization shell model and the Shell Model Monte Carlo (SMMC) method have both been used as variations of the interacting shell model.

A statistical description of the nucleus at a fixed temperature serves as the foundation for the SMMC method. In contrast to diagonalization, the shell model makes use of the pertinent nuclear correlations to derive nuclear properties at finite temperatures in very vast model spaces. The nuclear input necessary for simulations of the rapid neutron-capture (r-process) nucleosynthesis has been enhanced for both types of the interacting shell model. Half-lives for neutron-rich nuclei with magic neutron numbers (also known as waiting spots), which are essential for the mass flow throughout the nucleosynthesis process, have been calculated using the diagonal shell model. When a big star's inner core gravitationally collapses and is no longer supported by energy released in charged particles, a supernova explosion occurs.

Recently, stars with masses between 8 and 12 M have drawn a lot of attention because they bridge the gap between low-mass stars, which die as white dwarfs, and massive stars, which, as was mentioned above, go through the entire cycle of hydrostatic burning stages before exploding as core-collapse supernovae. The intermediate-mass stars degenerate into ONe or ONeMg cores because they lack the mass to ignite all advanced hydrostatic burning phases. The properties of nuclei must be modelled rather than directly observed in a laboratory because of the severe densities, temperatures, or neutron excesses present in astrophysical conditions. The diagonalization shell model is the preferred approach if nucleon correlations have a significant impact on these features.

Such investigations have recently advanced our understanding of the core evolution of intermediate-mass and massive stars by determining the electron capture rates and neutrino-induced cross sections for nuclei in the sd- and *pf*-shell. The determination of half-lives for fast neutron-capture process (r-process) nuclei with magic neutron numbers, which act as waiting for spots for the r-process' mass flow, was another significant use of the diagonalization shell model. This example also demonstrates the limitations of current shell model applications, as these studies are very desirable for the other nuclei on the r-process path but are currently not feasible due to the size of the required model spaces.

To compute r-process half-lives, which need a state-by-state analysis, the SMMC cannot be employed.

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KEYWORDS
Shell model, core-collapse supernova, r-process nucleosynthesis, neutrino- nucleous reactions, electron capture.