A Study of Charge Radii in Si, S, Ar and Ca Nuclides within Relativistic Hartree-Fock-Bogoliubov Approximation

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Introduction

The nuclear charge radius is one of the most salient nuclear parameters that gives information about the nuclear shell model and the impact of effective interactions on nuclear structure [1]. It can be measured experimentally by methods based on the electromagnetic interaction between the nucleus and electrons or muons. One of the recent methods to determine the nuclear radius is from fusion cross section measurements at low energy [2]. The change in charge radii and other nuclear ground state and excited state parameters as a function of neutron or proton number indicate the nuclear structure effects such as, shell closures and changes in deformation [3]. We present our theoretical results for nuclear charge radius R_c as a function of neutron number N in even-even isotopes of Si, S, Ar and Ca nuclei by employing meson coupling model with DDME2 parameterizations and point coupling model with DDPC1 parameterizations with a separable pairing interaction. The theoretical computed results are reasonably reproducing the available experimental data.

Theoretical Framework

We employed Covariant Relativistic self-consistent mean field models analogous to Kohn-Sham density functional theory to construct the Nuclear Density Functionals from Lagrangian densities based on mesons exchange and point coupling models. The pairing correlations of nucleons are considered by the relativistic Hartree-Bogoliubov functional based on quasi-particle operators of Bogoliubov transformations. The nuclear energy density functionals are constructed by using meson coupling model with DDME2 parameterizations [4] and point coupling model with DDPC1 parameterizations [5] with a separable pairing interaction [6].

Results and Discussions

We present the comparison of our theoretical results with available experimental data for charge radii R_c and our results are in reasonable good agreement with experimental data [1, 8]. In Figs.(1 and 2), we present theoretical results for the charge radii R_c in fm as a function of neutron number N for the even-even nuclides of Silicon, Sulphur, Argon and Calcium. The theoretical charge radius of a nucleus can be obtained by using a relationship as [7],

$$R_c = \sqrt{R_p^2 + < r_p^2 > + \frac{N}{Z} < r_n^2 >} (fm), \quad (1)$$

where, $< r_p^2 >= 0.8750$ fm denotes the mean-square charge radius of a proton and $< r_n^2 >= -0.1161$ fm is the mean-square charge radius of neutron [7]. In Fig.(1), we observed that the value of R_c is decreasing in ^{22}Si nucleus from 3.32 fm to 3.06 fm in ^{28}Si, thereafter the magnitude of R_c is increasing in chain of isotopes of Si to maximum $R_c = 3.28$ fm in ^{44}Si. Likewise, in case of Sulphur the theoretical value of R_c in ^{26}S is decreasing from 3.37 fm to 3.23 fm in ^{30}S, thereafter, it is increasing to the maximum $R_c = 3.39$ fm in ^{46}S. It is found that the minimum value of R_c at N/Z = 14, indicates $\nu(\pi)d_{5/2}$ orbit of Shell Model spin-orbit

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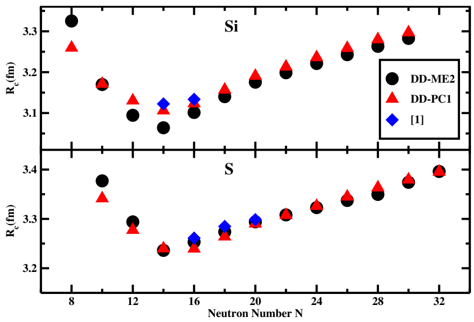

FIG. 1: (color online) The charge radius in fm plotted as a function of Neutron Number N, for the exotic nuclei of Silicon (upper panel) and Sulphur (lower panel). The theoretical estimates are computed by using relativistic nuclear density functional based on Meson Exchange model parameters DD-ME2 and Point Coupling model parameters DD-PC1. The experimental data is taken from [1].

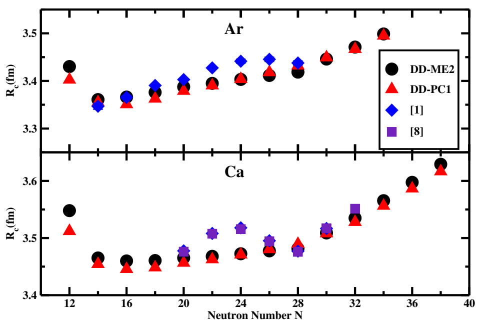

FIG. 2: (color online) The charge radius in fm plotted as a function of Neutron Number N, for the exotic nuclei of Argon (upper panel) and Calcium (lower panel). The theoretical estimates are computed by using relativistic nuclear density functional based on Meson Exchange model parameters DD-ME2 and Point Coupling model parameters DD-PC1. The experimental data is taken from [1, 8].

partner of $d_{5/2} - d_{3/2}$ orbitals is suggesting 14 as a new sub-shell closure. The available experimental data [1] of R_c is also reasonably in agreement with the theoretical calculations. In Fig.(2), we observed that the value of R_c is decreasing from 3.43 fm in ^{30}Ar nucleus to 3.36 fm in ^{32}Ar nucleus, further the magnitude of R_c is increasing in isotopes of Ar with maximum value 3.5 fm in^{52}Ar. In case of Calcium isotopes, the value of R_c is decreasing from R_c = 3.54 fm in ^{32}Ca to R_c = 3.46 fm in ^{34}Ca, thereafter the value R_c is gradually increasing in isotopes of Ca to maximum R_c = 3.63 fm in ^{58}Ca. Small magnitudes of R_c in ^{28}Si, ^{30}S, ^{32}Ar, and ^{34}Ca nuclei indicate N = 14 as a sub-shell closure. We observed a sharp increase in value of R_c after ^{48}Ca confirming the presence of shell closure in doubly magic ^{48}Ca nuclei.

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