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Isospin-Nonconserving Shell Model for Weak Interaction and Nuclear Astrophysics Applications

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The isospin symmetry has always been serving as a stringent guideline for various nuclear structure models, for example, for the shell model. However, it is only an approximate symmetry, and precise theoretical description of a tiny isospin-symmetry breaking (ISB) in nuclear states is of crucial importance.

Indeed, semileptonic processes in nuclei may provide valuable tests of the fundamental symmetries underlying the Standard Model. For instance, the constancy of the absolute $\mathscr{F}$t value of the superallowed $0^+ \rightarrow 0^+$ beta-decay would confirm the validity of the CVC hypothesis and would allow us to test the unitarity of the Cabbibo-Kobayashi-Maskawa (CKM) [1] quark mixing matrix. At present, the largest uncertainty in this context is due to the theoretical corrections to the beta-decay transition rates from the isospin symmetry breaking in nuclear states [2].

Moreover, the ISB is responsible for sometimes observed isospin-forbidden particle emission, such as beta-delayed proton emissions [3, 4], Fermi beta-decay between non-analogue states or gamma transitions in self-conjugate nuclei forbidden by the isospin selection rules. Such processes have small probability, but they may shed light on the degree of the isospin mixing in nuclear states and can help to constrain theoretical models.

Precise description of the proton spectroscopic factors and the masses and structure of proton-rich nuclei has important consequences for nuclear astrophysics. For example, the purity of the isobar-analogue states of ^{23}Al ground states in ^{23}Mg impacts ^{22}Na(p, γ)^{23}Mg nuclear reaction rates at novae temperatures [5].

With newly updated and extended (in the middle region of *sd* model space, and *pf* model space) experimentally measured mass excess data and excited levels [6], we develop an empirical shell model describing the isospin symmetry breaking for *psd* (0p1/2, 0d5/2, 1s1/2) and *sd* (1s1/2, 0d5/2 and 0d3/2) [7] shell model spaces. The derivied Hamiltonians allow us to calculate nuclear wave functions from mass 14 to mass 39, covering 99 light and medium mass nuclei. And such Hamiltonians will be able to reproduce experimentally measured isotopic mass shifts with low discrepancies. A special emphasis will be done on the validity of the isobaric mass multiplet equation of the second order [8]. A few appplications of calculations of (i) the corrections to superallowed beta decay, and (ii) of the isospin-forbidden proton emission rates will be presented.

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