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Review

Isospin Symmetry Breaking in Atomic Nuclei

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Abstract: In this paper, the importance of isospin symmetry and its breaking in elucidating the properties of atomic nuclei is reviewed. The quark mass splitting and the electromagnetic origin of the isospin symmetry breaking (ISB) for the nuclear many-body problem is discussed. The experimental data on isobaric analogue states cannot be described only with the Coulomb interaction, and ISB terms in the nucleon–nucleon interaction are needed to discern the observed properties. In the present work, the ISB terms are explicitly considered in nuclear energy density functional and spherical shell model approaches, and a detailed investigation of the analogue states and other properties of nuclei is performed. It is observed that isospin mixing is largest for the $N = Z$ system in the density functional approach.

Keywords: shell model; density functional theory; isospin symmetry; charge symmetry breaking; isobaric analog states; isobaric mass multiplet equation

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1. Introduction

The word "symmetry" is a 16th century Latin derivative from the Greek words for "syn-" (together) and "metron" (measure). Symmetries have played a pivotal role in the development of the physical laws and breaking of these symmetries gives rise to many phenomena occurring in nature. In the development of three monumental theories of physics, the Newtonian mechanics, Einstein's relativity and the Maxwell's electromagnetism, symmetries played a prominent role. The concepts of Galilean and Lorentz invariance principles, equivalence of inertial and gravitational masses and the duality between electric and magnetic fields are the building blocks of these theories. In quantum mechanics, symmetries are of paramount importance as they lead to conserved quantum numbers which allow the characterization of the quantum mechanical states. The fundamental translational and rotational symmetries in space-time lead to energy, momentum and angular momentum quantum numbers [1]. These symmetries have classical manifestations, but there is another class of symmetries that have no classical analogies and occur only in the quantum mechanical realm. These include exchange symmetry and the symmetries that are broken spontaneously. The former leads to the Pauli exclusion principle for fermions, and the latter is an important class of symmetries associated with phase transitions giving rise to the Nambu–Goldstone boson [2,3].

The main focus of the present work is to review and also to discuss some new results on isospin symmetry and its breaking in nuclear physics. The isospin symmetry is an approximate symmetry and is broken explicitly by Coulomb and isospin symmetry breaking (ISB) terms in nucleon–nucleon interactions. In this work, we shall investigate the implications of both of these on nuclear properties. Furthermore, isospin symmetry