

An Overview of the History of Cluster Conferences

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Abstract. An overview is given on the historical development of the cluster conference series which started at Bochum in 1969. I start with the discussion of the philosophy of Karl Wildermuth and then I make a review on the main subjects and topics in cluster conferences. Since the cluster dynamics is a main nuclear dynamics together with the mean-field dynamics, we see that development of the cluster conference has been along with the rises of many new subjects in nuclear physics itself. Examples of them include superheavy nuclei, nuclear astrophysics, neutron-rich nuclei, cluster-gas states and ab initio calculations. Finally I discuss that more activities in and attention to cluster physics are seen in recent days.

1. Introduction

According to the request of the organizer to me to give a short review of the history of the cluster conferences, I try to review the main subjects or topics of clustering phenomena and theories discussed in the cluster conferences since the first conference at Bochum. The list of cluster conferences is as follows:

1. Bochum, Germany (1969)
2. College Park, Maryland, United States (1975)
3. Winnipeg, Manitoba, Canada (1978)
4. Chester, United Kingdom (1984)
5. Kyoto, Japan, (1988)
6. Strasbourg, France (1994)
7. Rab, Croatia (1999)
8. Nara, Japan (2003)
9. Stratford-upon-Avon, United Kingdom (2007)
10. Debrecen, Hungary (2012)

I was absent from three conferences, Bochum, Maryland, and Strasbourg.

I first discuss the philosophy of Karl Wildermuth who started this conference series. His philosophy is based on the duality property of the shell-model wave function of the nuclear ground state and this duality character of the ground state has been recently revisited. Next I review that the development of the cluster conference has been along with the rises of many new subjects and topics in nuclear physics itself. Examples are molecular resonances, superheavy nuclei, nuclear astrophysics, fragmentation in nucleus-nucleus collisions, neutron-rich nuclei, cluster-gas states, and ab initio calculations. Finally I discuss the present status of nuclear cluster physics that more activities in and attention to cluster physics are seen in recent days.



2. Duality nature of the ground state and coexistence of cluster dynamics and mean-field dynamics

The first cluster conference at Bochum was held about 10 years after Karl Wildermuth had started his microscopic cluster model study of nuclear structure in 1958 [1]. At the year 1958, the shell model had already been well established because it was proposed about 10 years ago by Mayer and Jensen at 1949. Wildermuth aimed to discuss the cluster physics which coexists with mean-field physics. Wildermuth's cluster model was based on the duality property of the shell-model wave function of the ground state which means that the ground-state wave function can be rewritten in the form of the cluster-model wave function. A typical example is the closed-shell wave function of the ^{16}O ground state which is equivalent to $^{12}\text{C} + \alpha$ cluster-model wave function:

$$\det |(0s)^4(0p)^{12}| = c_L \mathcal{A} \left[R_{(4-L)/2,L}(r_{C-\alpha}, 3\nu) [Y_L(\hat{r}_{C-\alpha}) \phi_L(^{12}\text{C})]_{J=0} \phi(\alpha) \right] g(\mathbf{X}_G, 16\nu), \quad (1)$$

where $R_{nL}(r)$ is radial H.O. function, $g(r, \gamma) = (2\gamma/\pi)^{3/4} \exp(-\gamma r^2)$ and \mathbf{X}_G is the total center-of-mass coordinate. The duality character of ground state shell-model wave functions was known by many people who studied microscopic cluster-model wave functions in 1950's. For example, Perring and Skyrme wrote at the beginning of the abstract of their paper [2] "It is shown that it is possible to write down α -particle wave functions for the ground states of ^8Be , ^{12}C , and ^{16}O , which become, when antisymmetrized, identical with shell-model wave functions."

Wildermuth considered that the formation of cluster states is due to the activation of cluster degrees of freedom embedded in the ground state. So his philosophy can be shown as in Fig.1.

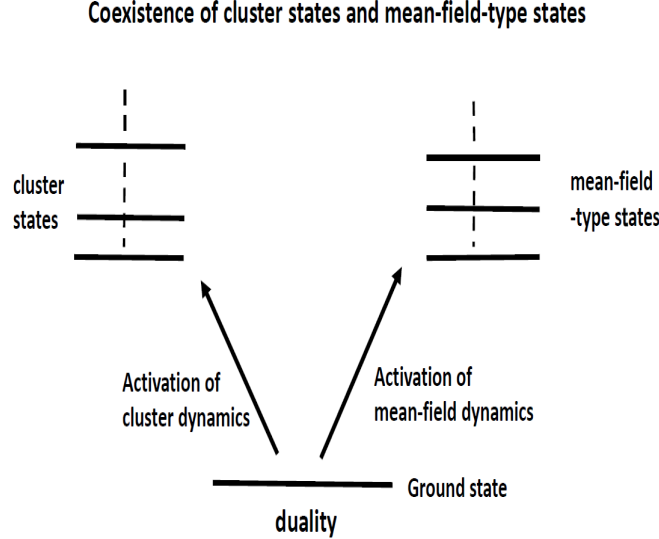


Figure 1. Coexistence of cluster states and mean-field-type states due to the duality of the ground state. Ground state is a compact shell-model state but it has degrees of freedom of clustering dynamics together with that of mean-field dynamics. Activation of cluster degrees of freedom yields cluster states while that of mean-field degrees of freedom yields mean-field-type excited states.

Recently the duality of the ground state has been revisited. It has been recognized that observed large values of $E0$ transitions between cluster states and the ground state in many nuclei can be explained very naturally by the duality property of the ground state. Large observed value means that it has the magnitude of single-particle value in spite of the fact that the cluster state has many-particle many-hole configurations in the shell-model language. But according to the Wildermuth's philosophy, the cluster state is formed by the excitation of the single degree of freedom which is the inter-cluster relative motion embedded in the ground state. Thus it is quite natural that the $E0$ transition between cluster state and the ground state has the magnitude of single-particle value.

3. Development of the cluster conference along with the rises of many new subjects in nuclear physics

At the time of Bochum conference the Brink model was already accepted as a powerful cluster model [3]. The Brink wave function has the form which is an antisymmetrized wave function of crystalline structure of clusters. When inter-cluster distance becomes zero, Brink wave function is equivalent to SU(3) shell-model wave function, which is nothing but the duality character of the shell-model wave function. As is well known, the RGM (resonating group method) calculation is now made by using the Brink wave function.

The orthogonality condition model (OCM) which has been one of the most important methods of cluster model was proposed around 1970. It is the point cluster model with orthogonalities of inter-cluster wave functions to the Pauli-forbidden states. At the second cluster conference at Maryland in 1975, D. Brink reviewed in detail in his introductory talk the results of $^{12}\text{C} + \alpha$ OCM by Y. Suzuki which is a masterpiece of the OCM approach to clustering.

The molecular resonance has been an important subject in cluster physics and many discussions were made in cluster conferences especially at Manitoba, Chester, Kyoto, and Strasbourg. At Chester conference in 1984, A. Bromley gave an introductory talk. In his talk, the Ikeda diagram was displayed for the first time in this series of cluster conferences. It was 16 years later after the publication of the diagram in 1968 whose presentation owed much on the observation of molecular resonances. An important recent study of the molecular resonance is about its possible relation with the superdeformed state. For example it was proposed that the $^{16}\text{O} + ^{16}\text{O}$ molecular states are generated as excited states of the ^{32}S superdeformed states which have the duality of cluster and mean-field structures.

At Kyoto conference in 1988 I gave an introductory talk under the session-chairmanship of K. Wildermuth. One of the subjects discussed by me was nuclear astrophysics especially "nucleosynthesis and cluster state". As is well known now, nuclear reactions of nucleosynthesis are largely influenced by the cluster states near the cluster-breakup threshold energies as seen in Ikeda diagram. Other subjects which I discussed included "cluster decay and fission" and "intermediate-energy heavy-ion collisions".

The fragmentation reaction in nucleus-nucleus collisions has been also an important subject in nuclear cluster physics. In cluster conferences especially at Strasbourg (1994), Rab (1999), Nara (2003), many discussions were made and, in the case of theoretical studies, research reports by the use of BUU (Boltzmann-Uehling-Uhlenbeck), QMD (quantum molecular dynamics), and AMD (antisymmetrized molecular dynamics) methods were presented. A very important harvest was obtained from the subject of the fragmentation reaction to the subject of nuclear structure study. It is the use of the AMD method as a novel method of nuclear structure. The AMD method enables the study of clustering without assuming the existence of clusters. The FMD (Fermionic molecular dynamics) also participated in the nuclear structure study.

The advent of beams of unstable nuclei has been extending the nuclear physics to wide region of nuclear chart beyond the stable nucleus region. This new trend of nuclear physics which started from around 1990 in a large scale immediately affected the nuclear cluster physics. Novel types of cluster structure in neutron-rich nuclei have been extensively discussed as is well known. At Rab conference in 1999 I gave a summary talk in which I gave a conjecture on clustering near neutron dripline as shown in Fig.2.

At Nara conference in 2003, two important novel subjects were discussed extensively; they are "cluster-gas states" and "ab initio calculations of cluster structure". The cluster-gas structure is a novel type of nuclear structure and can be investigated spectroscopically, which is in sharp contrast to nucleon gas. The starting point of this subject was the discovery that the Hoyle state (0_2^+) of ^{12}C has a structure of 3α condensate-like structure. As for the ab initio calculation, it is well known that in late 1990's the quantum Monte Carlo calculation reported that the exact calculation with realistic nuclear force yielded the 2α dumbbell structure for the ground band

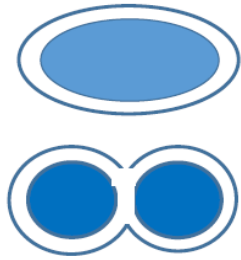


Figure 2. Possible cluster structure near neutron dripline with clusterized core surrounded by skin neutrons. Because of the constancy of thickness (≈ 1 fm) of neutron skin which is due to the incapability of selfbinding of neutrons, clusterized core can sustain more valence neutrons than ordinary deformed core. The core can have three-cluster structure.

states of ^8Be . What is remarkable in the status of present-day ab initio calculations is that an important check of the ability of an ab initio method is to examine whether the Hoyle state is well reproduced or not.

4. More activities in and attention to cluster physics

In 2008, a new series of cluster workshop was inaugurated, which is named SOTANCP (state of the art in nuclear cluster physics). The first workshop was held at Strasbourg (France) in 2008, the second was at Brussels (Belgium) in 2010, and the third was at Yokohama (Japan) in 2014. This clearly shows that in recent days we have more activities in and attention to cluster physics. I show in Fig.3 that the above trend in recent days is well reflected in the number of citations of the old paper of Ikeda diagram. [4].



Figure 3. Number of citations of the old paper of Ikeda diagram published in 1968. We can see that this paper is now cited more than before. Data is taken from Google Scholar Citations.

References

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