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ORIGINAL ARTICLE

Unique first-forbidden β-decay rates for neutron-rich nickel isotopes in stellar environment

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Abstract In astrophysical environments, allowed Gamow-Teller (GT) transitions are important, particularly for β-decay rates in presupernova evolution of massive stars, since they contribute to the fine-tuning of the lepton-to-baryon content of the stellar matter prior to and during the collapse of a heavy star. In environments where GT transitions are unfavored, first-forbidden transitions become important especially in medium heavy and heavy nuclei. Particularly in case of neutron-rich nuclei, first-forbidden transitions are favored primarily due to the phase-space amplification for these transitions. In this work the total β-decay half-lives and the unique first-forbidden (U1F) β-decay rates for a number of neutron-rich nickel isotopes, $^{72-78}$Ni, are calculated using the proton-neutron quasi-particle random phase approximation (pn-QRPA) theory in stellar environment for the first time. For the calculation of the β-decay half-lives both allowed and unique first-forbidden transitions were considered. Comparison of the total half-lives is made with measurements and other theoretical calculations where it was found that the pn-QRPA results are in better agreement with experiments and at the same time are suggestive of inclusion of rank 0 and rank 1 operators in first-forbidden rates for still better results.

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1 Introduction

Reliable and precise knowledge of the β-decay for neutron-rich nuclei is crucial to an understanding of the r-process. Both the element distribution on the r-path, and the resulting final distribution of stable elements are highly sensitive to the β-decay properties of the neutron-rich nuclei involved in the process (Klapdor 1983; Grotz and Klapdor 1990). There are about 6000 nuclei between the β stability line and the neutron drip line. Most of these nuclei cannot be produced in terrestrial laboratories and one has to rely on theoretical extrapolations for beta decay properties. In neutron-rich environments electron neutrino captures could not only amplify the effect of β-decays but the subsequent ν-induced neutron spallation can also contribute towards changing the r-abundance distribution pattern (McLaughlin and Fuller 1997). Correspondingly reliable predictions of β-decay for neutron-rich nuclei are considered to be very important for r-process nucleosynthesis.

The weak interaction rates are the important ingredients playing a crucial role in practically all stellar processes: the hydrostatic burning of massive stars, presupernova evolution of massive stars, and nucleosynthesis (s-, p-, r-, rp-) processes (see, for example, the seminal paper by Burbidge and collaborators (Burbidge et al. 1957)). For densities $\rho \lesssim 10^{11}$ g/cm^3, stellar weak interaction processes are dominated by Gamow-Teller (GT) and, if applicable, by Fermi transitions. For nuclei lying in the vicinity of the line of stability, forbidden transitions contribute sizably for $\rho \gtrsim 10^{11}$ g/cm^3 when the electron chemical potential

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