Relativistic Mean Field Description of the Ground State Properties of Nuclei Appearing in the α - Decay Chains of Recently Reported New Isotopes

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Introduction

Recently, five new neutron deficient unstable isotopes with $Z \geq 92$ have been identified [1] in the collisions of ^{48}Ca + ^{248}Cm,carried out at GSI. The decay energies (E_α) and half-lives of the respective α - decay chains of these new isotopes, $^{216}_{92}$U, $^{223}_{95}$Am, $^{219}_{93}$Np, $^{229}_{95}$Am and $^{233}_{97}$Bk have been measured. Here, we study and discuss the ground state properties of these new isotopes along with the nuclei appearing in their α-decay chains calculated in the relativistic mean field (RMF) framework [2, 3]. The calculated total binding energies, radii and sizes, the deformation parameter and Q values of the α - decay chains, reproduce the experiment well as expected.

1. Details of the calculation

Explicit calculations require the parameters appearing in the Lagrangian. Several such parameter sets are available in the literature (see, for example, Ref. [3]). We employ here the Lagrangian parameter set NL3* [4] (the improved version of the set NL3) in our illustrative calculations. It is to be mentioned that for odd/odd-odd deformed nuclei the time reversal invariance is violated. To overcome this difficulty we use the "tagging" prescription. The "tagging" here means assigning a fixed occupancy to the tagged level(s) through out the iterative RMF calculations. The left over even number of neutrons and even number of protons preserve the time reversal invariance and the calculation then proceeds in the conventional manner. For details see Refs. [2]

TABLE I: Calculated ground state properties of the nuclei investigated in this work.

	BE (MeV)			r_p (fm)	
Nucleus	NL3*	PC-PK1	AU	NL3*	PC-PK1
$^{233}_{97}$Bk$_{136}$	1757.8	1744.1		5.81	5.80
$^{229}_{95}$Am$_{134}$	1737.4	1726.9	1731.9	5.74	5.75
$^{225}_{93}$Np$_{132}$	1718.3	1709.9	1711.7	5.69	5.70
$^{221}_{91}$Pa$_{130}$	1700.2	1692.8	1692.2	5.64	5.65
$^{217}_{89}$Ac$_{128}$	1680.8	1674.8	1673.1	5.59	5.60
$^{213}_{87}$Fr$_{126}$	1662.7	1657.6	1654.7	5.54	5.54
$^{209}_{85}$At$_{124}$	1638.4	1633.1	1633.2	5.50	5.50
$^{223}_{95}$Am$_{128}$	1693.7	1684.0		5.68	5.70
$^{219}_{93}$Np$_{126}$	1677.1	1669.3	1665.5	5.63	5.63
$^{215}_{91}$Pa$_{124}$	1656.8	1649.1	1646.3	5.59	5.60
$^{211}_{89}$Ac$_{122}$	1634.6	1626.5	1626.2	5.55	5.56
$^{207}_{87}$Fr$_{120}$	1616.7	1603.4	1605.5	5.52	5.52
$^{203}_{85}$At$_{118}$	1588.5	1580.2	1584.1	5.48	5.47
$^{216}_{92}$U$_{124}$	1658.9	1651.3		5.60	5.61
$^{212}_{90}$Th$_{122}$	1636.6	1629.1	1628.6	5.57	5.58
$^{208}_{88}$Ra$_{120}$	1614.5	1606.2	1608.3	5.53	5.53
$^{208}_{87}$Fr$_{121}$	1620.7	1612.1	1613.4	5.52	5.52
$^{204}_{85}$At$_{119}$	1597.1	1588.5	1591.9	5.48	5.48

2. Results and Discussion

The calculated total nuclear binding energyies (BE) and the corresponding point *rms*

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proton r_p radius of the nuclear density distributions, are listed in Table I labeled as NL3* for illustration. Recently, extensive Relativistic Continuum Hartree - Bogoliubov calculations using the successful relativistic energy density functional PC-PK1, have been reported and the results are presented in [5]. These spherical calculations properly treat the time odd terms. and use blocking (Tagging) procedure in the calculation. The relevant results are also presented in the same table labelled as PC-PK1 for comparison and discussion. The binding energies taken from the recent compilation by Wang *et al.* [6] labeled as AU are also listed in the same table.

The inspection of Table I reveals that the calculated values of BE are in good agreement with the experiment as expected. The PC-PK1 values overall are in better agreement with the experiment (AU). The average deviation for NL3* (PC-PK1) is $\sim 0.6\%$ (0.1%).

Both NL3* and PC-PK1 calculated point *rms* proton r_p radius are very close to each other, the differences appear only at second decimal place of fermi. For example the maximum deviation for point *rms* proton radius (r_p is ~ 0.1 fermi.

The calculated NL3* quadrupole deformation parameter β values are very similar to the corresponding values of Möller and Nix for most of the nuclei, except for the nucleus ^{229}Am. Further, most of the calculated NL3* β values are small except for ^{233}Bk where its value is 0.218, indicating that most of these nuclei are close to spherical.

The experimental charge radii are available [7] for the following four nuclei in this region and are listed in Table II. Clearly, both NL3* and PC-KC1 reproduce the corresponding experimental values very well. The deviations appear only in third decimal place of fermi.

The calculated (NL3*) Q values of α - decay and the corresponding PK-PC1 values taken from [5] of the new isotopes are similar and reasonably agree with the experiment. Quantitatively, the deviations rise even up to 3 MeV in some cases. This type of agreement is considered to be quite acceptable in view of the fact that the Q value is the difference between

TABLE II: The calculated (RMF) charge radii along with the corresponding experimental values (Expt.) taken from [7].

	r_c (fm)		
Nucleus	NL3*	PC-PK1	Expt.
$^{213}_{87}$Fr$_{126}$	5.595	5.601	5.598
$^{208}_{87}$Fr$_{121}$	5.577	5.580	5.573
$^{207}_{87}$Fr$_{120}$	5.573	5.576	5.572
$^{208}_{88}$Ra$_{120}$	5.590	5.592	5.585

the binding energy (BE) of the parent nucleus and those of the α particle and of the daughter nucleus. The BE themselves are very large. A small error in one may easily upset the quality of the obtained agreement.

3. Summary and Conclusion

In conlusion we restate that the Relativistic Mean Field (Relativistic energy density functional) theories provide accurate and reliable description of nuclear ground state properties for nuclei spread over the entire periodic table.

References

[1] H. M. Devaraja *et al.*, Phys. Lett. B **748**, 199 (2015).
[2] Y. K. Gambhir, P. Ring and A. Thimet, Ann. Phys. (NY) **198**, 132 (1990).
[3] S. E. Agbemava *et al.*, Phys. Rev. C **89**, 054320 (2014) and references cited therein. .
[4] G. A. Lalazissis *et al.*, Phys. Lett. B**671**, 36 (2009).
[5] X.W. Xia *et al.*, arXiv:1704.08906v2[nucl-th], 14 Sept. 2017.
[6] M. Wang *et al.*, Chinese Phys. C **36**, 1287 (2012), **36**, 1603 (2012), **41**, 03003 (2017).
[7] I. Angeli and K. P. Marinova, *At. Data Nucl. Data Tables* **99** (2013) 69.