S-matrix studies of resonances in the A $= 3, 4, 5, 6$ and 12 nucleon systems

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Selected resonances of the $A = 3, 4, 5, 6$ and 12 nuclei are investigated by studying the analytic properties of the S matrices at complex energies. The nuclei are described within the Resonating Group Model, assuming 2- or 3-cluster dynamics. The S-matrix poles are localized by using a direct analytic continuation method for two-cluster systems and by applying a complex scaling transformation in the case of three-cluster dynamics, respectively. Certain S-matrix poles are also extracted from R-matrix fits of experimental data by extending the S matrix, generated from the R matrix, to complex energies. The main motivation of the present work is to better understand the relation of the resonance parameters, which are determined by such a dynamical way, to the conventional resonance parameters, which are extracted from observables at real energies.

A=3: We searched for three-neutron resonances [1], which had been predicted from pion double charge exchange experiments on ^{3}He. All partial waves up to $J = 5/2$ were nonresonant except the $J^\pi = 3/2^+$ one, where we found a state at $E = 14$ MeV energy with 13 MeV width. The parameters of the mirror state in the three-proton system are $E = 15$ MeV and $\Gamma = 14$ MeV. Fig. 1 shows the localization of the three-neutron resonance in the complex scaling method. We have also begun a charge-independent R-matrix analysis of $N + d$ data at energies below the breakup threshold [2]. Preliminary indications from the analysis are that a number of S-matrix poles exist is the S-wave and P-wave states, some of which are (subthreshold) virtual resonances.

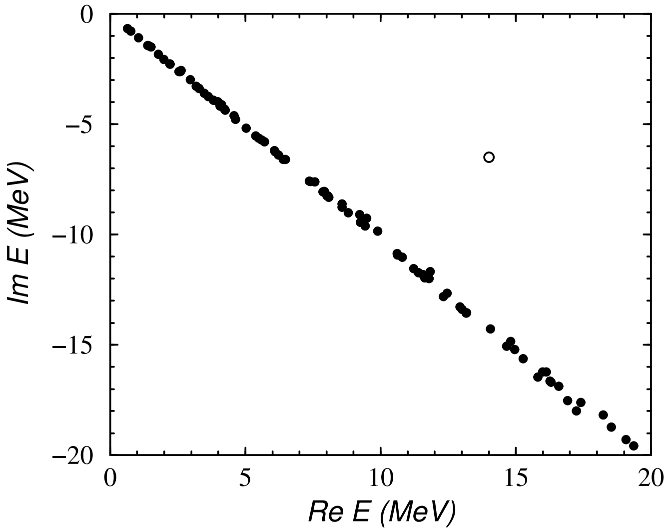

Figure 1: *Energy eigenvalues of the complex scaled Hamiltonian for* $3/2^+$ *three-neutron states. The dots are the points of the rotated discretized continuum, while the circle is a three-neutron resonance.* $E_r = \mathrm{Re}(E)$, $\Gamma = 2\,\mathrm{Im}(E)$.

A=4: We studied the 0_2^+ state of ^{4}He [3], which state is notoriously difficult to reproduce in shell-models. In a $\{^3\mathrm{H}+p, ^3\mathrm{He}+n\}$ model, which reproduced well the relevant $^1S_0$ $^3\mathrm{H}+p$ phase shift, an S-matrix pole was found corresponding to $E_r = 93$ keV and $\Gamma = 390$ keV resonance parameters. This state was also localized with $E_r = 114$ keV and $\Gamma = 392$ keV parameters in an S matrix that was constructed from a comprehensive R-matrix fit to the data. Both calculations agree that this is the first excited state of ^{4}He, and is a conventional resonance between the $^3\mathrm{H}+p$ and $^3\mathrm{He}+n$ thresholds.

A=5: We studied the low-energy ^{5}He and ^{5}Li resonances [4] with the aim to resolve the apparent contradiction between the experimentally recommended resonance parameters and the ones that appear, e.g., in the neutron halo studies of ^{6}He. Our complex S-matrix resonance parameters coming from an $\alpha + N$ RGM model and from an extended R-matrix model, respectively, were found to be in good agreement with each other. However, they differed from the conventional parameters, extracted from reaction cross sections at real energies. We recommended using the S-pole prescription to specify resonance parameters for all light nuclear states, especially for broad resonances.

A=6: The low-lying three-body resonances of ^{6}He, ^{6}Li, and ^{6}Be were studied in an $\alpha + N + N$ RGM model [5]. Our motivation was to confirm or refute the existence of a new type of collective excitations, the soft dipole resonance, in the neutron halo nucleus ^{6}He. We found all experimentally known three-body resonances of the $A = 6$ nuclei, but no indication for the existence of a 1^- state in ^{6}He. Thus, using one of the most comprehensive models of that nucleus, we showed that the soft dipole resonance does not exist in ^{6}He.

A=12: We studied the low-lying natural-parity three-alpha resonances in ^{12}C in order to shed light on the nature of the 0_2^+ state [6]. This state, which plays an important role in stellar nucleosynthesis, was believed to be a three-alpha resonance. However, there was no unambiguous proof to support this claim. We localized all known low-energy natural-parity states of ^{12}C by using $N - N$ forces which correctly reproduced the ^{8}Be ground state resonance. We unambiguously showed for the first time in a microscopic model, that the 0_2^+ state is really a three-alpha resonance.

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