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EDITED AND REVIEWED BY
Jie Meng,
Peking University, China

*CORRESPONDENCE
Valdir Guimaraes,
✉ valdirg@if.usp.br

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Editorial: Clustering in light nuclei: current research, new aspects, challenges and perspectives

Valdir Guimaraes[1]*, Hidetoshi Yamaguchi[2] and Jesus Lubian Rios[3]

[1]Departamento de Física Geral, Instituto de Física, University de São Paulo, SãoPaulo, Brazil, [2]Center for Nuclear Study, The University of Tokyo, RIKEN Campus, Wako, Japan, [3]Instituto de Física, Universidade Federal Fluminense, Rio de Janeiro, Brazil

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Editorial on the Research Topic
Clustering in light nuclei: current research, new aspects, challenges and perspectives

The complexity of nuclear structure and reactions is governed by the interplay of the strong and weak nuclear forces, as well as electromagnetism interactions between the protons and neutrons, inside the nucleus. Besides these forces, it has been observed that protons and neutrons, in some light nuclei, can be arranged as cluster structures inside the nucleus. The need to understand how these forces act in the nucleus and how the cluster effects emerge from the many-body structure motivated experimental and theoretical efforts to explore the limits of nuclear existence. Understanding the transition of many-body to few-body structure is still a challenge for both theory and experiments. Several interesting phenomena have emerged from the investigations of nuclear structure near the boundaries of stability, where open quantum effects start playing a role. For instance, neutron and proton-rich nuclei, near the so-called driplines, have displayed exotic structure, such as halo and Borromean structures, where valence neutrons or protons orbit a core at large distance. The study of the structure of clusters in light nuclei has therefore become both an experimental and theoretical challenge, given the wide range of possible configurations that are very sensitive to interactions between the nucleons. The present collection of articles of this Research Topic edition deals with these issues.

Borromean configuration, where the three-body system is arranged as a core with two valence neutrons (n) connected in a such way resembling the Borromean ring, is a clear effect of cluster structure. The stability of this system is given by the connection of the three interacting bodies since the subsystems, core-n and n-n, are unbound. Although ^{9}Be, ^{6}He, and ^{11}Li are well known example of such borromean nuclei, there are other candidates as ^{14}Be. The contribution by Jones et al. presents a discussion on the different configuration of the beryllium isotopes, giving emphasis on the structure of ^{13}Be, which is unbound and a subsystem of the ^{14}Be borromean nucleus. A nice review and the results of the recent ^{12}Be(d,p)^{13}B experiment performed with ISAC Charged Particle Reaction Spectroscopy Station (IRIS) in TRIUMF is presented.

It is well known that the structure and nuclear properties of nuclei are important ingredients to define the evolution of the stars, as well to describe the violent phenomena such as supernova, kilonova and nova explosions. Knowing cluster structures in the nuclei is, thus, essential for understanding the synthesis of elements such as Carbon, Oxygen, Nitrogen, among other light elements. The impact of the cluster structure in nuclei on explosive astrophysical scenarios is described in the contribution of Bardayan. In this contribution he describes how important are the cluster resonances near the threshold to determine the reaction flow and reaction path in these environments. The also presents some indirect methods developed for these investigations. Alpha-cluster structure is the most important structure in multiple alpha nuclei such as ^{12}C, ^{16}O and ^{24}Mg, etc. The famous example of this cluster formation is the Hoyle state ($J^{\pi} = 0^{+}$) at 7.654 MeV in ^{12}C, predicted by Hoyle in 1954. The specific conditions for the formation of clusters, in light nuclei, such as the degrees of grouping and their possible configurations (linear, triangular chains, three-dimensional structures), are still subjects of study and investigation. In this Research Topic, the contribution of Kahl et al. is the one discussing the importance of alpha clustering in astrophysics. They presented studies on several nuclei, on both sides of the valley of stability and from both nuclear astrophysics and/or structural perspective. It contains a nice discussion on rotational band and on the importance of subthreshold resonances for some light nuclei. The contribution by Cha et al. presents a more specific result on alpha cluster in the ^{22}Mg nucleus. The structure of this nucleus was investigated at the low-energy RI beam separator CRIB (RIKEN) using the ^{18}Ne+α resonant scattering. Resonant scattering combined with R-matrix calculation is one of the indirect methods widely used to obtain spectroscopic information of resonances in nuclei.

The addition of neutrons in some light nuclei, such as ^{14}C and ^{16}C, has the potential to form even more complex cluster structures as the neutrons in these systems may play the role of covalent bonds (as in molecules). The contribution by Huang and Yang goes even further and analyze the importance of pure neutron cluster formation (2n, 3n and 4n) in nuclei. These clusters, composed purely of neutrons, could serve as a mini prototype of neutron matter to study the still elusive properties of the extremely neutron-rich nuclear matter.

There is a strong synergy between the configuration nature of the nuclei and the dynamics of the processes involved in the nuclear reaction. Thus, halo and cluster structures arising in light weakly bound nuclei can have strong effects on nuclear reactions. The low binding energy and a strong cluster configuration in these nuclei would produce a decoupling between the valence particle and the core nucleus, which would give rise to an increase of the breakup and/or transfer probability in the total reaction cross section. To take the effect of the breakup into account, one has to perform the continuum discretized coupled channel calculations (CDCC), accounted for in a three-body model with pairwise potentials. Although the interaction potentials between complex systems are nonlocal, due to the existence of excitation channels and antisymmetrization, usually local optical potentials are used in cluster scattering studies. The contribution by Timofeyuk and Gomez-Ramos deals with the validity of replacing nonlocal optical potentials by their local equivalents. They applied and extended the local equivalent discretized coupled channel (LECDCC) calculations to cluster scattering. In conclusion, investigation of cluster structure in light nuclei has been one of the most interesting topics in nuclear physics and some of these works have been presented in this Research Topic.

Author contributions

VG: Writing original draft, writing review and editing. HY: Writing review and editing. JL: Writing review and editing.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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