2版

様 式 Ｃ－１９、Ｆ－１９－１、Ｚ－１９ （共通）

科学研究費助成事業　　研究成果報告書

令和　元 年　５ 月 ２３ 日現在

機関番号：１０１０１
研究種目：若手研究(B)
研究期間：2017～2018
課題番号：１７Ｋ１４２６２
研究課題名（和文）Nonlocalized cluster dynamics and multi-cluster resonance states

研究課題名（英文）Nonlocalized cluster dynamics and multi-cluster resonance states

研究代表者
周　波（ZHOU, BO）

北海道大学・高等教育推進機構・助教

研究者番号：８０７４９７５５

交付決定額（研究期間全体）：（直接経費）　　1,400,000円

研究成果の概要（和文）：原子核クラスター物理における新しい試行波動関数を提案し、重心運動の問題を解決した。新しい試行波動関数では、一粒子ガウス波束の幅とクラスター間の相関を表す相対ガウス波動関数の幅を原子核クラスター系の明示的な内部波動関数の変数として扱った。
12Cの負パリティ状態である3-と4-をシンプルなコンテナーモデルでよく描写することができ、非局在クラスター運動が二次元コンテナーモデルによって非常に明確に再現された。
11Bにおける2α + tクラスター構造が微視的なクラスターモデルによって調べられ、2α + tの閾値近傍の多くの状態で発達したクラスター構造が見つかった。

研究成果の学術的意義や社会的意義
A new picture was provided for understanding the 3alpha cluster structure for the negative-parity states of 12C. As a new proposed nuclear cluster wave function, the distortion effects of clusters in light nuclei are very likely to be investigated in a more realistic way in this new framework.

研究成果の概要（英文）：A new trial wave function is proposed for nuclear cluster physics, in which an exact solution to center-of-mass problem is given. In the new approach, the widths of the single-nucleon Gaussian wave packets and the widths of the relative Gaussian wave functions describing correlations of clusters are treated as variables in the explicit intrinsic wave function of the nuclear cluster system.
We successfully described the negative-parity 3- and 4- states of 12C in a simple container model and the nonlocalized cluster motion in the two-dimensional container was very clearly demonstrated. The 2α + t cluster structure in 11B is investigated by the microscopic cluster model. It is found that many states around the 2α + t threshold show the feature of developed clusters.

研究分野：Theoretical nuclear physics

キーワード：cluster structure　nonlocalized clustering　THSR wave function

１．研究開始当初の背景

Traditionally, the cluster states in $N\alpha$ nuclei was considered to have some kind of rigid geometric structure indicating alpha clusters make localized motion in the nucleus. In this picture, various rotational bands and deformation characters of cluster nuclei can be easily understood. In recent studies of the algebraic cluster model, the ^{12}C was further considered to have one simple geometric 3α equilateral-triangular configuration (D3h symmetry), in which the rotation-vibration spectrum including the states of J^{π} = 0^+, 2^+, 3^-, $4^{\pm}$, and 5^- were reproduced and predicted. The existence of the negative-parity states was the main support for this model, in particular, a new high spin 5^- state at 22.4 MeV in ^{12}C were observed recently and it seems to fit well to the predicted rotational band by this algebraic cluster model. Moreover, the Hoyle state in this picture was suggested to have the geometrical arrangement of the three alpha particles.

On the other hand, different from the above rigid cluster picture, some developed cluster states were proved to have gas-like character in the microscopic THSR wave function. Now, the Hoyle state was considered as one alpha condensate candidate and the 3α clusters almost occupy the (0S) orbit. Subsequently, based on the spirt of the alpha condensate, the concept of nonlocalized clustering and container picture was proposed by studying the inversion doublet bands of ^{20}Ne, in which the key step is one technique developed for dealing with the negative-parity states. Because the original design for the THSR wave function is for the alpha condensate states and the negative-parity states cannot be treated in principle. Thus, many nuclear systems were studied well in the container picture and the concept of nonlocalized clustering has been extended to more and more cluster systems. It is expected that the nonlocalized motion is the essential feature of the cluster structure in nuclei.

２．研究の目的

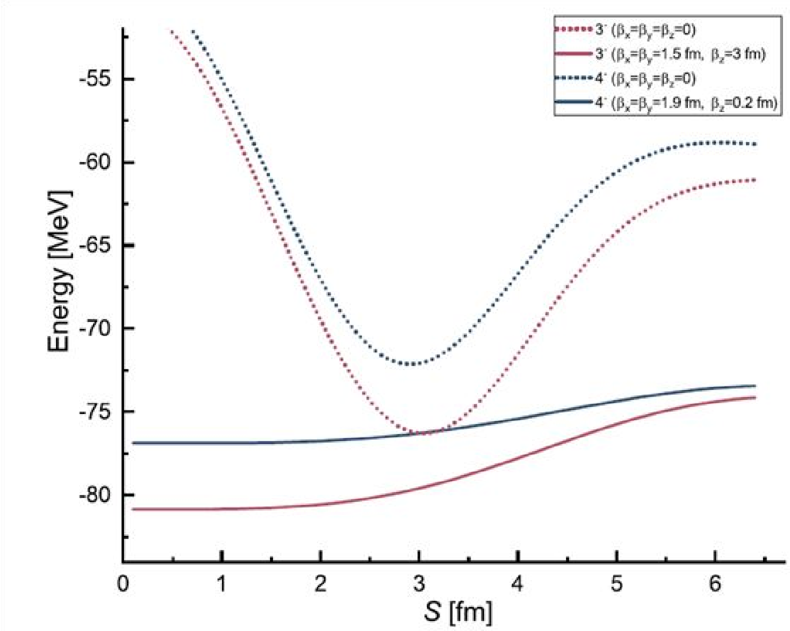
The purpose of this research is, by studying the cluster states in a new container picture, (1) to clarify the concept of nonlocalized motion is the essential feature to understand the cluster correlations in light nuclei and (2) to develop some method to deal with the different width problems in nuclear cluster physics.

３．研究の方法

Recently, we proposed a container picture for the general cluster system underlying the concept of nonlocalized clustering, which was obtained by studying the inversion doublet band of ^{20}Ne. Now, the container picture has been extended to many nuclear systems including not only the stable Nα nuclei but the neutron-rich nuclei and hyper nuclei. To deal with further the negative-parity states of ^{12}C in the container picture, we developed further the container picture by introducing some auxiliary parameters to break the parity of systems for the parity projection. This technique has been successfully used for dealing with the negative-parity states of two-cluster system. One important fact is that the introduced auxiliary parameters only play an intermediate role in the container picture. Thus, by using the auxiliary-parameter technique, the concept of nonlocalized motion of the clusters can be applied in both positive-parity and negative-parity states.

４．研究成果

The two main achievements are as follows,
(1) The first 3^- and 4^- states of ^{12}C are studied in the present container model, in which the shift parameter is introduced to break the parity symmetry for projecting out the negative-parity states. Taking the limit as the shift parameter approaches zero and by variational calculations for one deformed size parameter, the local energy minima are obtained for the 3- and 4- states.



In the above Figure, we compare the energy curves obtained from the THSR wave functions with those from the Brink cluster model. After variational calculations, it can be seen that there are two distinct pockets around 3 fm for the 3^- and 4^- states. It seems that, from this microscopic cluster model, there is a support for the rigid geometrical structure due to the non-zero inter-cluster distance parameter S. However, if we introduce the width variable of the relative wave function, i.e., the non-zero size parameter, the minimum energy points appear around S -> 0. This means the introduced S parameter, only plays an important role for treating the negative-parity states as a shift parameter in this three-cluster system. In particular, the energy curves from the THSR wave function are very flat within the range S < 2 fm. The obtained energies are almost degenerate without depending on the inter-cluster distance parameter S. Furthermore, it can be seen that the obtained energies in the container model for 3^- and 4^- states are 2.5 MeV deeper than those obtained from the Brink model. It is found that the obtained single THSR (Tohsaki-Horiuchi-Schuck-Röpke) wave functions for 3- and 4- states are 96% and 92% equivalent to the corresponding GCM wave functions, respectively. The calculated intrinsic densities further show that these negative-parity states of three clusters, different with the traditional understanding of rigid triangle structure, are found to have nonlocalized clustering structure in the two-dimensional container picture.

(2) A new trial wave function is proposed for nuclear cluster physics, in which an exact solution to the long-standing center-of-mass problem is given. In the new approach, the widths of the single-nucleon Gaussian wave packets and the widths of the relative Gaussian wave functions describing correlations of nucleons or clusters are treated as variables in the explicit intrinsic wave function of the nuclear system. As an example, this new wave function was applied to study the typical ^{20}Ne(α+^{16}O) cluster system. By removing exactly the spurious center-of-mass effect in a very simple way, the energy curve of ^{20}Ne was obtained by variational calculations with the width of the α cluster, the width of the ^{16}O cluster, and the size parameter of the nucleus. These are considered the three crucial variational variables in describing the ^{20}Ne (α+^{16}O) cluster system. This shows that the new wave function can be a very interesting new tool for studying many-body and cluster effects in nuclear physics.

５．主な発表論文等
〔雑誌論文〕（計７件）
[1]B. Zhou, Y. Funaki, H. Horiuchi, M. Kimura, Z. Ren, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, and T. Yamada, "Nonlocalized motion in a two-dimensional container of alpha particles in 3- and 4- states of 12C". Phys. Rev. C 99, 051303(R) (2019).(refereed)
[2]B. Zhou, Y.Funaki, H.Horiuchi, and A. Tohsaki, "Nonlocalized Clustering and Evolution of Cluster Structure in Nuclei",arXiv:1905.00788 (2019)(invited paper).(refereed)
[3]B. Zhou, A. Tohsaki, H. Horiuchi, and Z. Ren, "Container model for the ground and excited 0+ states in 12C", AIP Conf. Proc. 2038, 020017 (2018). (refereed)
[4]B. Zhou and M. Kimura, "2alpha+t cluster structure in 11B,Phys. Rev. C 98,054323 (2018). (refereed)
[5]B. Zhou, "New trial wave function for the nuclear cluster structure of nuclei", Prog. Theor. Exp. Phys. 2018, 041D01 (2018). (refereed)
[6]Q. Zhao, Z. Ren, M. Lyu, H. Horiuchi, Y. Funaki, G. Röpke, P. Schuck, A. Tohsaki, C. Xu, T. Yamada, and B. Zhou, "Investigation of the 9B nucleus and its cluster-nucleon correlations", Phys. Rev. C 97, 054323 (2018). (refereed)
[7]Z. Ren and B. Zhou, "Alpha-clustering effects in heavy nuclei", Front. Phys. 13, 132110 (2018). (refereed)
〔学会発表〕（計０件）

〔図書〕（計 0　件）
〔産業財産権〕
○出願状況（計０件）

名称：
発明者：
権利者：
種類：
番号：
出願年：
国内外の別：

○取得状況（計０件）

名称：
発明者：
権利者：
種類：
番号：
取得年：
国内外の別：
〔その他〕
ホームページ等
６．研究組織
(1)研究分担者
研究分担者氏名:

ローマ字氏名：

所属研究機関名：

部局名：

職名：

研究者番号（８桁）：

(2)研究協力者
研究協力者氏名：
ローマ字氏名：