Symmetry Projected Density Functional Theory and Neutron Halo's

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The appearance of halo phenomena near the drip line nuclei has challenged our traditional understanding of the nuclei as an incompressible charged liquid drop and extended nuclear physics to low density and inhomogeneous system, where the coupling to the continuum has to be treated in a consistent way.

Recently Relativistic Hartree Bogoliubov (RHB) theory in the continuum has been applied successfully to the description of halo phenomena in light and medium heavy nuclei [1, 2, 3]. This theory provides a self-consistent treatment of pairing correlation in the presence of the continuum and allows a microscopic description of halo phenomena in the framework of density functional theory. Essential conditions for the formation of a neutron halo have been found: (a) the Fermi surface of the neutrons has to be close to the continuum limit, (b) there has to be a large level density in the vicinity of the Fermi surface, such that pairing correlations can develop and (c) there have to be single particle states with zero or small angular momentum barrier in close neighborhood. This is the case in ^{11}Li [1], where the $2s_{1/2}$ level is shifted downwards and where a neutron halo as been observed, but also in Ne-nuclei [2] close to the neutron drip line, where $2p_{3/2}$ and $2p_{1/2}$ reach the continuum limit and where a neutron halo has been predicted. The same theory also predicts further halo phenomena in the Zr-region [3] with multi-particle halos containing up to 6 neutrons.

One of the essential shortcoming of mean field theories is the fact, that they violate symmetries. In Hartree-Bogoliubov (HFB) approximation gauge symmetry of particle number conservation is broken and the wave functions are linear combinations of wave functions with different particles. In principle one has to project onto the eigenspace of good particle number and this projection has to be carried out before the variation. In heavy nuclei, where many particles contribute to the pairing correlations one has found that an explicit projection is not necessary and the BCS-approach, where the particle number is only conserved on the average presents already a very reasonable approximation. However, in light nuclei it is a priori not clear, whether such arguments are not applicable and whether the simple Hartree-Bogolubiov theory is applicable.

Recently a new method has been developed to solve the number projected Hartree-Fock-Bogoliubov problem [4]. So far this method has only been applied to simple non-relativistic models. We have now implemented this method for realistic RHB theory. For this purpose a new code has been developed to solve the number projected relativistic Hartree-Bogoliubov equations in by a variation after projection.

This method has been applied in several areas of the periodic system [5]. Here we show as an example calculations for the chain of Ne-isotopes, where in Ref. [2] extended halo phenomena have been found. In Fig. 1 we show neutron density distributions of Ne-isotopes as a function of the radius r on a logarithmic scale. Number projected results (full lines) are compared with those without number projection (dashed line). In both cases we find halo phenomena and there is only a small difference in the density distributions. Going from ^{30}Ne to ^{40}Ne we find a phase transition from zero pairing in ^{30}Ne to rather strong pairing in ^{34}Ne and all the heavier isotopes. Because of vanishing pairing there is no difference between projected and unprojected calculations in ^{30}Ne. ^{32}Ne is a transitional nucleus with week pairing. In this case we find the largest differences between the projected and the unprojected calculations. For heavier nuclei with strong pairing, simple Hartree-Bogoliubov theory without projection provides already a rather good approximation and therefore number projection is not necessary and the conclusions found in the earlier calculations are valid.

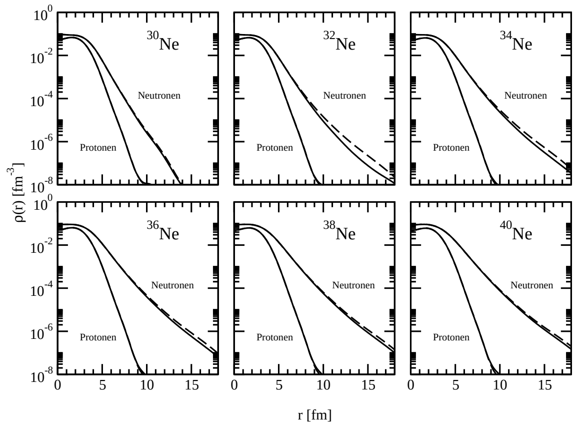

Figure 1: The neutron density distributions as a unction of radius r for ^{30}Ne, ^{32}Ne, ^{34}Ne ^{36}Ne, ^{38}Ne, and ^{40}Ne in Projected RHB theory (solid line) compared with that in the case without projection (dashed line).

Concluding we have implemented full number projection before variation in relativistic Hartree-Bogoliubov theory. This will allow many other applications in transitional nuclei in the future.

References

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