Masses, deformations, and charge radii
—the first complete mass table in the RMF+BCS theory

L. S. Geng[a,b], H. Toki[a], and J. Meng[b]

[a]*Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan*
[b]*School of Physics, Peking University, Beijing 100871, P.R. China*

`Introduction of the RMF theory:` In the past twenty years, the relativistic mean field (RMF) theory has been successfully applied to study various phenomena in nuclear physics: from stable nuclei to exotic nuclei; from nuclear ground-state properties to collective multipole excitations; from normal nuclei to hepernuclei; from nuclear matter to neutron star and supernova, to name just a few. Compared to its nonrelativistic counterpart, the RMF theory has two major advantages: the self-consistent description of the spin-orbit interaction and the Dirac structure. The Dirac structure has more significance than it seems to have. For example, recently the origin of the pseudospin symmetry has been naturally explained as a relativistic symmetry in the RMF theory.

`Motivation of the present work:` Despite all the successful applications of the RMF theory, a complete mass table based on this model is still missing due to several difficulties encountered in this process. The first one is that the self-consistent calculation of the RMF model for deformed nuclei is very time consuming. Secondly and more importantly, an efficient and economical pairing method which can treat all the nuclei from the proton drip line to the neutron drip line is not well known till recently. That is why first Hirata et al. constructed a mass table for 2174 even-even nuclei with $8 \leq Z \leq 120$ without including the pairing correlations at all in 1997, then Lalazissis et al. developed a mass table for 1315 even-even nuclei with $10 \leq Z \leq 98$ adopting a constant-gap BCS method in 1999. In recent years, a state-dependent BCS method with a zero-range delta force has been found to be an efficient and economical method to treat the pairing correlations for all the nuclei from the proton drip line to the neutron drip line [1, 2]. Equipped with this method, now we are ready to construct the first complete mass table in the RMF theory for all the nuclei with $Z, N \geq 8$ and $Z \leq 100$ from the proton drip line to the neutron drip line.

`A brief description of the numerical details:` The parameter set TMA is used for the Lagrangian density, which has proved to be one of the best modern parameter sets. We solve the RMF equations using the expansion method on the Harmonic-Oscillator basis. 14 shells are used for both the fermion fields and the meson fields. In the particle-particle channel, a zero-range delta force is used, $V = -V_0\delta(\mathbf{r_1} - \mathbf{r_2})$. The strength of this force, V_0, is determined by fitting the experimental odd-even staggerings and kept the same for both protons and neutrons. In order to account for the observed variation of V_0 with the mass number A, we used a mass-dependent formula for it: $V_0 = 300 + 120/A^{1/3}$. In order to correctly locate the ground-state configuration in the deformation space, a quadrupole-constrained calculation is performed for each nucleus. More details can be found in Ref. [3].

`Results for nuclear masses and separation energies:` The predicted nuclear masses are compared with the experimental data compiled in Audi 2003 [4]. The rms deviations of masses and one-proton separation energies for 2157 nuclei are about 2.1 MeV and 0.6 MeV, respectively. The corresponding quantities for the Finite-Range Droplet Model (FRDM) and the Hartree-Fock-Bogoliubov-2 (HFB-2) mass formula are 0.6(0.4) and 0.7(0.5) (where the numbers in parenthesis are for one-proton separation energies). Considering the fact

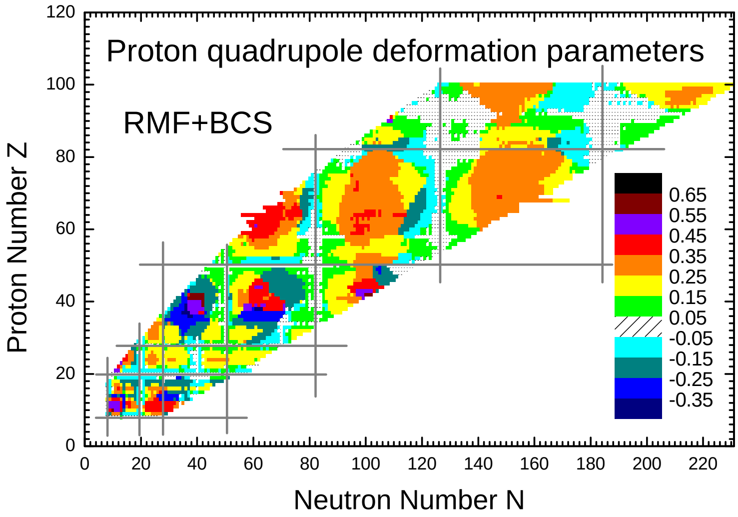

Figure 1: Proton quadrupole deformation parameters, β_2, for 6969 nuclei obtained in the present work.

both these two nonrelativistic models have more model parameters (FRDM($\approx$ 30) and HFB-2($\approx$ 20)) and both used masses of more than 1000 nuclei to fit their parameters, it is fair to say that our results are fairly good.

`Results for deformations:` In Figure 1, we plot the proton quadrupole deformation parameters, β_2, as a function of proton number Z and neutron number N for 6969 nuclei calculated in the present work. It is easily seen that only very few number of nuclei are spherical and most of these are at or near the magic numbers. In the region where $Z > 50$, when nuclei move away from the magic numbers either isotopically or isotonically, there is a tendency for them to become prolate deformed and the maximum of deformation is reached at the middle of the major shells.

`Results for charge radii:` The calculated charge radii are compared with the compilation of Nadjakov et al. [5] for 523 nuclei in 42 isotopic chains. The overall rms deviation is 0.037 fm. Furthermore, the much discussed kinks in the charge radii of the Pb isotopes together with other anomalous kinks in the isotope shifts of rare-earth nuclei can be described very well by our calculations.

To summarize, the first complete mass table in the relativistic mean field theory has been constructed for 6969 nuclei with $Z, N \geq 8$ and $Z \leq 100$. Comparisons with both available experimental data and the predictions of other nonrelativistic models have been made. Further investigation is in progress.

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