Self-Consistent Random Phase Approximation Calculations with Skyrme Interactions

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Introduction

The Hartree-Fock (HF) method involves the two-body operator that provides a base to the many-body problem. This helps in obtaining a self-consistent solution to the problem of many-body theory in a quantum system. The skyrme effective interaction is incorporated into the Hartree-Fock method and a self-consistent solution for ground state values are obtained. The parameters of these interactions are tuned to reproduce the experimentally observed bulk properties of a number of nuclei. The excited states can then be calculated through the Random-Phase Approximation (RPA) method for any nuclei that satisfy the constraints. Now, this method provides the basis for applying this theory to nuclei with various angular momentum and parity and calculate their ground state energies as well as excited states. This provides information on the strength functions, transition densities, charge radius, etc. [1]. In this work, we have studied the ground state properties of ^{38}Ar nuclei.

Theoretical Framework

In Hartree-Fock theory, each particle in a multi-particle system is described by its own wave function. In a nucleus, it can now be considered that the average field in it emerges from an approximation connected to the Hartree-Fock method. The effective interaction utilize the self-consistent mean-field models which focus on the self-consistent determination of the atomic ground state and low-energy collective dynamics. The idea in non-relativistic HF strategy is to calculate the N-N interaction, like the zero-range (Skyrme-model [2]) to depict ground state and low energy excitation properties of the nucleus and nuclear matter. The Skyrme equation can be written as [1]

$$\begin{aligned}\langle \mathbf{P}\,|v_{12}|\,\mathbf{P}'\rangle \; &= t_0\,(1+\chi_0 P_\sigma) \\ &+\tfrac{1}{2}t_1\,(1+\chi_1 P_\sigma)\left(\mathbf{P}^2\delta(\mathbf{r})+\mathbf{P}'^2\delta(\mathbf{r})\right) \\ &+t_2\,(1+\chi_2 P_\sigma)\,\mathbf{P}'\cdot\delta(\mathbf{r})\mathbf{P} \\ &+\tfrac{1}{6}t_3\,(1+\chi_3 P_\sigma)\,\rho^\alpha(\mathbf{R})\delta(\mathbf{r}) \\ &+iW_0\,(\sigma_1+\sigma_2)\,[\mathbf{P}'\times\delta(\mathbf{r})\mathbf{P}]\ . \end{aligned} \tag{1}$$

For closed-shell nuclei, the HF core can be broken and a nucleon from the core can be raised to above Fermi level, making it feasible to treat the collective excited state as particle-hole pair linear combination states. This model is known as Random-Phase Approximation.

Results

We have studied the ground-state properties of ^{38}Ar nuclei. The nuclear interactions are incorporated through different Skyrme type interactions. Mainly SLy5, Sly4 and SKP parameter sets are used in our calculations.

We solve the radial equation of Skyrme-HF with by Numerov Algorithm where we started with an ensemble of trial wave functions. The calculations continue self-consistently until the convergence occurs. From this, all wave functions of unoccupied states are calculated. We have studied ^{38}Ar nucleus with 18 protons and 20 neutrons with angular momentum and parity of 3^-. The results obtained with different parameter sets are presented in figure 1. The results obtained with different parameter sets agree well. The number of protons gives information about the

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TABLE I: Skyrme forces used and radii

Skyrme	E/A(MeV)	r_n(fm)	r_p(fm)	r_c(fm)
SLy4	-8.629	3.348	3.335	3.429
SLy5	-8.622	3.334	3.331	3.425
SKP	-8.623	3.373	3.354	3.448

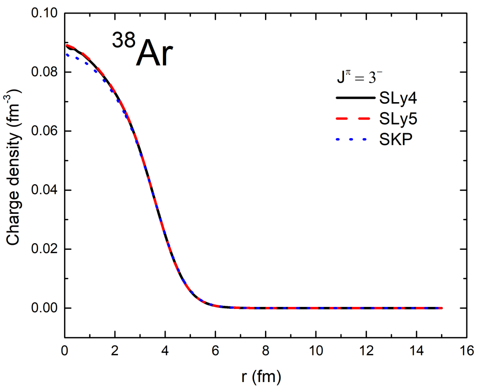

FIG. 1: Charge density of ^{38} Ar nucleus obtained with SLy4, SLy5 and SKP skyrme parameter sets.

charge density of the nucleus. So these results are similar to the proton densities of the nucleus. The charge density depends on the number of single-particle densities. These are corrected for the spurious center of mass motion. In this self-consistent calculation, the potential of proton and neutron depends on the total proton and neutron densities. The ground state charge density gives an insight into the proton distribution in the nuclei. The RMS radii were obtained to act as a constraint to the Skyrme parameters. The features of charge density can be understood in terms of its decomposition into its occupied orbitals.

The RPA calculations, which start with building an N-dimensional basis for particle-hole configuration further the construction and diagonalisation of the matrix, provides us with the excited states and the quantities associated with the transition amplitude, transition strength and transition densities.

Conclusions

The ground-state properties of ^{38}Ar are studied with the self-consistent random phase approximation calculations. These calculations will help us to get an insight into the nuclear interactions and how these interactions behave under different conditions.

References

[1] Colo, Gianluca, et. al. Comp. Phys. Comm. **184**, 142 (2013).

[2] Vautherin, D., and D. M. T. Brink. Phys. Rev. C **5**, 626 (1972).