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Symmetry in physics

On the occasion of receiving the 2002 Lise Meitner medal

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Abstract. The role of symmetry in Physics, especially in Nuclear Physics, is briefly reviewed.

PACS. 02.20.Sv Lie algebras and Lie groups – 21.60.Fw Models based on group theory

1 Symmetry

Symmetry is a unifying concept in many human endeavors. The word symmetry comes from the Greek, $\sigma\upsilon\mu\mu\varepsilon\tau\rho o\nu$, meaning well proportioned, well ordered. It was used originally to describe properties of artifacts, such as paintings, sculptures and architectural designs (fig. 1). The concept was further developed in the Renaissance, when mathematical descriptions of symmetry begun to appear (fig. 2) culminating in Kepler's *Mysterium Cosmographicum* (fig. 3) in which the structure of the entire Universe is symmetric.

The first applications of the concept to Physics were along lines similar to those of the geometric symmetries in art. Symmetries were used to describe certain geometric arrangements of atoms in molecules and crystals. As time went on, the concept of symmetry was enlarged further and further. First there came permutational symmetries, relevant to the description of a set of identical objects. Then, towards the beginning of the 20th Century, there came space-time symmetries. Examples of these symmetries are rotational invariance in non-relativistic quantum mechanics and Lorentz invariance in relativistic quantum mechanics. Because of their importance, these symmetries are often called fundamental. They have played a crucial role in the development of Physics. Another type of symmetry that has become important in recent years is gauge symmetry. This symmetry has to do with the transformation properties of the basic interactions of Nature. It has assumed a prominent role in Physics after the discovery that also the weak interactions, in addition to the electromagnetic one, are governed by gauge symmetries. With increasing sophistication of both theoretical and experimental techniques, other types of symmetry have been introduced in Physics. An important new type is *dynamic* symmetry, the symmetry that is being recognized by the 2002 Lise Meitner Prize. These are symmetries of the interactions, hence the name dynamic. They are particularly useful to describe the *structure* of physics. Finite quantum systems are characterized by a set of discrete levels. Dynamic symmetries describe *patterns* of energy levels. Although the first example of dynamic symmetry is rather old [1], it was only in the early 1960s that their role was clearly recognized [2,3]. From 1974 on, dynamic symmetries have been extrensively used in many areas of Physics and Chemistry, especially in Nuclear [4] and Molecular [5] Physics.

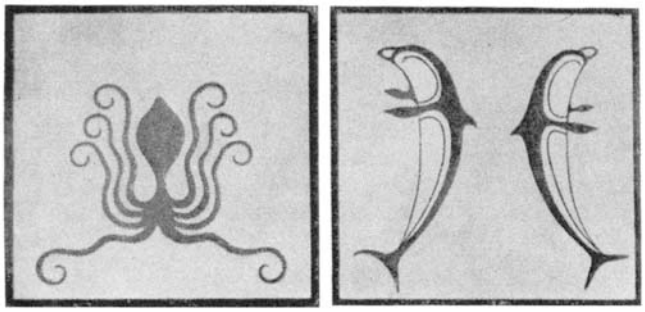

Fig. 1. Floor patterns from the Megaron in Tyrins, Greece, Late Helladic, ca. 1200 B.C.

2 Dynamic symmetries in Nuclear Physics

Indeed, Nuclear Physics is the most fertile ground for the study of dynamic symmetries in Physics producing the best examples of this type of symmetry. The introduction of the Interacting Boson Model in 1974, allowed a classification of nuclear spectra in terms of $U(6)$. It predicted the occurrence of three dynamic symmetries $U(5), SU(3), SO(6)$ [6–8], all of which have been experimentally observed (fig. 4). Particularly important is the role of $SO(6)$, whose experimental confirmation came after its prediction.

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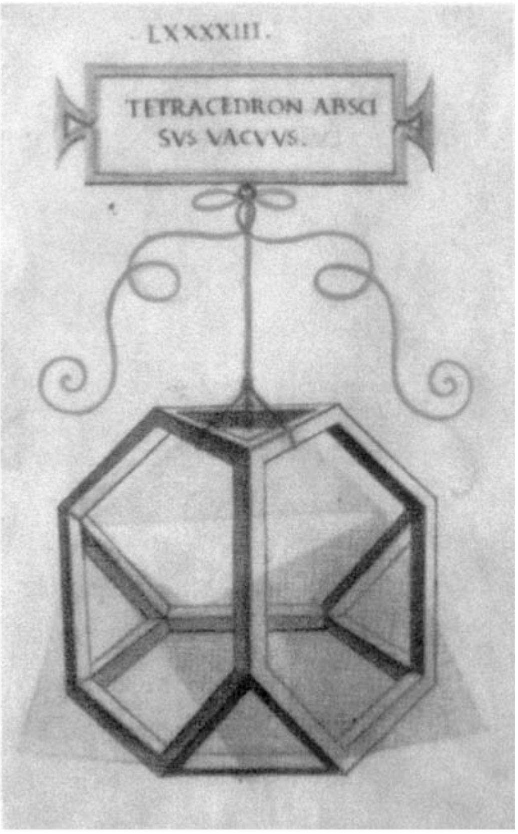

Fig. 2. A polyhedron studied by Piero della Francesca to classify all symmetry types. (From Luca Pacioli, *De Divina Proportione*, Venice, 1509).

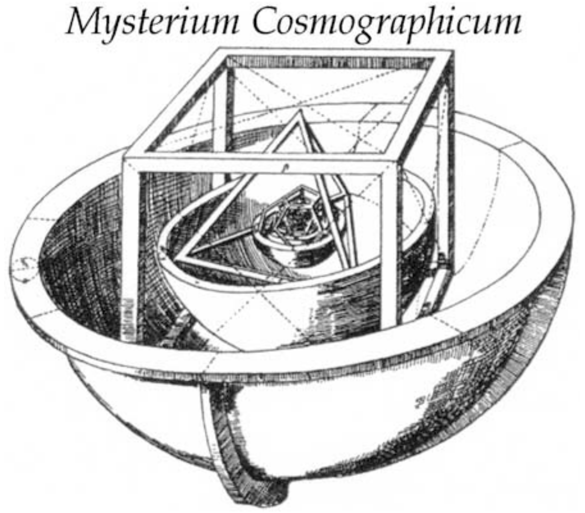

Fig. 3. The planetary system in Kepler, *Mysterium Cosmographicum*, published in 1595.

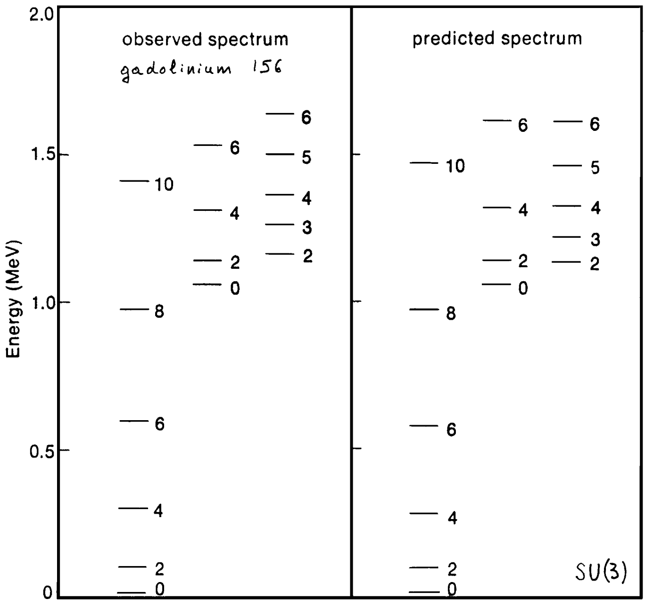

Fig. 4. The spectrum of ^{156}Gd: an example of dynamic symmetry in nuclei, $SU(3)$.

3 Supersymmetry

In recent years, the concept of symmetry has been enlarged even further to include symmetries of mixed systems of bosons and fermions, called supersymmetries [9]. Since 1980, when supersymmetries were introduced in Nuclear Physics [10], there has been a very active search for supersymmetry in nuclei (fig. 5), culminating in the 1999 confirmation [11]. In this context, it is very important to note that it has been the recent development of experimental techniques that has allowed the discovery of supersymmetry. Supersymmetry predicted a set of closely spaced energy levels that could not be resolved in previous experiments. The development of a magnetic spectrometer at the Ludwig-Maximilian University in Munich, Germany, with energy resolution of few keV, allowed the separation of the levels predicted by supersymmetry (fig. 6). Supersymmetry in nuclei is the only experimental example so far occurring in Nature.

4 Recent developments

At the present time, an attempt is being made to further enlarge the concept of symmetry, to encompass interactions that are discontinuous. Since these interactions appear to describe the situation at the critical point of phase transitions, they have been called critical-point symmetries and named $E(5)$, $X(5)$ [12,13]. Examples of these symmetries have been found (fig. 7) [14,15]. Again, it must be noted that it has been the development of very sensitive detector arrays that has allowed the discovery of these symmetries, since the test of symmetry often relies on measurements of very weak transition lines. The Laboratori Nazionali di Legnaro where this Ceremony is taking place are an ideal ground to test (and eventually discover) dynamic symmetries and supersymmetries in nuclei, especially the newly proposed ones.

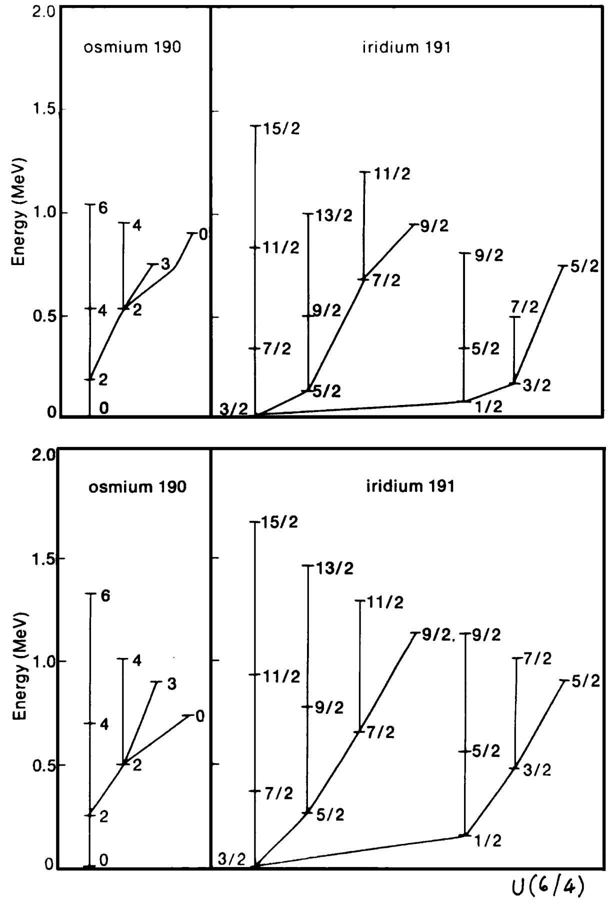

Fig. 5. The spectra of ^{190}Os and ^{191}Ir: early examples of supersymmetry in nuclei.

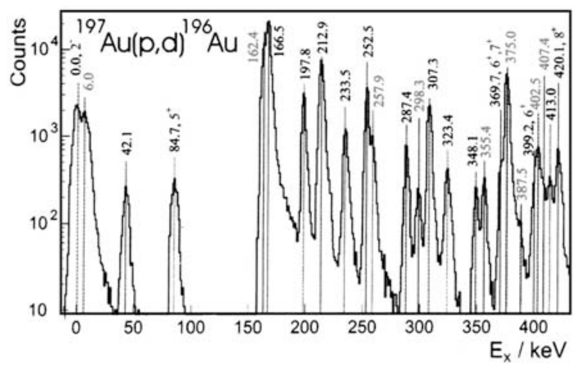

Fig. 6. The reaction ^{197}Au$(p,d)^{196}$Au, studied at the Ludwig-Maximilian University in Munich, Germany, displaying the close doublets of energy levels predicted by supersymmetry. (Courtesy of J. Jolie, G. Graw, 1999, adapted from [11].)

5 Conclusions

Dynamic symmetries and supersymmetries provide patterns for measurable quantities. These patterns may be very intricate and difficult to recognize. The more intricate the pattern, the more useful the symmetry concepts. The examples mentioned previously, and those found in other fields of Physics, such as Molecular physics, Atomic

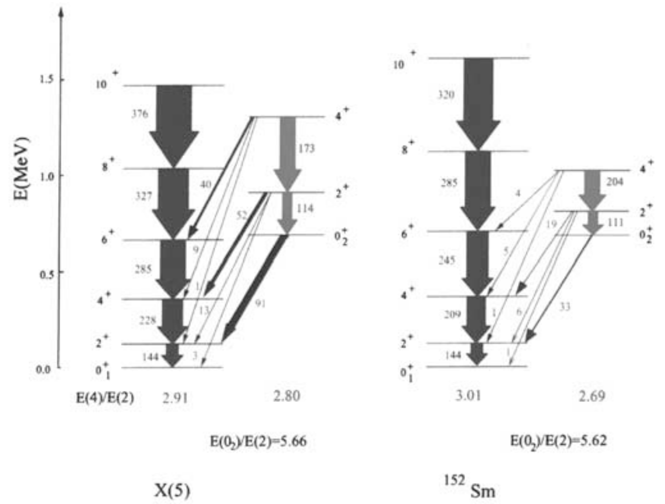

Fig. 7. The spectrum of ^{152}Sm: an example of critical-point symmetry. (Courtesy of R.F. Casten, V. Zamfir, 2001, adapted from [15].)

physics and Particle physics, indicate that dynamic symmetry is a concept that can be used in all branches of Physics. Perhaps the reason why Nature displays symmetry in its manifestations is similar to the motivation, particulary present in the Greek world, that stimulated ancient civilizations to produce artifacts with symmetry properties: beauty is bound up with symmetry. In the words of P.A.M. Dirac "If a theory of Nature is beautiful, it must be true". To find a symmetry is thus to find a key to Nature.

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