Study of ground-state properties of even-even Polonium isotopes

Deby Treasa K. M.[1],* A. K. Rhine Kumar[1], and P. Arumugam[2]
[1] *Department of Physics, Cochin University of Science and Technology, Kerala - 682 022, India and*
[2] *Department of Physics, Indian Institute of Technology Roorkee, Uttarakhand - 247 667, India.*

Introduction

The complementing efforts of experimental and theoretical studies have led to understanding the properties of the nuclei far from the stability region. The self-consistent Relativistic Mean Field (RMF) models have been successfully applied in analyses of nuclear structure properties over the whole periodic table, from light nuclei to super heavy elements [1]. The Covariant Density Functional Theory (CDFT) is such a model capable of explaining the properties of the nuclei over the entire nuclear chart. The CDFT is not only successful in reproducing bulk properties of nuclear ground-states such as binding energies, radii or deformation parameter but it also allows the investigation of collective phenomena such as giant resonances and rotational excitations [1].

Theoretical Framework

We have calculated the ground-state properties of even-even isotopes of Polonium (Po) employing the DIRHB package [2]. Here, the Relativistic Hartree-Bogoliubov (RHB) model which encloses a uniform description of mean-field and pairing correlations [3] are solved using the axially deformed oscillator basis. The effective Lagrangian representing the system can be written as,

$$\mathcal{L} = \mathcal{L}_N + \mathcal{L}_m + \mathcal{L}_{int} \tag{1}$$

$\mathcal{L}_N$ denotes the Lagrangian of the free nucleon

$$\mathcal{L}_N = \overline{\psi}(i\gamma_\mu \partial^\mu - m)\psi \tag{2}$$

Where m is the bare nucleon mass and ψ is the Dirac spinor. $\mathcal{L}_m$ is the Lagrangian for the free meson fields and electromagnetic field

$$\begin{aligned}\mathcal{L}_m = & \frac{1}{2}(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma^2) \\ & - \frac{1}{2}(\frac{1}{2}\Omega_{\mu\nu}\Omega^{\mu\nu} - \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu) \\ & - \frac{1}{2}(\frac{1}{2}\vec{R}_{\mu\nu}\vec{R}^{\mu\nu} - \frac{1}{2}m_\rho^2\rho_\mu\rho^\mu) - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}\end{aligned} \tag{3}$$

The minimal set of interaction terms is contained in

$$\begin{aligned}\mathcal{L}_{int} = & -g_\sigma\overline{\psi}\psi\sigma - g_\omega\overline{\psi}\gamma^\mu\psi\omega_\mu \\ & - g_\rho\overline{\psi}\vec{\tau}\gamma^\mu\psi.\vec{\rho_\mu} - e\overline{\psi}\gamma^\mu\psi A_\mu\end{aligned} \tag{4}$$

where m_σ, m_ω and m_ρ are the rest masses of the meson.

$$\Omega_{\mu\nu} = \partial_\mu\omega_\nu - \partial_\nu\omega_\mu \tag{5}$$

$$\vec{R}_{\mu\nu} = \partial_\mu\vec{\rho}_\nu - \partial_\nu\vec{\rho}_\mu \tag{6}$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \tag{7}$$

where g_σ, g_ω, g_ρ and e are the coupling constants and $\vec{\tau}$ is the isospin Pauli matrix [2].

There exist a number of non-relativistic and relativistic parameter sets for solving the effective Lagrangian. We performed our calculations with the density-dependent meson exchange model (DD-ME2) and the density-dependent point coupling model (DD-PC1). The basic difference between these two models lies in the treatment of the mesons, density dependence and interaction range [1, 4].

Results

The ground-state properties like the binding energy, charge radii, pairing energy, proton and neutron quadrupole moment, proton and neutron radii of even-even Po isotopes are

*Electronic address: debytreasakm@cusat.ac.in

TABLE I: The total binding energy (MeV) obtained with CDFT (DD-ME2, DD-PC1) model for even-even $^{190-220}$Po isotopes are compared with the experimental data [5].

Nucleus	Nuclear binding energy (MeV)		
	Expt.	DD-ME2	DD-PC1
^{190}Po	1472.31	1472.28	1471.73
^{192}Po	1492.03	1486.55	1491.84
^{194}Po	1511.07	1508.72	1508.51
^{196}Po	1529.58	1527.48	1527.50
^{198}Po	1547.96	1546.11	1546.34
^{200}Po	1565.40	1564.43	1564.56
^{202}Po	1582.67	1582.40	1583.03
^{204}Po	1599.16	1600.00	1600.82
^{206}Po	1615.04	1617.20	1618.17
^{208}Po	1630.51	1633.86	1634.90
^{210}Po	1645.14	1649.85	1650.72
^{212}Po	1655.72	1658.18	1659.41
^{214}Po	1665.99	1666.44	1668.02
^{216}Po	1675.94	1674.65	1676.56
^{218}Po	1685.36	1682.88	1685.04
^{220}Po	1694.88	1691.67	1693.61

evaluated using the DD-ME2 and DD-PC1 interactions. The total binding energy obtained with two-parameter sets is listed in Table I along with the experimental data. The theoretical results are in good agreement with the experimental results.

The nuclear charge radii is an important parameter that gives information about the nuclear shell model and the influence of effective interactions on nuclear structure [6]. Here we present the charge radii of the $^{192-218}$Po isotopes in Table II along with the available experimental data for comparison. Our calculated results show nice agreement with experimental values. We have also studied the ground state properties of even-even isotopes of Osmium and Platinum.

We have also compared our results with the results reported within the self-consistent Hartree-Fock-Bogoliubov method and transformed harmonic-oscillator (THO) framework, using the Skyrme SLy4, SkP, and SkM* forces along with the Lipkin-Nagomi (LN) prescription followed by exact particle-number projection (PNP) [7].

TABLE II: The nuclear charge radii obtained with CDFT (DD-ME2, DD-PC1) model for even-even $^{192-218}$Po isotopes are compared with the experimental data [6].

Nucleus	Nuclear charge radii (fm)		
	Expt.	DD-ME2	DD-PC1
^{192}Po	5.522	5.513	5.508
^{194}Po	5.517	5.477	5.470
^{196}Po	5.514	5.486	5.480
^{198}Po	5.515	5.495	5.489
^{200}Po	5.512	5.506	5.499
^{202}Po	5.528	5.515	5.509
^{204}Po	5.538	5.525	5.518
^{206}Po	5.548	5.533	5.527
^{208}Po	5.558	5.542	5.535
^{210}Po	5.570	5.551	5.542
^{212}Po	—	5.570	5.562
^{214}Po	—	5.588	5.581
^{216}Po	5.636	5.606	5.600
^{218}Po	5.656	5.623	5.619

In summary, the ground-state properties of the even-even isotopes of Po are calculated within the framework of CDFT. The results are in good agreement with the experimental data.

Acknowledgement

This work is supported by the Department of Science and Technology, India, via the DST-INSPIRE Faculty award.

References

[1] D. Vretenar, et. al., Phy. Rep. **409**, 101 (2005).
[2] T. Nikšić, N. Paar, D. Vretenar, and P. Ring, Comp. Phys. Comm. **185**, 1808 (2014).
[3] T. Nikšić, D. Vretenar, P. Finelli, and P. Ring, Phys. Rev. C **66**, 024306 (2002).
[4] A. Karim and S. Ahmad, Phys. Rev. C **92**, 064608 (2015).
[5] M. Wang, et. al., Chin. Phys. C **41**, 030003 (2017).
[6] I. Angeli and K. Marinova, Atom. Data. Nucl. Data **99**, 69 (2013) .
[7] M. V. Stoitsov, et. al., Phys. Rev. C **68**, 054312 (2003).