Relativistic quasiparticle RPA with applications to exotic nuclei

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Studies of the structure and stability of nuclei with extreme isospin values provide new insights into every aspect of the nuclear many-body problem. In neutron-rich nuclei far from the valley of β-stability, in particular, new shell structures occur as a result of the modification of the effective nuclear potential. Neutron density distributions become very diffuse and the phenomenon of the evolution of the neutron skin and, in some cases, the neutron halo have been observed. The weak binding of outermost neutrons gives rise to soft excitation modes. In particular, the pygmy dipole resonance (PDR), i.e. the resonant oscillation of the weakly-bound neutron mantle against the isospin saturated proton-neutron core, have important implications on theoretical predictions of the radiative neutron capture rates in the r-process nucleosynthesis, and consequently to the calculated elemental abundance distribution. Furthermore, the detailed knowledge of the structure of low-energy modes of excitation would also place stringent constraints on the isovector channel of effective nuclear interactions. An interesting problem is the isotopic dependence of the PDR, and especially the behavior of the PDR in the vicinity of major spherical shell gaps.

We have solved the relativistic RPA [1], and corresponding QRPA equations in the canonical basis of the Relativistic Hartree-Bogoliubov model [2, 4]. In general, the dipole response of very neutron-rich isotopes is characterized by the fragmentation of the strength distribution and its spreading into the low-energy region, and by the mixing of isoscalar and isovector modes. In relatively light nuclei the onset of dipole strength in the low-energy region is due to non-resonant independent single particle excitations of the loosely bound neutrons. However, the structure of the low-lying dipole strength changes with mass. As we have shown in the RRPA analysis of Ref. [1], in heavier nuclei low-lying dipole states appear that are characterized by a more distributed structure of the RRPA amplitude. Among several peaks characterized by single particle transitions, a single collective dipole state is identified below 10 MeV, and its amplitude represents a coherent superposition of many neutron particle-hole configurations.

In Fig. 1 we plot the calculated PDR peak energies and the one-neutron separation energies for the Ni and Pb isotopic chains. The density-dependent effective interaction DD-ME1 [3] is used. In the pairing channel we worked with the finite range Gogny interaction D1S. The RHB results for the neutron separation energies are compared with the experimental values. For both chains the RQRPA calculation predicts a very weak mass dependence of the PDR peak energies. In the sequence of Ni isotopes the crossing between the theoretical curves of one-neutron separation energies and PDR peak energies is calculated already at $A = 64$. In heavier, neutron-rich Ni nuclei the PDR is expected to be located high above the neutron emission threshold. For the Pb isotopes the crossing point is calculated at $A = 208$, in excellent agreement with very recent experimental data on the PDR in ^{208}Pb [5]. Future (γ, γ') experiments on Pb nuclei could confirm the predictions of the present analysis.

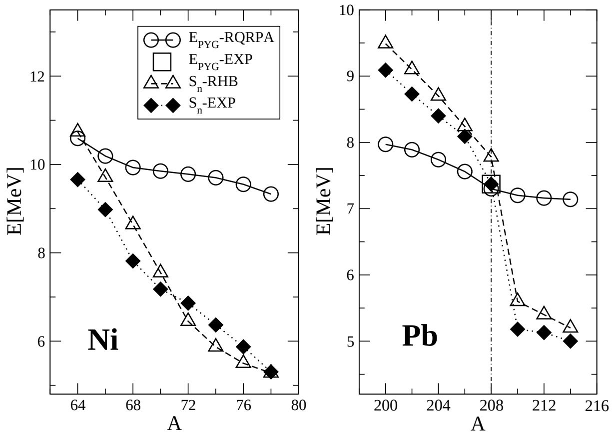

Figure 1: The calculated PDR peak energies and the one-neutron separation energies for the sequence of chain of Ni and Pb isotopes, as functions of the mass number. The open square denotes the experimental position of the PDR in ^{208}Pb [5].

In addition two important technical improvements of the computer code for solving the relativistic QRPA equations have been developed this year, (i) we are implementing full relativistic continuum RPA calculations and (ii) we developed a computer code for the solution of the deformed relativistic QRPA equations. It has been successfully tested for the correct treatment of the spurious mode connected with the rotational motion and shall be used for the investigation of the low lying $K = 1^+$ resonance in deformed nuclei far from stability.

References

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