Localization and clustering in atomic nuclei

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Workshop of the *Espace de Structure et de réactions Nucléaires Théorique and Institut de Physique Nucléaire d'Orsay*

Talks: 30th-31st May, 2013

CEA, IRFU, SPhN, Orme des Merisiers, blg. 703, rooms 125-135, F-91191 Gif-sur-Yvette Cedex

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I. SCIENTIFIC CASE

Nucleonic matter displays a quantum liquid structure, but in some cases finite nuclei behave like molecules composed of clusters of protons and neutrons. The occurrence of molecular states in atomic nuclei and the formation of clusters of nucleons were already predicted in the 30's by von Weizsacker and Wheeler. Even though the description of nuclear dynamics became predominantly based on the concept of independent nucleons in a mean-field potential, a renewed interest in clustering phenomena in the 60's led to the development of dedicated theoretical methods. Numerous experimental studies have revealed a wealth of data on clustering phenomena in light nuclei [1], and modern theoretical approaches use microscopic models that fully take into account single-nucleon degrees of freedom [2, 3]. Clustering gives rise to nuclear molecules. For instance, in ^{12}C the second 0^+ state, the Hoyle state that plays a critical role in stellar nucleosynthesis, is predicted to display a three-α structure [4, 5]. The binding energy of the α-particle, formed from two protons and two neutrons, is much larger than in other light nuclei. Cluster radioactivity [6], discovered in the 80's, is another manifestation of clustering in atomic nuclei. Experimental signatures of clustering are usually indirect. Quasi-molecular resonances are probed by scattering one cluster on another, such as in the ^{12}C+^{12}C system [1], and cluster structures are also discernible in the breakup of nuclei. Evidence has been reported for the formation of clusters in ground and excited states of a number of α-conjugate nuclei, that is nuclei with an equal even number of protons and neutrons, from ^{8}Be to ^{56}Ni.

The mechanism of cluster formation in nuclei has not yet been fully understood, and the nature of cluster states is very much under debate: can clusters behave like a dilute gas of α-particles [7, 8] ? As illustrated in the well-known Ikeda diagrams [9], cluster structures are predicted to appear as excited states close to the corresponding decay threshold. The origin of cluster formation lies, however, in the effective nuclear interaction and signatures should also be present in the ground state [10, 11]. Deformation plays an important role because it removes the degeneracy of single-nucleon levels associated with spherical symmetry. Clustering is an essential feature of many-nucleon dynamics that coexists with the nuclear mean-field. Therefore, although in most cluster models the existence of such structures is assumed a priori and the corresponding effective interactions are adjusted to the binding energies and scattering phase shifts of these configurations, a fully microscopic understanding of cluster formation necessitates a more general description that encompasses both cluster and quantum liquid-drop aspects in light as well as in heavier nuclei. It is well known that deformation, as well as the vicinity of the cluster emission threshold, favor cluster formation. States close to the particle emission threshold cannot be isolated from the environment of scattering states and, therefore, cluster states at threshold belong to an open quantum system [12]. The aim of this workshop is to further explore the

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origin of localization and clustering, that is, to examine the conditions for cluster formation in ground and excited states of finite nuclei. These considerations are also relevant for the description of the crust of neutron stars, where it is known that decreasing matter density (further from the center of the star) leads to a transition from the nuclear matter phase (liquid) to a Wigner crystal, with a pasta (cluster) phase in between [13].

II. GOALS OF THE WORKSHOP

The principal goal of the proposed two-days workshop is to provide a forum for the discussion of the following issues in nuclear clustering:

1. Microscopic origin of localization in nucleonic matter and clustering in finite nuclei.
2. The respective roles of the inter-nucleon interaction, deformation effects, and the coupling to the continuum.
3. Connections and interplay between dedicated cluster models and a more general, EDF-based, description that encompasses both cluster and quantum liquid-drop aspects in light as well as in heavier nuclei.
4. Similarities and differences between quantum liquid, cluster, and crystal phases in nucleonic matter (finite nuclei) and neutron star crusts.

Useful references:

[1] W.v Oertzen, M. Freer, Y. Kanada-En'yo, Phys. Rep. 432, 43-113 (2006), and references therein.

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[11] P.-G. Reinhard, J.A. Maruhn, A.S. Umar, V.E. Oberacker, Localization in light nuclei, Phys. Rev. C 83, 034312 (2011).

[12] J. Okolowicz,M. Ploszajczak, W. Nazarewicz, On the origin of nuclear clustering, arXiV:1202.6290 (2012).

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III. LIST OF SPEAKERS

C. Beck: *Alpha Clustering in Nuclear Reactions Induced by Light Ions*
J.P. Ebran: *How atomic nuclei cluster*
M. Freer: *Experimental challenges in nuclear clustering*
M. Girod: *Clusters in nuclei with the Gogny interaction*
F. Gulminelli: *Similarities and differences between two aspects of nuclear clustering: stellar matter and nuclear fragmentation*
M. Marques: *Around and beyond the neutron dripline for Z<10*
J.A. Maruhn: *Clustering in the Skyrme-force Hartree-Fock Approach*
T. Neff: *Clusters and Halos in Structure and Reactions of light Nuclei studied in Fermionic Molecular Dynamics*
M. Ploszajczak: *Clustering in open quantum systems*
P. Schuck: *alpha condensation in nuclei*
D. Vretenar: *Energy Density Functional description of nuclear clustering*

IV. PROGRAM

Thursday, May 30th	Friday, May 31th
	9h00 J.A. Maruhn
	10h00 M. Freer
10h30 P. Schuck	
	11h00 **Break**
11h30 M. Girod	11h30 M. Marques
12h30 **Lunch**	12h30 **Lunch**
14h00 C. Beck	14h00 M. Ploszajczak
15h00 T. Neff	15h00 J.P. Ebran
16h00 **Break**	16h00 **Break**
16h30 D. Vretenar	16h30 F. Gulminelli
17h30 **end**	17h30 **End**