Evolution of Efimov States into the Continuum in Neutron Rich (2n-Core) Nuclei - A General Study

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Introduction

The nuclear three-body system, with two halo neutrons very weakly coupled to a heavy core, is studied to investigate necessary conditions for the occurrence of Efimov states. Extending the analysis to the scattering sector, we find that these states evolve into Feshbach type resonances. This behaviour is very similar to the ^{20}C nucleus in which the occurrence of Efimov states evolving into resonances in the elastic scattering of n-^{19}C system has been investigated in recent publications. This work, thereby, extends the study of the Efimov effect beyond ^{20}C, showing that ^{32}Ne and ^{38}Mg exhibit a very similar dynamical structure. These nuclei are, therefore, also candidates for probing experimentally the Efimov effect.

Structural Calculations and Search for Efimov States in ^{38}Mg and ^{32}Ne

Since the first experimental observation of Efimov states in an ultracold gas of cesium and the subsequent demonstration in other dilute atomic gases, there has been an upsurge of research in "Efimov physics" in general [1]. On the nuclear side, while there is no experimental observation yet of these states, attempts [2] have been made in recent years to identify 2n-rich halo nuclear systems that would be suitable candidates. The halo nucleus ^{20}C is an example. In recent publications we have carried out a detailed study to provide evidence for the occurrence of Efimov states in this ^{20}C(n-n-^{18}C) system. It has been shown through numerical analysis and also from analytical considerations that a non-Borromean halo nucleus like ^{20}C in which the halo neutron is supposed to be in the intruder low-lying bound state with the core, appear to be a promising candidate to have at least one Efimov state. It has generally been agreed that the only halo candidate for excited Efimov states is ^{20}C, consistent with the three-body ^{20}C energy and n-^{18}C bound state energy.

We have also extended the analysis to the scattering sector in order to address the problem of the evolution of the bound Efimov state(s) in ^{20}C with increasing n-core binding energy. For weak pair binding, study of the elastic scattering of neutron-^{19}C shows the bound Efimov states evolving into Feshbach resonances with a characteristic asymmetric structure. The evolution of such resonant structures, commonly seen in atomic and molecular systems has also been the route to their recent observation in cesium and other trimers [1]. Our analysis of the Efimov state in neutron-rich nuclei moving above threshold into the continuum is thus in close analogy to the recent observations of a similar weakening of binding and consequent disappearance as reflected in the loss rate of cold atoms from an optical trap. The left panel of Fig. 1. depicts the behaviour of the elastic scattering cross section σ_{el} vs incident energy of the neutron for two different n-core binding energies of 250 and 150 keV for a hypothetical case of very heavy core (A=100) 2-n halo nucleus. We find an asymmetric reso-

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nance structure with the centroid around 1.5 keV and width of approximately 0.5 keV. This behaviour is remarkably similar to that of n-(^{19}C) elastic scattering [2]. These results for a hypothetical nucleus with a very heavy core (mass = 100) and two valence halo neutrons show the same behaviour as that of a realistic 2-n halo nucleus, ^{20}C. This helps to reinforce the results obtained in [2] over a large mass range. While ^{20}C is by far the most promising case for experimental observation, we suggest a few others such as ^{38}Mg and ^{32}Ne [3]. For both these nuclei the 2-n separation energies are comparable to that of ^{20}C (2570 and 1970 keV, respectively) as are the energies of the n-core systems of ^{37}Mg and ^{31}Ne which are, respectively, nominally bound by 250 and 330 keV. We have carried out detailed calculations for both these nuclei assuming compact cores of ^{36}Mg and ^{30}Ne with two valence neutrons forming the halo in ^{38}Mg and ^{32}Ne, respectively. For ^{38}Mg, the second excited state disappears in the continuum around 120 keV n-core energy and the first excited state disappears around 220 keV. In ^{32}Ne, a very similar trend continues with the first excited state vanishing around 220 keV and the second just beyond 120 keV. These bound state calculations are followed by probing the scattering sector as was done in the case of the heavy core of 100 and also in the case of ^{20}C [2]. The results for the elastic scattering cross sections for n and the bound n-core systems for ^{38}Mg and ^{32}Ne are shown in the middle and right panels of Fig. 1., respectively, for n-core interaction energies of 250 and 150 keV. These are the regions where the first and the second excited states disappear and show up as resonances in the two-body continuum. The figures show the resonance structures with centroids around 1.5-1.6 keV and widths of 0.5-0.6 keV. It is to be noted that 250 keV is also the n-core separation energy (ϵ_2, one neutron separation energy for ^{37}Mg) as given in the latest mass evaluation table.

References

[1] E. Braaten and H.W. Hammer, Phys. Rep. 428, 259 (2006).

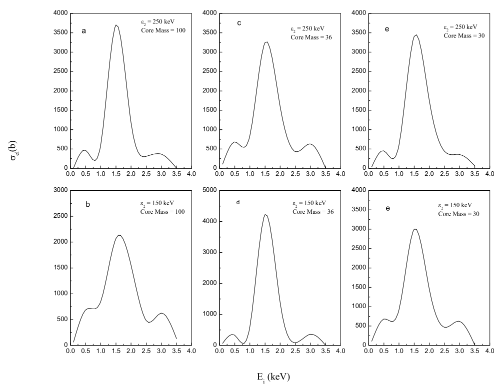

FIG. 1: Plots of elastic scattering cross sections for nuclei with a heavy core of 100 (a & b), a ^{36}Mg core (c & d), and a ^{30}Ne core (e & f) for two different n-core interaction energies of 250 keV and 150 keV.

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