A new step of microscopic cluster model

The present status of the THSR wave function

Akihiro Tohsaki

1 Research Center for Nuclear Physics, Osaka University, Osaka 567-0047, Japan
E-mail: tohsaki@rcnp.osaka-u.ac.jp

Abstract. In this talk, we present new developments concerning the cluster-gas wave function of a fully microscopic description.

1. Introduction

A whole cycle of the Oriental Zodiac has passed since we proposed a specific form of the wave function describing $\alpha$-cluster-gas-like states. Thanks to the fully microscopic description, this form of the wave function can naturally describe some ground states as well as other ordinary cluster-model states. The microscopic model of nuclei takes account of the Pauli principle correctly and is based on an effective nuclear force. We call this model wave function the THSR wave function, which comes from the names of the authors (Tohsaki, Horiuchi, Schuck, Röpke) of our first article [1]. Until now the idea has been applied to the aggregates of 2 to 5 $\alpha$-clusters. First of all, the Hoyle state of $^{12}$C has been conjectured to be a $3\alpha$ gas state which can be regarded as an $\alpha$-condensate.

The idea is characterised by the following:

(i) Some kind of container for an $\alpha$-aggregate is introduced.
(ii) The behaviour of the container is not a priori given but self-consistently determined by the Hill-Wheeler equation.
(iii) At the beginning, the container was assumed to be spherical, but then, it became possible to have it deformed. The wave function has been applied to positive parity states [2].
(iv) The competition of the attractive nuclear force and the repulsive Coulomb force around the rarefied density of the $\alpha$-gas plays an important role in guaranteeing its stability.

In the new microscopic cluster model defined by the THSR wave function one can vary the variational parameters so as to change the distances between clusters as well as the density of clusters. This enables one to reduce the number of variational parameters drastically. The $\alpha$-gas state is an excited state orthogonal to the ground one. The Hill-Wheeler equation results in a density which is about 1/3 of that of the ground state. The THSR wave function has the remarkable advantage of being constructed from $\alpha$-clusters free from the c.m. energy, which we could not achieve in a conventional cluster model written as a geometrical configuration. Unfortunately, at that moment, the container is still restricted to a kind of spheroid, which excludes the treatment of negative-parity states.
2. Present status
The idea of the container has been recently applied to systems that contain other clusters in addition to the $\alpha$-aggregate. For instance, we have already investigated the $^{16}\text{O}-\alpha$ system in a container [3]. Introducing the distance parameter between $^{16}\text{O}$ and $\alpha$, we have succeeded in estimating the negative-parity state as well as the positive-parity ones. Surprisingly enough, the stationary energy of the negative-parity state is obtained to be at the limit of zero distance. This shows that the idea of the container is more important in showing the cluster structure than that of the distance between the clusters.

The present status can be summarised as follows:

(i) The description of negative-parity states is also possible by using the THSR wave function.
(ii) The door is open to the study of a wide range of nuclear systems which can be regarded as including various kinds of clusters in a container.
(iii) The interaction between $\alpha$-aggregates can be described within the scope of the THSR wave function. The suprious c.m. coordinate is naturally removed by going back to the idea of the resonating group method which is free from he c.m. variable.
(iv) A clarification of the mathematical structure of the formalism and the development of computer facilities allow us to tackle larger nuclear systems with THSR wave functions.

The idea of the cluster density is not appropriate for the nuclear systems consisting of different kinds of clusters. At this stage, we should see the nucleon density and the mean deviation caused by cluster conformation.

3. Conclusion and remaining problem
We introduced the idea of the cluster-gas in the nuclear system, in which the complete inclusion of the Pauli principle is absolutely important in describing the cluster structure. This is because the Pauli principle is indispensable in producing the ground state and the excited states simultaneously. The distances between clusters are replaced by the nuclear container which confines nuclear clusters. It is of utmost importance that it is self-consistently determined by the Hill-Wheeler equation.

It is, however, unfortunate that we do not have a suitable effective nuclear force that reproduces the saturation properties of a wide range of nuclei.

Acknowledgments
The speaker thanks Y Funaki, B Zhou, H Horiuchi, T Yamada, G Röpke, P Schuck, Z Ren and C Xu for their good collaboration with him.

References
[1] Tohsaki A, Horiuchi H, Schuck P and Röpke G 2001 Phy. Rev. Lett. 87 192501
[2] Funaki Y et al 2003 Phys. Rev. C 67 051306
[3] Zhou B et al 2012 Phys. Rev. C 86 014301