Highlights

Arguments in the favor of coherent state description. Since the coherent state was used for the first time by Glauber for a system of photons, many progresses have been made in extending the concept to other systems with various goals. The ground state properties of a many body system is often described by coherent state as happens within BCS theory, random phase approximation or the time dependent Hartree-Fock (TDHF) formalisms. In general, the dequantization procedure defined by a time dependent variational equation is most reliable when the trial function is of a coherent type. Indeed, only in this case quantizing the classical trajectories the resulting spectrum might be close to that associated with the initial many-body Hamiltonian. Such a treatment can be applied also to quadrupole boson Hamiltonians.

The over-complete property of a coherent state allows for accounts of the dynamics causing the collective motion. Indeed, by expanding the coherent state in a Hilbert space basis, no expansion coefficient is missing. Due to this property, for a quadrupole boson Hamiltonian contributions in the whole boson space are included, which is not the case when a diagonalization procedure is adopted. The useful consequence of the mentioned property is the role of the coherent state as a generating function for a basis of states in the considered Hilbert space.

Here we deal with quadrupole boson Hamiltonians and therefore we use axially symmetric coherent state defined by the quadrupole boson, b^+_{20} and b_{20}, and simple polynomial excitations of that. It is generally accepted that the nuclear system behaves more or less classically in a state of high angular momentum. This fact recommends the coherent states as an efficient tool for treating the high spin states. Indeed, it is well known that the coherent states minimize the Heisenberg uncertainty relations, which in fact reflects a classical character. However, the coherent state breaks several symmetries among which the most important are the rotational and the gauge ones. The question is whether restoring these symmetries, the classical properties are preserved or not. This feature is studied in Phys. Rev. C 86, 054307 for the mentioned symmetries and two pairs of conjugate coordinates: the quadrupole coordinate and its conjugate momentum and the boson number operator and the conjugate phase.

Studying a second order boson Hamiltonian within a time dependent variational formalism with a quadrupole coherent state as a trial function, and a constraint, the corresponding classical equation is exactly solvable, which results in having a closed formula for the ground band energies, which generalizes the result of Holmberg and Lipas. In the classical picture the kinetic and potential energies are naturally separated. The potential is just the Davidson potential. Alternatively, the energy can be obtained with the angular momentum projected state, i.e. within an approach of variation after projection. An analytical formula for energies, similar to that resulting in a semi-classical treatment, is obtained. The two very simple formulas have been applied to 44 nuclei covering regions characterized by different dynamic symmetries or, in other words, belonging to various known nuclear phases. In all cases one obtains a very good agreement with the experimental data.

The coherent state description. Being encouraged by the results obtained for the ground band, we extended these ideas to three interacting bands, ground, beta and gamma. We started with an axially symmetric coherent state as a model state of the ground band in the intrinsic frame and two polynomial excitations of that, which are associated to the beta and gamma band. The excitations where chosen such that the three states to be orthogonal before and after angular momentum projection. The three sets of projected states have very attractive properties:1) they depend on a real parameter which simulates the nuclear deformation. 2) when the deformation is going to zero the functions for the ground band tend to the highest seniority states $|\frac{J}{2}\frac{J}{2}0JM\rangle$, while those for gamma and beta bands go the the second and third highest seniority states. When the deformation is large the projected wave functions are identical with those provided by the liquid drop model. Moreover, the continuous link between the two sets of wave functions, in vibrational and rotational limits, is the same as the correspondence established empirically by Sheline and Sakai. Within the restricted boson space of projected states we considered an effective boson Hamiltonian, which yields maximally decoupled bands. For a given J the energies for beta band and gamma band states of odd angular momentum are taken to be the corresponding average values while the states of ground band and gamma band of even angular momenta are obtained by diagonalizing a 2x2 matrix. Energies and quadrupole transition probabilities are given in an analytical form, which in the vibrational as well as rotational limits become very simple. This model is called the Coherent State Model (CSM) and has been applied to a huge number of nuclei belonging to different symmetry regions. Salient features are analytically pointed out within both the laboratory and intrinsic frame.

Several Extensions of CSM. The CSM was subject of several extensions: 1) A particle-core Hamiltonian with the core described by the CSM was considered in particle-core space to describe the properties caused by the crossing of the ground, beta and gamma bands with a two quasiparticle-core band where the particle-like angular momentum is aligned to the collective one leading to several backbendings. The model was applied to the Pt region where several states 12^+ have been seen. In a similar spirit we described the one and three quasiparticle bands in even odd nuclei 2) We attached to the quadrupole bosons an isospin quantum number distinguishing the proton-like from the neuron-like bosons. The formalism obtained following a similar path and arguments as for CSM was conventionally called the Generalized Coherent State Model (GCSM). This new approach describes simultaneously the major bands , ground, beta and gamma, and one band built on the top of the scissors state 1^+. We proved analytically that the GCSM predicts for the total M1 strength, of exciting 1^+ from the ground state 0^+, a quadratic dependence on the nuclear deformation, which in fact confirms the collective character of the mode. Based on a semi-classical calculations we have derived an analytical expression for the gyromagnetic factor of neutrons which corrects the M1 transition operator towards improving the agreement with the data. The GCSM was the first approach which was extended as to describe the scissors modes in the even-odd nuclei, our predictions being later on confirmed by experiment.

3) Recently, the GCSM Hamiltonian was amended by a mean field, a pairing and a particle-core term consisting of a quadrupole-quadrupole and a spin-spin interaction. The collective magnetic dipole band is crossed by four two quasiparticle magnetic bands which have a chiral character. The chiral symmetry is broken by the spin-spin term in four different ways, which results in having four twin bands. I just mention that this is the first formalism which treats the twin bands in even-even nuclei.

4) The CSM may be easily extended to the negative parity states if the unprojected state of ground band is replaced by a product function of two coherent states, one of quadrupole and one of octupole type. In this way the unprojected ground state violates not only the rotational symmetry but also the space reflection symmetry. Therefore, in the laboratory frame we have to restore not only the rotational symmetry but also the parity. In this way, instead of three bands described by the CSM we have three pairs of parity bands. The space was enlarged by adding two dipole parity partner bands. We kept the principles governing the CSM in constructing the generating functions for independent bands and the effective

Hamiltonian. Thus, the extension provides a realistic description of four rotational bands, four of positive and four of negative parity. The properties of these bands have been studied in several publications. Excitation energies of these bands as well as B(E2), B(E1) and B(E3) values have been described for a large number of nuclei.

5) Adding to the Hamiltonian used at 4) an odd particle we extended the description to the odd nuclei. Here we describe realistically six rotational bands, three of positive and three of negative parity bands. One points out that one pair of parity partner bands exhibits a chiral symmetry.

Projected spherical single particle basis Averaging a particle core-Hamiltonian with a coherent state one obtains a deformed mean field which resembles the Nilsson Hamiltonian. On the other hand averaging the particle-core Hamiltonian with the spherical single particle wave function one obtains a boson Hamiltonian which admits the axially deformed quadrupole coherent states as eigenfunctions. This suggest that projecting out the good angular momentum from the product function of a spherical shell model state and an axially deformed quadrupole coherent state might be an efficient basis to treat the particle core-Hamiltonian. From the projected states we succeeded to select a basis. This basis can be used to treat particle-like Hamiltonians. Indeed, when the matrix element of a particle operator is calculated, first the boson factors are orthogonalized leading to a factor depending on nuclear deformation. In particular, the average of the particle-core Hamiltonian with an element of the projected spherical basis gives a set of single particle energies whose deformation dependence is similar to that of Nilsson model states. Moreover, when the deformation is going to zero the single particle energies go to those of spherical shell model. Therefore the defined basis has the nice property that recovers the shell model basis in the vibrational limit, while when the deformation goes apart from zero the Nilsson model energies are obtained. This feature allows us to treat in an unified fashion the spherical and deformed nuclei. This was tested by describing the scissors-like modes and the rate of the $2\nu\beta\beta$ decay. A systematic analysis including 190 nuclei from all regions of the nuclides periodic table, is presented in a very recent paper submitted to Annals of Physics (NY).

A phenomenological solvable model. Starting from the Bohr-Mottelson Hamiltonian written in the intrinsic coordinates supplemented by a specific potential term, by expanding the rotational and potential terms in series of the variable γ around its static values, 0^0 and 30^0, we obtained a separable form for the differential equations associated to the dynamic deformation variables, which are fully solvable. Thus, the equation in γ is satisfied by the spheroidal or Mathieu functions. Regarding the β variable, the equations used are alternatively those for a sextic oscillator potential with a centrifugal barrier included, an infinite square well or a Davidson potential. Solutions were used to describe the ground, beta and gamma bands energies and E2 transition probabilities for axially deformed and triaxial nuclei, respectively.

Comparison with other models A special chapter is devoted to the comparison of our methods and some phenomenological models which are very popular in the field nuclear structure: a) The liquid drop model b) The deformed liquid drop the model of Greiner and Faessler c) The model of Gneuss and Greiner d) The Interacting Boson Approximation proposed by Arima and Iachello. e) The model of Lipas and Hapakowski f) The methods developed by the group of Bonatsos for interacting rotational bands g) The two rotors model proposed by Lo Iudice and Palumbo h) Nilsson model i) The phenomenological solvable models mentioned above.

The book covers the essential features of a large variety of nuclear structure properties of both collective and microscopic nature. Most of results are given in an analytical form which give a deep insight of the considered phenomena. The detailed comparison with all existent nuclear structure models provides the readers a proper framework and, at a time, the perspective of new developments. The book is very useful for young as well as for experienced researchers. Due to the selfcontent exposure, the book can be succesfully read and used also by the undergaduate students.

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