

Article

The Power of Symmetries in Nuclear Structure and Some of Its Problems

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Abstract: A review of several classical, algebraic models in nuclear structure physics, which use symmetries as an important tool, are presented. After a conceptual introduction to group theory, a selection of models is chosen to illustrate the methods and the power of the usage of symmetries. This enables us to describe very involved systems in a greatly simplified manner. Some problems are also discussed, when ignoring basic principles of nature, such as the Pauli exclusion principle. We also show that occasionally one can rescue these omissions. In a couple of representative models, applications of symmetries are explicitly applied in order to illustrate how extremely complicated systems can be treated. This contribution is meant as a review of the use of algebraic models in nuclear physics, leading to a better understanding of the articles in the same special volume.

Keywords: algebraic models; nuclear physics; group theory



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1. Introduction

Symmetries play a primordial role in all fields of physics, just think of the cyclic variables in classical mechanics, which imply conserved generalized momenta. A cyclic variable thus exhibits a symmetry of the Lagrangian. Alternatively, take Noether's theorem, which allows us to identify continuous symmetries, so it is essential not only in field theory. The rotational symmetry is one example of a continuous symmetry and the corresponding conserved quantum number is the angular momentum, which is in most models and theories a good quantum number.

A symmetry is related to a transformation that leaves the Lagrangian and Hamiltonian invariant, or in other words, that the Hamiltonian commutes with the operator, which generates the symmetry transformation.

Nuclear physics is no exception; here, the Hamiltonian commutes with the generators of the angular momentum group. However, there is more. The use of symmetries in nuclear physics is nearly as old as quantum mechanics. Remember the seminal work in 1931 of H. Weyl [1]. The first noticeable application of symmetries in nuclear physics is the shell model [2], recognizing that the special unitary group $SU(3)$ plays a central role. We will see in Section 2 that this is a trivial consequence, as it is nothing but counting the degrees of freedom of a system correctly. In fact, in Section 2, I will present a basic introduction to symmetry, also known as group theory (a less attractive word), resuming mainly well-known methods and facts that are very useful in understanding all models in nuclear theory based on symmetry. The content of Section 2 may seem to be too trivial for most physicists accustomed to the use of symmetry. This is intentional, because some points will be stressed that are often easily overlooked and taken as guaranteed.

Several years after the presentation of the shell model, J.P. Elliott [3,4] proposed a $SU(3)$ model for the description of deformed nuclei and we will see how this approach taught us to also describe nuclear clusters. Another advantage is that the method of using symmetry groups, such as the $SU(3)$, provides very simple formulas for the spectrum of a nucleus.

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