Self-consistent calculations of surface vibrations

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The spectrum of low lying nuclear states is traditionally associated with the collective motion of the nuclear surface. Various empirically developed collective models (Bohr-Hamiltonian, fluid dynamics, interacting boson model) have been used for its description. The link with a microscopic description has been established on the grounds of a deformed shell model and, more recently, using constrained Skyrme-Hartree-Fock (SHF) calculations [1]. We report here result of such a fully microscopic and self-consistent calculation of low lying spectra as well as its consequences for ground state correlations.

The microscopic input is obtained in the spirit of an adiabatic picture from deformed SHF. This produces the collective path, a dense series of mean field states along which the collective motion is supposed to evolve. We deduce from these states: the potential energy surface (PES), the self-consistent cranking mass (often called ATDHF cranking), and the associated zero-point energy corrections [2]. These pieces are used to build a collective Bohr-Hamiltonian for quadrupole vibrations The rules to link the microscopic information to a collective model are deduced theroetically from dynamical generator-coordinate method augmented by appropriate consideration of the topology of the collective mode [2]. Actually, we are performing the deformed SHF calculations with axial symmetry and describe triaxial properties by interpolation. This approach is acceptable for nuclei close to sphericity or with only small defomation. The Bohr-Hamiltonian thus derived is solved numerically. The solutions provide the low lying collective spectra of the nucleus. The ground state of the collective calculation yields immediately the ground state energy of the total nucleus including the correlation energy from quadrupole vibrations.

Figure 1 shows a first result of excitation spectra for ^{186}Pb as test case. This proton rich nucleus is particularly interesting because its PES shows several isomers. As a consequence it produces an unusual spectrum where two excited 0^+ states come below the first excited 2^+. It is comforting to see that our microscopic calculation produce at once (i.e. without adjustable paremeter) these typical spectral pattern. Even the actual excitation energies are hit fairly well in view of the precision one can expect from such an involved and parameter free calculation. It is, of course, clear that one has to perform now systematic investigations. It is known that there exist a large variety of Skyrme forces with different features. One needs to check a handful of them to disentangle which features of the microscopic force are repsonsible for that (pertinent) result.

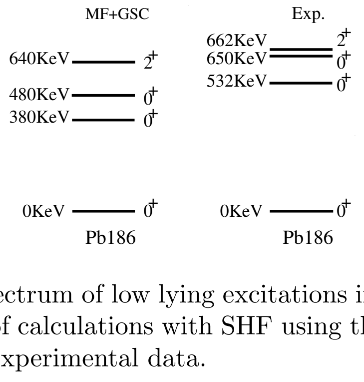

Figure 1: Spectrum of low lying excitations in ^{186}Pb. Left part: result of calculations with SHF using the force SkI3. Right part: experimental data.

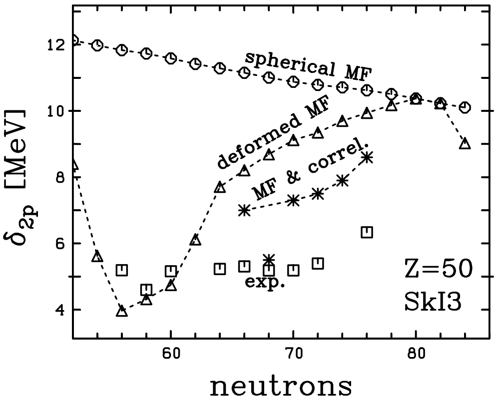

Figure 2: Two–proton shell gap δ_{2p} for Sn isotopes calculated with SHF (force SkI3) at various levels of approximation and compared with experimental data.

Figure 2 shows results on collective ground state correlations. Test case are the two-proton shell gaps $\delta_{2p} = E(Z-2,N) - 2E(Z,N) + E(Z+2,N)$ for the chain of Sn isotopes (Z=50). This second difference of energy is very sensitive to any correction on the ground state energy. Purely spherical SHF is clearly not enough as it even produces the wrong trends. The reason is that Sn keeps its spherical shape but the neighbours (Z=48 and 52) develop already a small deformation. Obviously, the deformed SHF improves the results, but not sufficiently. All involved nuclei with non-magic neutron numbers are rather soft and thus we obtain a visible effect from correlations, helping towards the experimental results. Correlations are obvisouly important for two-nucleon shell gaps. There remains still a discrepancy. This may be due to the actual force used. More systematic investigation for a broad selection of forces are to come.

References

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