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# Study of drip-line nuclei with a core plus multi-valence nucleon model

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**Abstract.** We study neutron- and proton-rich nuclei with an extended cluster-orbital shell model (COSM) approach, which we call Neo-COSM. The binding energies and r.m.s. radii of oxygen isotopes are reproduced. For $N = 8$ isotones, the tendency of the abrupt increase of the r.m.s. radii is qualitatively improved.

**PACS.** 21.10.-k Properties of nuclei; nuclear energy levels – 21.60.-n Nuclear structure models and methods

## 1 Introduction

New techniques and other experimental developments have widen the area of observation near the neutron drip line [1]. Exotic phenomena such as halo structures and the inversion of single-particle orbits have been observed and can be considered a new aspect of nuclear structure which differs greatly from that observed from stable nuclei. For example, the observed $^{23}$O r.m.s radius is large compared with the empirical $A^{1/3}$ scaling. An analysis using the Glauber theory suggests that $^{23}$O is not a simple $^{22}$O core plus one valence neutron structure, and the spin parity of the $^{23}$O ground state is determined to be $5/2^+$ [2] or $1/2^+$ [3]. Therefore, a theoretical study which is able to describe the halo structure of $^{23}$O is required.

## 2 Model and method

To study such a complex halo structure, we develop a method using the cluster-orbital shell model (COSM) approach and extend it so as to be able to treat the dynamics of the total system. For treating the dynamics of the core, we introduce the degrees of freedom for the width parameter $b$. In the case that we use the lowest configuration of the core wave function, the energy of the core can be calculated analytically [4]. The potential between the core and the valence nucleon (the core-$N$ potential) is a folding-type potential, which is constructed microscopically using the core density. Hence, the change in $b$ affects both the core energy and the core-$N$ potential. Therefore, the optimum value of $b$ can be determined by combining the energies of the core and core-$N$ parts. Further, to reproduce the asymptotic shape of the core-$N$ wave function, the radial part is expressed by a linear combination of the Gaussian basis functions. The motion of valence nucleons is solved by using the same technique of the stochastic variational method (SVM) [5]. We call this approach "Neo-COSM".

We use the effective nucleon-nucleon potential, Volkov No. 2 [6] with the exchange parameter $m_k = 0.58$:

$$v(r) = \sum_k V_0^{(k)} \left( w_k + m_k \hat{P}_M + b_k \hat{P}_B - h_k \hat{P}_H \right) e^{-\beta_k r^2}. \quad (1)$$

For valence nucleons, we artificially introduce non zero $h_k$ and $b_k$ parameters, as $h_k = b_k = 0.07$ to adjust the ground state energy of $^{18}$O. Note that we do not introduce any other adjustable parameters in the calculation.

## 3 Results

### 3.1 Calculation with fixed and changed b parameters

First, we perform calculations at a fixed $b$. For oxygen isotopes ($^{16}\mathrm{O} + \mathrm{X}n$ systems), calculated binding energies show good agreement to the experiments. And, the r.m.s. radii are well reproduced as shown in fig. 1. On the other hand, for $N = 8$ isotones ($^{16}\mathrm{O} + \mathrm{X}p$ systems), calculated r.m.s. radii are much smaller than the observed values in $^{18}$Ne and $^{20}$Mg, while the binding energies are well reproduced. The calculated and observed r.m.s. radii are shown in fig. 2.

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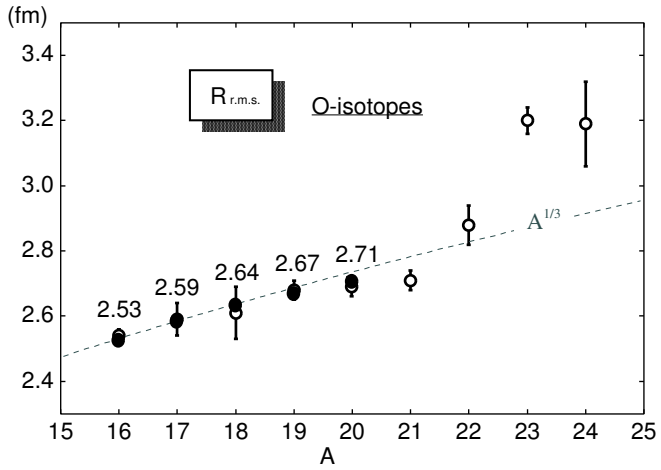


**Fig. 1.** The calculated r.m.s. radii of the oxygen isotopes with a fixed core $b$ parameter. The experimental values [1] are shown with error bars.

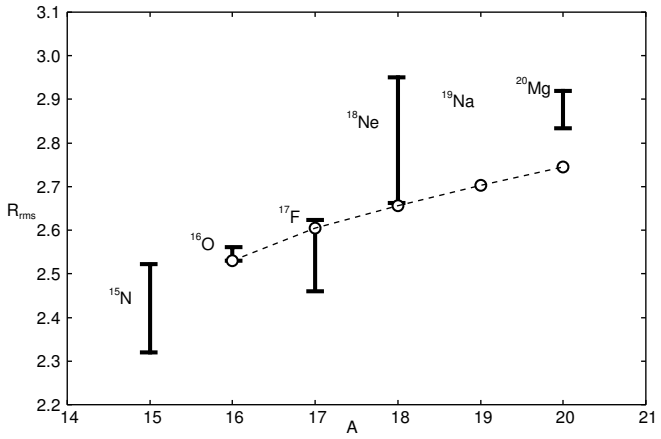


**Fig. 2.** The calculated r.m.s. radii of $N = 8$ isotones with a fixed core $b$ parameter. The experimental values [1] are shown with error bars.

The difference for the r.m.s. radii between $^{16}\mathrm{O} + \mathrm{X}n$ and $^{16}\mathrm{O}+\mathrm{X}p$ systems suggests that we need to introduce a new mechanism or improve the description of the system, which includes the improvement of the interaction.

Therefore, to reproduce the difference, we perform the Neo-COSM calculation by changing the core $b$ parameter. We calculate the energies of the core and valence nucleons and determine the optimum value of the core $b$ width parameter. The obtained r.m.s. radii are qualitatively improved from the fixed $b$ calculation, see fig. 3.

### 3.2 Comparison with the Gamow shell model

If we expand the wave function obtained by the Neo-COSM approach in terms of the components of the single-particle eigen functions, each component corresponds to the weight calculated by the Gamow shell model (GSM) [7] approach.

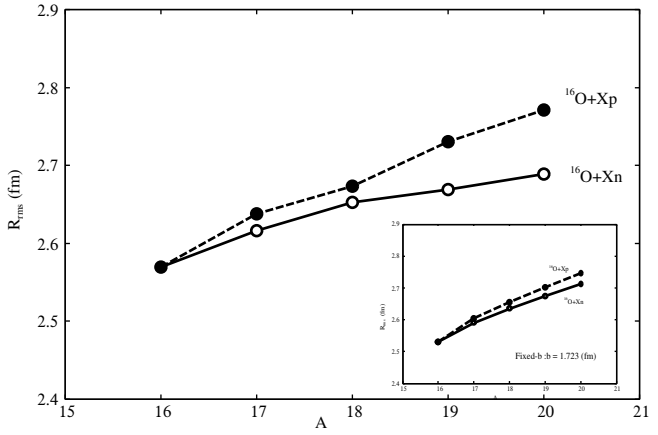


**Fig. 3.** The calculated r.m.s. radii by Neo-COSM by changing the core $b$ parameter.

We make a comparison between the Neo-COSM and GSM calculations in two systems, $^{18}$O and $^{6}$He, which are tightly bound and loosely bound (Borromean) systems, respectively.

In $^{18}$O, the Neo-COSM calculation gives almost the same result as the GSM one. A difference appears in the result of $^{6}$He. The contribution of $(0p_{3/2})^2$, which is the largest one, is the same in both calculations. But contribution of $(0p_{1/2})^2$, which is the second largest one, becomes different each other. The Neo-COSM calculation shows that the contribution of $(0p_{1/2})^2$ is almost the same as that of $(0p_{3/2})^2$. However, the contribution of $(0p_{1/2})^2$ of the GSM calculation is much smaller than that of $(0p_{3/2})^2$.

## 4 Summary

In summary, we developed a new method of studying the particular structures of the neutron- and proton-rich nuclei. The essential point of our method is that we treat the total system by introducing the degrees of freedom of the core $b$ parameter in the COSM formalism. The Neo-COSM approach showed the promising results. In the future, calculations for systems of larger number of valence nucleons are hopeful.

## References

1. A. Ozawa *et al.*, Nucl. Phys. A **691**, 559 (2001).
2. R. Kanungo *et al.*, Phys. Rev. Lett. **88**, 142502 (2002).
3. D. Cortina-Gil *et al.*, Phys. Rev. Lett. **93**, 062501 (2004).
4. T. Ando, K. Ikeda, A. Tohsaki-Suzuki, Prog. Theor. Phys. **64**, 1608 (1980).
5. V.I. Kukulin, V.M. Krasnopol'sky, J. Phys. G **3**, 795 (1977).
6. A.B. Volkov, Nucl. Phys. **74**, 33 (1965).
7. N. Michel, W. Nazarewicz, M. Płoszajczak, J. Okołowicz, Phys. Rev. C **67**, 054311 (2003).