Ground state properties of some new isotopes: Relativistic Mean Field approach

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Since the discovery of the radioactive ion beam, quite a large number of new isotopes have been synthesized that are far away from the $\beta-$stability line on both sides of it. In this vein, recently 45 new isotopes have been discovered by the RIKEN group [1]. From the theoretical point of view, studies on exotic nuclei are doubly significant - (a) for satisfactory description of the observed properties of the known nuclei, and (b) for it may provide new input to explore the nuclear landscape. It is well known that the theoretical descriptions of atomic nuclei are all model dependent. Of course, fully self-consistent calculations with effective interactions are always advantageous. The Relativistic Mean Field (RMF) theory in that sense is always a prefered technique [2]. In this contribution, we have reported the RMF prediction of some ground state properties namely, binding energy, rms neutron and proton radii (r_n, r_p), and quadrupole deformation parameter (β_2) of the 45 new neutron rich isotopes reported by the RIKEN group [1].

The conventional RMF calculation starts with the Lagrangian density that consists free baryon and meson fields along with some linear and non-linear/self-coupling terms. We have started with the Lagrangian density with the well known NL3 parameters [3]. The NL3 parameter set is supposed to be more consistent in reproducing the ground state properties of even-even nuclei throughout the periodic table [4]. For odd A nuclei, the time reversal (TR) invariance is broken due to the extra unpaired nucleon. This gives rise to additional spatial components of the vector meson fields. So in principle, for the odd-A systems the field equations have to be solved taking these spatial components into account. However, it has been shown [5] that the TR symmetry breaking has a marginal effect on the collective properties like binding energy, rms radii, etc. Therefore, in the present calculations we have considered a TR invariant Lagrangian density.

We consider anisotropic harmonic oscillator finite basis expansion method, which is parameterized in terms of the average frequency $\hbar\omega_0$ and the deformation parameter β_0. The average frequency is fixed at $\hbar\omega_0 = 41A^{1/3}$ and β_0 is set following [4]. Center of mass energy correction is made according to the formula, $E_{cm} = \frac{3}{4}41A^{-1/3}$. We consider 16 (20) oscillator shells for the fermion (boson) field expansion. The effective pairing interaction is added according to the standard BCS formalism. The pairing gaps for neutrons $\Delta_n = 13.3/\sqrt{A}$ and for protons $\Delta_p = 13.9/\sqrt{A}$ are considered. The neutron and the proton rms radii can be calculated from the knowledge of their distribution functions. The quadrupole deformation parameter β_2 is extracted form the calculated values of the proton and the neutron quadrupole moments through the relation, $Q = Q_n + Q_p = \sqrt{\frac{16\pi}{5}}\frac{3}{4\pi}AR_0^2\beta_2$, where $R_0 = 1.2A^{1/3}$, A being the mass number.

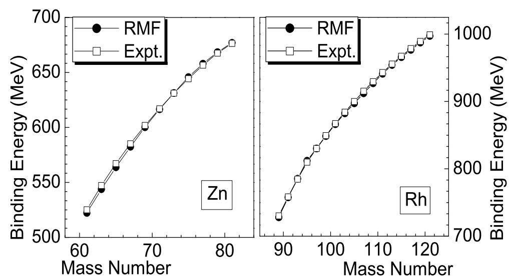

FIG. 1: Total binding energies of odd-A Zn isotopes and odd-A Rh isotopes. Experimental values are taken from Ref. [6].

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TABLE I: RMF prediction of the ground state properties of 45 new isotopes. Follow text for headers.

Isotopes	BE (MeV)	r_n(fm)	r_p(fm)	β_2	Isotopes	BE (MeV)	r_n(fm)	r_p(fm)	β_2
^{71}Mn	573.738	4.293	3.798	0.215	^{115}Mo	940.547	4.912	4.488	-0.181
^{73}Fe	594.959	4.296	3.825	0.186	^{116}Mo	944.657	4.931	4.495	-0.175
^{74}Fe	598.063	4.327	3.832	0.182	^{117}Mo	948.441	4.950	4.501	-0.168
^{76}Co	619.983	4.298	3.842	0.003	^{119}Tc	967.729	4.959	4.525	-0.159
^{79}Ni	645.377	4.358	3.881	0.003	^{120}Tc	971.591	4.969	4.509	0.087
^{81}Cu	664.040	4.398	3.920	0.007	^{121}Ru	987.453	4.962	4.528	0.096
^{82}Cu	666.041	4.444	3.928	0.021	^{122}Ru	991.866	4.977	4.533	0.082
^{84}Zn	685.748	4.488	3.995	0.186	^{123}Ru	995.974	4.991	4.536	0.051
^{85}Zn	688.402	4.528	4.010	0.203	^{124}Ru	1000.194	5.005	4.541	-0.002
^{87}Ga	707.982	4.557	4.058	0.223	^{123}Rh	1007.573	4.970	4.550	0.083
^{90}Ge	730.259	4.632	4.121	-0.241	^{124}Rh	1012.075	4.983	4.554	0.058
^{95}Se	772.324	4.708	4.213	-0.254	^{125}Rh	1016.533	4.996	4.558	-0.002
^{98}Br	794.628	4.756	4.270	-0.271	^{126}Rh	1021.281	5.014	4.566	-0.001
^{101}Kr	817.250	4.799	4.319	-0.272	^{127}Pd	1037.708	5.006	4.581	-0.001
^{103}Rb	836.361	4.814	4.351	-0.266	^{128}Pd	1041.991	5.026	4.589	-0.001
^{106}Sr	859.588	4.890	4.444	0.417	^{133}Cd	1080.944	5.100	4.642	-0.000
^{107}Sr	862.816	4.921	4.456	0.423	^{138}Sn	1117.445	5.168	4.702	0.040
^{108}Y	878.797	4.912	4.480	0.424	^{140}Sb	1134.449	5.197	4.754	0.139
^{109}Y	882.059	4.947	4.494	0.437	^{143}Te	1153.858	5.248	4.804	0.177
^{111}Zr	901.477	4.886	4.429	-0.182	^{145}I	1170.363	5.270	4.839	0.194
^{112}Zr	905.327	4.906	4.435	-0.172	^{148}Xe	1189.921	5.315	4.884	0.219
^{114}Nb	925.082	4.919	4.466	-0.176	^{152}Ba	1222.680	5.367	4.967	0.296
^{115}Nb	927.871	4.930	4.440	0.001					

Since our interest is on the new isotopes consisting even-A as well as odd-A nuclei for which till date no experimental data exists, therefore, we have verified the RMF (with TR invariant Lagrangian) results of two well known odd-A nuclei (Zn and Rh) with the corresponding experimental values. FIG.1 shows the results of such calculations, where the total binding energies of Zn and Rh isotopes are plotted against A. The graph shows complete agreement between the RMF prediction and the experimental values taken from Ref.[6]. Other parameters like r.m.s. radii and β_2 also match nicely (not shown). The RMF prediction of the ground state properties of the 45 new isotopes are listed in TABLE I. In some cases RMF predicts spherical shaped nuclei - for instance ^{127,128}Pd and ^{133}Cd, all very close to the neutron magic numbers $N = 82$. In this calculation a large number of isotopes are found in $A \sim 87 - 111$ region, which have less than 1.0 MeV energy difference between prolate and oblate configurations, indication of shape coexistence.

In summary, we have studied the ground sate properties of some newly identified isotopes in RMF+BCS approach. Due to lack of experimental data it is certainly not possible to make a strong conclusion about the results at this stage. However, the RMF theory with TR invariant Lagrangian is seen to provide very accurate results (collective) for the odd-A isotopes of Zn and Rh.

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