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Dynamical Boson-Fermion symmetries in nuclei

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Chapter 9

SUMMARY AND CONCLUSIONS

The properties of medium and heavy mass odd-even nuclei have been studied in the framework of the interacting boson-fermion model. This model introduces several new aspects in the description of odd-A nuclei.

First the structure of the interaction between the odd nucleon and the even-even core nucleus can be derived using a semi-microscopic theory. For the first time the neutron-proton degree of freedom has been taken into account explicitly. In this extended version of the model it is then assumed that an odd neutron (proton) only interacts with the protons (neutrons) in the even-even core nucleus. The neutron-proton IBFM has several advantages over the simpler version of the model with only one kind of bosons.

(i) Since the neutron-proton IBFM is related more closely to the underlying shell model, the various terms in the coupling hamiltonian have a more direct physical interpretation. In addition the dependence of the interaction strengths on mass number can be predicted. This last aspect enables one to predict properties of nuclei hitherto unknown by extrapolating the set of parameters which have been obtained by fitting to the available experimental data, to regions far from stability.

(ii) The neutron-proton degree of freedom introduces novel features in the description of the even-even core nuclei, such as the occurrence of collective $K^\pi=1^+$ bands in deformed nuclei and triaxial shapes, which are not present in the model with only one type of boson. It would be interesting to see whether these explicit neutron-proton effects are also present in the neighbouring odd-even nuclei.

(iii) In addition to the explicit neutron-proton effects mentioned in (ii) other effects of this degree of freedom in odd-even nuclei can be studied by applying the model simultaneously to a chain of odd-neutron and odd-proton nuclei, which have the same even-even core nuclei.

As an illustration we have presented a set of calculations for the

negative and positive parity states in the odd-neutron Xenon and the odd-proton Cesium isotopes. It was shown that the main differences in the energy spectra between the two chains of nuclei, Xe and Cs, can then be ascribed to the difference in coupling between an odd neutron and an odd proton to the core nucleus. In these schematic calculations the values of the interaction parameters were kept constant for the whole chain. In order to investigate the scope and limitations of the present formulation of the neutron-proton IBFM further, also other nuclear properties, such as electromagnetic transition rates and spectroscopic factors for one-nucleon transfer reactions have to be studied in more detail both theoretically and experimentally.

Second in addition to providing a unified framework for the description of odd-even nuclei the group structure of the IBFM hamiltonian makes it possible to construct dynamical (boson-fermion) symmetries in a mixed system of boson (collective) and fermion (single-particle) degrees of freedom. The concept of dynamical symmetries is an important tool for spectroscopic studies both in elementary particle, nuclear, atomic and molecular physics. Examples are the SU(3) symmetry in elementary particle physics proposed by Gell-Mann and Ne'eman [Ge62,Ne61], Wigner's SU(4) supermultiplet theory [Wi37] and the Elliott SU(3) model [El58] for light nuclei, the interacting boson model [Ar75] for medium and heavy mass even-even nuclei, the SO(4) symmetry [Ke78,He80,Ia81d] for atoms and the vibron model [Ia81c,82,Ro82,83] for polyatomic molecules. All of these cases refer to systems consisting of either boson or fermion degrees of freedom alone.

Especially in the description of odd-A nuclei where both boson and fermion degrees of freedom are present, the concept of dynamical (boson-fermion) symmetries becomes an important tool to classify and interpret experimental data because of the complexity of the spectra. A comparison of the predictions of the various possible boson-fermion symmetries discussed in this thesis with known properties of odd-even nuclei, shows that in several cases these dynamical symmetries provide a first order description of the energy spectra and the electromagnetic transition rates. In particular for the energies there is a one to one correspondence between observed and predicted states, while for E2 transitions the selection rules are satisfied: the allowed transitions are indeed strong and the forbidden ones weak or not seen. For the spectroscopic factors for one-nucleon

transfer reactions which we have discussed in detail in terms of the $U^{(BF)}(6) \times U_s^{(F)}(2)$ limit of the IBFM, the situation is less clear. For the reactions $^{194,196}\text{Pt} \rightarrow ^{195}\text{Pt}$ and $^{195}\text{Pt} \rightarrow ^{194}\text{Pt}$ the spectroscopic factors are in good agreement with the theoretical values: the ones allowed by the selection rules are strong and the forbidden ones either weak or not seen. However, for the stripping reaction $^{195}\text{Pt} \rightarrow ^{196}\text{Pt}$ there is a larger breaking of the selection rules due to the population of the 2_2 , 0_2 , 0_3 and 2_5 states. The excitation of other states, such as the 3_1 , 2_3 and 2_4 states which are also forbidden have indeed not been observed experimentally. This situation is very similar to that encountered previously [B182] in a comparison of the spectroscopic factors for one-proton transfer reactions involving ^{193}Ir with the predictions of the $\text{Spin}^{(BF)}(6)$ limit of the IBFM. There could be several reasons for this discrepancy: (i) It is not clear whether the general form of the transfer operator which was derived semi-microscopically on the basis of the generalized seniority scheme, is also correct for non-spherical nuclei. A derivation of this operator for the deformed region using intrinsic states may clarify this point. (ii) A recent analysis of the even-even Pt nuclei in terms of the neutron-proton IBM shows [Vi82] that the inclusion of the triaxial degree of freedom improves the wave functions of the states belonging to the quasi-gamma band, such as for example the 2_2 state. To test whether this discrepancy is due to the structure of the wave functions themselves, a full numerical calculation of the spectroscopic factors in terms of the neutron-proton IB(F)M including all single-particle orbits in the valence shell and the triaxial degree of freedom has to be performed.

Third, the almost equal values of the parameters extracted from a fit to the excitation spectrum of an odd-even nucleus in a dynamical boson-fermion symmetry and those extracted from fits to the adjacent even-even nuclei suggest the presence of even a larger class of symmetries, in which both the odd-even and the even-even nuclei belong to the same multiplet. These larger symmetries which contain both bosonic states with integer spin and fermionic states with half-integer spin, are called supersymmetries. Although the concept of supersymmetries has been used in various other fields, such as elementary particle and gravitational physics, the first (and up to now the only) experimental evidence for the occurrence of such

symmetries in nature was found in nuclear physics. We have shown that in various regions of the nuclear mass table, e.g. Ru-Rh, Cu-Zn and Ir-Pt, there exists experimental evidence for the occurrence of dynamical supersymmetries. The best evidence for such a coupling scheme is provided by the excitation energies of both even-even and odd-even nuclei, which in a supersymmetric scheme are described by a single energy formula with the same value of the parameters for all nuclei belonging to the same supermultiplet. In addition as a further test it is interesting to compare the sum of the $B(E2)$ values leading to the ground states of an even-even and an odd-even nucleus belonging to the same supermultiplet. In a supersymmetric coupling scheme the ratio of these values is parameter free and only depends on the number of bosons in the even-even and the odd-even nucleus. The good agreement (within the experimental error bars) between the theoretical and the experimental values of this ratio can be considered as a strong indication of the presence of effects of the finite number of bosons already in low spin states.

Finally, it has been shown that there exist experimental evidence for the occurrence of complex symmetries in even-even and odd-even nuclei. In first approximation, the properties of these nuclei can be described in terms of such a symmetry. The breaking of these symmetries can be studied numerically by adding successively extra terms to the hamiltonian. The symmetry hamiltonian can then be used as a starting point for a more detailed analysis of the experimental data.