Progress in Particle and Nuclear Physics 79 (2014) 1–56

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

Recent development of complex scaling method for many-body resonances and continua in light nuclei

Takayuki Myo[a,b,*], Yuma Kikuchi[c], Hiroshi Masui[d], Kiyoshi Katō[e]

[a] General Education, Faculty of Engineering, Osaka Institute of Technology, Osaka 535-8585, Japan
[b] Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki 567-0047, Japan
[c] Nishina Center for Accelerator-based Science, The Institute of Physical and Chemical Research (RIKEN), Wako 351-0198, Japan
[d] Information Processing Center, Kitami Institute of Technology, Kitami 090-8507, Japan
[e] Nuclear Reaction Data Centre, Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan

ARTICLE INFO

Keywords:
Complex scaling method
Resonances
Level density
Extended completeness relation
Halo nuclei

ABSTRACT

The complex scaling method (CSM) is a useful similarity transformation of the Schrödinger equation, in which bound-state spectra are not changed but continuum spectra are separated into resonant and non-resonant continuum ones. Because the asymptotic wave functions of the separated resonant states are regularized by the CSM, many-body resonances can be obtained by solving an eigenvalue problem with the L^2 basis functions. Applying this method to a system consisting of a core and valence nucleons, we investigate many-body resonant states in weakly bound nuclei very far from the stability lines. Non-resonant continuum states are also obtained with the discretized eigenvalues on the rotated branch cuts. Using these complex eigenvalues and eigenstates in CSM, we construct the extended completeness relations and Green's functions to calculate strength functions and breakup cross sections. Various kinds of theoretical calculations and comparisons with experimental data are presented.

Contents

* Corresponding author at: General Education, Faculty of Engineering, Osaka Institute of Technology, 5-16-1 Omiya Asahi-ku, Osaka 535-8585, Japan. Tel.: +81 6 6954 4340; fax: +81 6 6957 2137.
E-mail addresses: myo@ge.oit.ac.jp, takayuki.myo@oit.ac.jp (T. Myo).

http://dx.doi.org/10.1016/j.ppnp.2014.08.001
0146-6410/

1. Introduction

In the atomic nucleus, the properties of the unbound states are fundamental to the nuclear structures and reactions. The recent experimental developments in the field of unstable nuclear physics, starting from the discovery of neutron halo structure in the neutron-rich nuclei such as ^{6}He and ^{11}Li, have shown the various interesting phenomena related to the unbound states of nuclei [1,2]. In unstable nuclei, a few extra nucleons are bound to the system with small binding energies. This fact indicates that unstable nuclei can easily emit one or two nucleons with small excitation energies around a few MeV. This, in turn, implies that the position of the lowest threshold is very close to the ground state and that the coupling effect of the continuum states becomes important even in the ground state. This property of unstable nuclei is quite different from that of stable nuclei, in which the average binding energy is about 8 MeV per nucleon [3]. One of the interesting features of the unstable nuclei is their so-called Borromean nature, in which no two-body subsystem has the bound states. With this feature, the constituents of the system can have a bound state in the three-body case and the lowest threshold is of a three-body emission, not of a two-body one. This condition requires both experimental and theoretical studies of the unbound states in the subsystem. The physics of unstable nuclei is extended to the understanding of the scattering properties of the nuclei. There are many experiments to investigate the scattering states of unstable nuclei, such as the observation of new resonances in the spectroscopy, the various responses to an external Coulomb field, and the breakup reactions of an unstable nucleus as a projectile. In theory, the unified description of structures and reactions is essential to the unstable nuclear physics. The resonances embedded in the scattering states provide important information on the structures of the compound system in addition to the scattering observables such as cross sections.

Nuclear resonances are described by applying the R-matrix theory [4], which was developed by Kapur and Peierls [5], and characterized using the resonance energy and width [6]. They are often expressed by a complex energy and theoretically calculated as a pole of the S-matrix. However, it is difficult for such conventional methods to treat many-body resonances and non-resonant continuum states. Here, we refer to the states decaying into more than two-body constituents as "many-body resonances". A significant development in the treatment of resonances from two-body systems to many-body systems