

Preface

The main goal of this monograph is to demonstrate the relevance of dynamical symmetry and its breaking to the rapidly growing field of nanophysics in general, and nanoelectronics in particular. It is intended to amalgamate seemingly highly abstract concepts of Group theory with the physics of recently fabricated nanoobjects such as single electron transistors. In all these systems, dynamical symmetries are shown to be intimately related with many-body physics, and in particular, the ubiquitous Kondo effect and other hallmarks of quantum impurity problems. Thereby, we expose yet another facet of the existing deep and profound relations between quantum field theory and condensed matter physics.

The concept of symmetry in quantum mechanics has had its golden age in the middle of the last century. In that period, the beauty, elegance and efficiency of group theoretical physics has been exposed in numerous remarkable revelations, from classification of hadron multiplets, isospin in nuclear reactions, the orbital symmetry in Rydberg atoms, point-groups in crystallography, translational symmetry in solid state physics, and so on. At the focus of all these studies stands the symmetry group of the underlying Hamiltonian. Using the powerful formalism of group theory, the energy spectrum of the physical system possessing the pertinent symmetry could be extracted within an elegant and time saving formalism. Exploiting the properties of discrete and infinitesimal rotation and translation operators, general statements about the basic properties of quantum mechanical systems could be formulated in a form of theorems (Wigner theorem, Bloch theorem, Goldstone theorem, Adler principle, etc). The intimate relation between group theory and quantum mechanics is therefore well established and has been exposed in numerous excellent handbooks.

A somewhat more subtle aspect featuring group theory and quantum mechanics emerged and was formulated later on, that is, the concept of dynamical symmetry. The notion of dynamical symmetry group is distinct from that of the familiar symmetry group. To understand this distinction in an heuristic way let us recall that all generators of the symmetry group of the Hamiltonian $\hat{H}$ encode certain integrals of the motion, which commute with $\hat{H}$. These operators induce all transformations which conserve the symmetry of the Hamiltonian, and may have non-diagonal matrix elements only within a given irreducible representation space of $\hat{H}$. On the other

hand, dynamical symmetry of $\hat{H}$ is realized by transformations implementing transitions between states belonging to *different* irreducible representations of the symmetry group. One may then say that the generators of dynamical symmetry group of a quantum mechanical system are in fact the generators of the energy spectrum or some part of it. Special examples of dynamical symmetries in quantum mechanics emerge as *hidden symmetries*, where additional degeneracy exists due to an implicit symmetry of the interaction. Another example is *supersymmetry*, where the group algebra includes both commutation and anticommutation relations.

The starting point in most of our analysis is a generalized Anderson Hamiltonian which, under certain conditions can be approximated by a generalized spin Hamiltonian encoding a myriad of exchange interactions between localized electrons in nano-objects (such as quantum states in complex quantum dots) and itinerant electrons in the reservoirs made in contact with the localized electrons. These exchange interactions may be due to spin as well as to orbital degrees of freedom. They lead to effective exchange Hamiltonians that display a rich pattern of dynamical symmetries. Mathematically, these symmetries are exposed as the pertinent exchange Hamiltonian includes, in addition to the standard spin operators, new sets of vector operators which form the basis for the representation of irreducible tensor operators entering the effective Hamiltonian. These operators induce transitions between different spin multiplets and generate dynamical symmetry groups (such as $SU(n)$ and $SO(n)$) that are not exposed within the bare Anderson Hamiltonian. Like in quantum field theory, the most dramatic aspects of dynamical symmetry in the present context is not its relation with the spectrum but, rather, the manner in which it is broken. An indispensable tool for manipulating the pertinent mathematics required for identifying the relevant dynamical symmetry groups is the superalgebra of Hubbard operators, upon which we will heavily rely.

The role of dynamical symmetries and their manifestations will be reviewed and analyzed in several systems such as complex quantum dots (planar, vertical and self-assembled), molecular complexes adsorbed on metallic surfaces and attached to quantum wires, cold gases confined in magnetic traps. It will be shown how these dynamical symmetries are activated by Coulomb and exchange interactions with itinerant electrons in the macroscopic Fermi or Bose reservoirs (metallic leads and substrates in various nanodevices). We will then develop the concept within numerous physical situations, including the Kondo cotunnelling in various environments. The notion of dynamical symmetry is meaningful also for the systems out of equilibrium, in presence of electromagnetic field and stochastic noise and in time-dependent problems like Landau –Zener effect.

Thus, the main goal of this book is to generalize the principles of dynamical symmetries formulated for the integrable systems to the many-body systems, for which only the low-energy part of the excitation spectrum is known.

Tel Aviv - Trieste - Beer Sheva,
October 31, 2011

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Dynamical Symmetries for Nanostructures
Implicit Symmetries in Single-Electron Transport
Through Real and Artificial Molecules

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2012, XIII, 351 p. 129 illus., Hardcover

ISBN: 978-3-211-99723-9