Mean-field calculations of ground states of exotic nuclei

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The production and the study of nuclei with neutron excess is one of the major topics of interest of modern nuclear physics. Microscopic mean-field (MF) theories are suitable to investigate these nuclei. These theories use effective nucleon-nucleon interactions whose parameters are chosen by making a global fit of some properties of a large set of nuclei. Since these parametrizations are unique for all the nuclei, microscopic MF approaches are suitable to be applied in experimentally unexplored regions of the nuclear chart.

We have investigated the predictions of three MF theoretical approaches in the description of the ground state properties of some spherical nuclei far from the stability line. We compare the results obtained by using two non-relativistic Hartree-Fock (HF) approaches and those of a relativistic Dirac-Hartree approach.

The older, and more exploited approach, is based on the non-relativistic HF calculations done with a zero-range interaction of Skyrme type, with the modern parametrization called SLy5 [1]. The other non-relativistic HF approach uses a finite range interaction of Gogny type with the recent D1M parametrization [2] built to produce a reasonable behavior of neutron matter densities values larger than that of nuclear matter saturation. The third approach we have considered is based on relativistic field theory where nucleons are treated as Dirac particles moving in several classic meson fields. In our work we used a phenomenological parametrization of the meson-nucleon coupling called DDME2 [3].

We have applied these three approaches to the study of four isotope chains, each of them containing four isotopes selected because all the proton and neutron single particle levels are fully occupied. This ensured us that these nuclei are spherical and that pairing effects, when present, are negligible. We have considered the oxygen isotopes 16, 22, 24, 28, the calcium isotopes 40, 48, 52, 60, the nickel isotopes 48, 56, 68, 78 and the tin isotopes 100, 114, 116, 132.

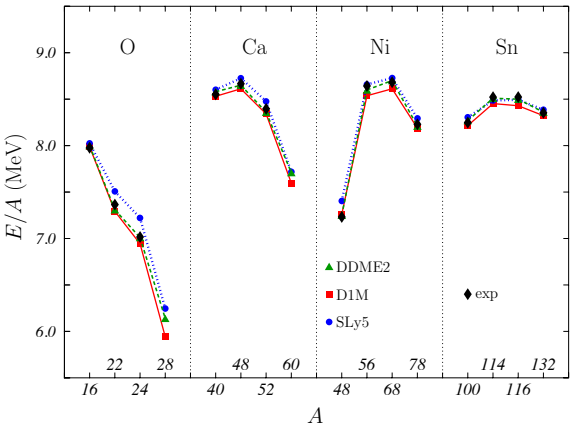

Figure 1. Binding energies per nucleon calculated with the three different MF models and compared with the experimental values. The lines are drawn to guide the eyes.

We shown in Fig. 1 the binding energies per nucleon calculated with these three different approaches and compared with the experimental values [4]. The agreement between the results of the various calculations is remarkable. We should point that binding energies are observed quantities that are used in the global fits done to select the values of the parameters of the interactions, therefore this agreement is not so surprising. It is worth to remark, however, that also for the nuclei not yet identified, ^{28}O and ^{60}Ca, the three mod-

els predict similar values. We observe that the results for all the isotopes show the same trend. The D1M calculations produce the smaller bindings, followed by the DDME2 and then by the SLy5.

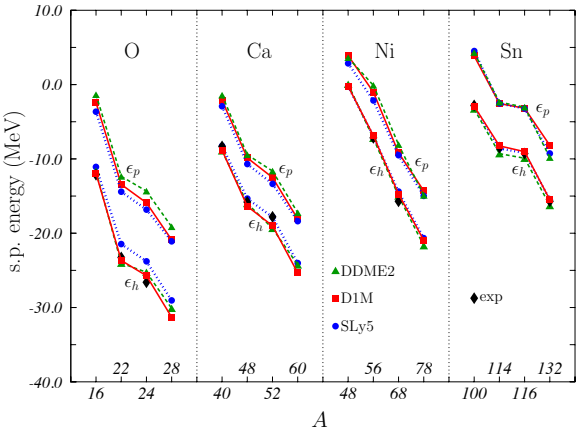

Figure 2. Energies of the single particle proton levels just below (ϵ_h) and above (ϵ_p) the Fermi energy.

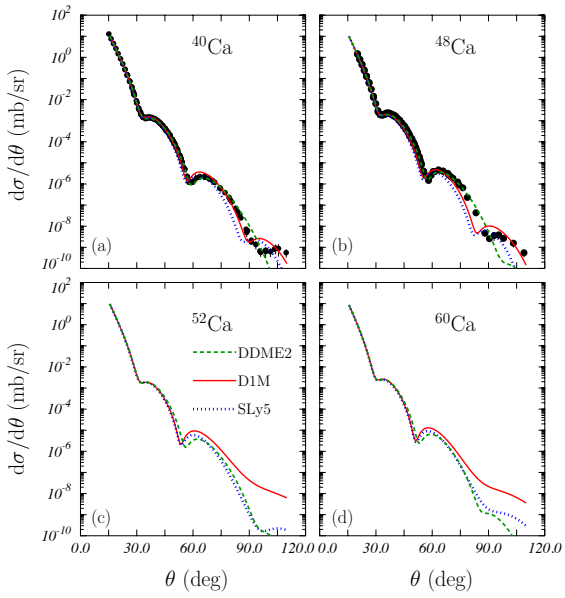

Figure 3. Elastic electron scattering cross sections calculated with the charge densities produced by the three different MF approaches as a function of the scattering angle. The electron energies of all the calculations have been fixed at 400 MeV.

We show in Fig. 2 the energies of the single particle levels just below, (ϵ_h), and above, (ϵ_p), the Fermi level. The ϵ_h energies can be compared with the experimental separation energies [4]. Also in this case the agreement between the various calculations is remarkable for all the nuclei considered. These quantities have not been included in the fit procedure, therefore the results presented in Fig. 2 are genuine predictions of the three models.

We have carried on a detailed investigation of the proton and neutron distributions of the various nuclei. Also in this case the three models produce rather similar results. The various densities agree very well at the nuclear surface, while we found some differences in the nuclear interior. We have studied the possibility of disentangling these effects with (e,e'p) experiments [5], as it is discussed in another contribution of this annual report. The case of the calcium isotopes is that where we found the largest differences in the densities of the various calculations. We compare in Fig. 3 the elastic electron scattering cross sections calculated in a DWBA approach which used the charge distributions produced by the three MF approaches with the available experimental data [6]. The agreement between the results of the various calculations and the experimental data is quite remarkable. We observe that only at large values of the scattering angle, corresponding to large values of the transferred momentum, the various results start to differ. The main differences are present in the heavier calcium isotopes, the unstable ones, where the D1M densities are remarkably different with respect to those of the other two calculations.

This investigation shows a large convergence of the results of the three MF models that we have adopted, also in the predictions for the unstable nuclei with neutron excess which have not yet been measured. We remark the relevance of making these measurements, also from the theoretical point of view. The comparison between the observed properties and the MF predictions can confirm, or invalidate, the MF model in itself, and not a specific implementation of it.

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