Recent progress and open issues on pseudospin and spin symmetries†

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Pseudospin symmetry (PSS)[1,2] was introduced to explain the near degeneracy between pairs of nuclear single-particle states with the quantum numbers $(n-1, l+2, j=l+3/2)$ and $(n, l, j=l+1/2)$. They are regarded as pseudospin doublets by defining the quantum numbers $(\tilde{n}=n-1, \tilde{l}=l+1, j=\tilde{l}\pm 1/2)$, as illustrated in Fig. 1.

This observation raised a fascinating question whether such near degeneracy is accidental (a degeneracy not explained by an obvious symmetry) or due to symmetry breaking (more descriptively hidden symmetry). Since PSS was recognized as a relativistic symmetry in the 1990s,[3] many special features, including the spin symmetry (SS) for anti-nucleons,[4] and many new concepts have been introduced in relevant studies, which led to several exciting discoveries during the past decade.

In this review article,† we intended to systematically provide a comprehensive overview on the recent progress. The PSS and SS in various systems and potentials were discussed based on the following aspects:

- From stable nuclei to exotic nuclei
- From non-confining to confining potentials
- From local to non-local potentials
- From central to tensor potentials
- From bound states to resonant states
- From nucleon spectra to anti-nucleon spectra
- From nucleon spectra to hyperon spectra
- From spherical nuclei to deformed nuclei

Then, three of the open issues in this field were selected and discussed in detail, i.e., the perturbative nature of PSS, the puzzle of intruder states, and the supersymmetric (SUSY) representation of PSS.

For the perturbative nature of PSS, we emphasized that the symmetry breaking behaves perturbatively depending on whether an appropriate symmetry limit is chosen and an appropriate symmetry-breaking term is identified. As long as an appropriate symmetry limit is chosen, the nature of PSS is indeed perturbative.[5]

For the puzzle of intruder states, we showed several different features about this puzzle, i.e., the bound states in the non-confining or confining potentials, the bound and resonant states identified by the zeros of Jost function,[6] a continuous transformation between SS and PSS, and the SUSY transformation of the PSS scheme. By doing so a number of "contradicting" results in the literature for the spin (pseudospin) partners have been clarified explicitly.

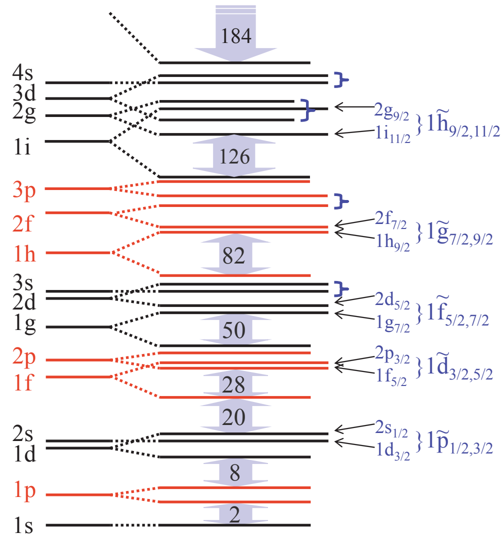

Fig. 1. Schematic nuclear single-particle spectrum. Pairs of single-particle states in braces are defined as the pseudospin doublets.

For the SUSY representation of PSS, we pointed out one of the promising ways for understanding the PSS and its symmetry breaking, by combining the similarity renormalization group, the SUSY quantum mechanics, and the perturbation theory.[7] Meanwhile, application of the SUSY technique directly to the Dirac equations, which have non-trivial scalar and vector potentials, remains an interesting and open proposition.

Another important issue is the experimental signals of these symmetries. So far, several nuclear structure phenomena have been interpreted directly or implicitly by the PSS, including nuclear superdeformed configurations, identical bands, quantized alignment, and pseudospin partner bands. The relevance of PSS in the structure of halo nuclei and superheavy nuclei was also pointed out. More experimental evidences for PSS are highly desired for future studies.

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† Condensed from the article in Phys. Rep. **570**, 1 (2015)

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