Evaluation Activities at JCPRG

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Abstract

In this report, we briefly introduce some evaluation activities in Japan Charged-Particle Nuclear Reaction Data Group (JCPRG) in 2016. Evaluation as one of the important activity at JCPRG, covers the theoretical investigation of wide range of nuclear systems close to stability line, at drip-lines and beyond the drip-lines. The established theoretical approaches helps to predict new data which further purposes the demand for new experiments.

1 Introduction

Evaluation of nuclear reaction data is a diligent process of comparison, selection, renormalization and averaging of the available experimental data, complemented by theoretical calculations. Over the past few decades, theoretical approaches have encountered various challenges on different fronts mainly computaional costs. We at JCPRG [1] deals with various theoretical approaches and evaluate nuclear data used for various applications like PET (positron emission therapy) and to improve the EXFOR database, such as missing data, wrong order of data etc.

This report presents the activities on the evaluation of the nuclear data at JCPRG in 2016. The report is organized as follows: section 2 describes the nuclear octupole correlation investigated with the constraint three-dimensional Skyrme Hartree-Fock+BCS model [2, 3]. Section 3 describes the analysis of ^{6,7}Li $+n$ reactions using continuum discretized coupled channel (CDCC) method [4–6]. Section 4 presents the study of continuum excitations in the Borromean systems and the unbound 2n-systems [7–11]. Finally, section 5 presents our conclusions.

2 Nuclear octupole correlation investigated with the constraint three-dimensional Skyrme Hartree-Fock+BCS model

To understand the nuclear deformation and to evaluate theoretically the reaction cross sections using folding or Glaubeer model, we performed a systematic calculation for the ground state of over 1000 even-even nuclei. The ground states are prepared with the full self-consistent Hartree-Fock plus BCS (HF+BCS) method represented in the three-dimensional coordinate space, which can describe any deformations. A Skyrme effective interaction (SkM$*$) is employed and for the

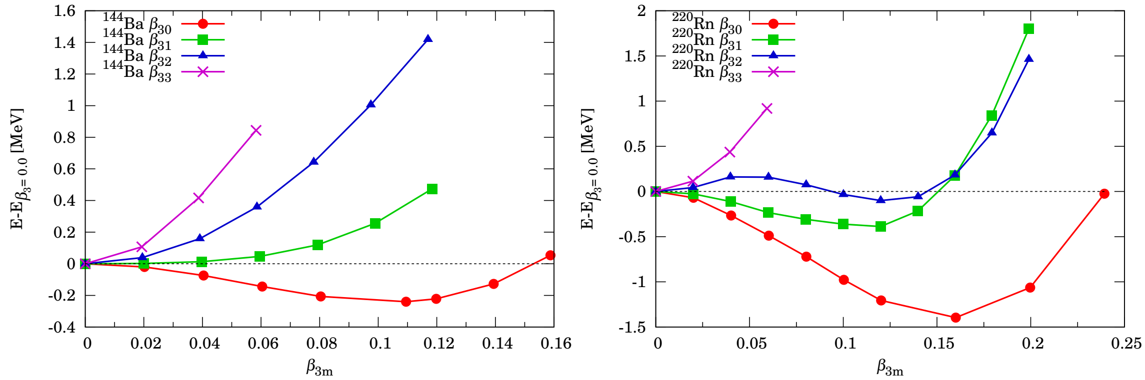

Figure 1: Multi-octupole potential energy surfaces for (left) ^{144}Ba and (right) ^{220}Rn with respect to the octupole deformation parameter $\beta_{3m}; m = 0, 1, 2, 3$.

pairing correlation the smoothed pairing constant which is deduced from the level density of the nuclear system, is applied according to same manner in Ref. [2].

The present investigation was able to show the distribution of quadrupole and octupole deformations [3]. We focus on the mass dependence of octupole correlation and evaluate the amplitude and behaviour of octupole potential energy surface. They are investigated by using the constraint Skyrme HF+BCS method with the quadratic constraint terms.

Figure 1 shows the potential energy surfaces with respect to the multi-octupole deformation $\beta_{3m}; m = 0, 1, 2, 3$ which are shown with circle, square, triangle and cross respectively, for ^{144}Ba in the left and for ^{220}Rn in the right. ^{144}Ba is one of the lighter octupole deformed nuclei which has $Z = 56$ and $N = 88$. It has a local minimum on the only β_{30} (pear shape) potential energy surface. The amplitude of correlation might be estimated as about 200 keV. ^{220}Rn is one of the heavier octupole deformed nuclei which has $Z = 86$ and $N = 134$. The local minimum appears in the not only β_{30} but also β_{31} (banana shape) and β_{32} (tetrahedral shape) potential energy surfaces. The amplitude of β_{30} octupole correlation might be about 1.5 MeV which is much larger than ^{144}Ba. Furthermore, the ^{220}Rn results indicate it has the excitation states with different ocutpole deformation. They will be useful knowledge for the isomers of heavier octupole deformed nuclei.

The study will be extended to not only nuclear structure but also nuclear reaction. We will construct a theoretical database based on these results for not only ground states but also reaction cross sections etc. The theoretical database will be able to correct the EXFOR database, such as missing data, wrong order of data and strange angler distribution.

3 Analysis of ^{6,7}Li $+n$ reactions using CDCC method

In this fiscal year, we extend the CDCC [12] analysis of the integrated elastic and inelastic scattering cross sections of n+Li with incident neutron energies below 14.1 MeV using the JLM (J.-P. Jeukenne, A. Lejeune, and C. Mahaux) which was proposed for an energy region lower than 10 MeV [13]. This is because of the fact that the various parameter sets are defined for the JLM effective nucleon-nucleon interaction in the different energy regions [13, 14]. Furthermore, we employ the normalization factors to adjust folding potentials of the JLM for the $n+$ ^{6,7}Li elastic scattering in a similar way as the previous studies [4, 5, 15]. The energy-dependent normalization factors λv and λw for real and imaginary parts, respectively, of the $n-$ ^{6,7}Li folding potentials are determined from the integrated elastic cross section data. Using the obtained normalization factors, we calculate the inelastic scattering cross sections and angular distributions and compare the results with the

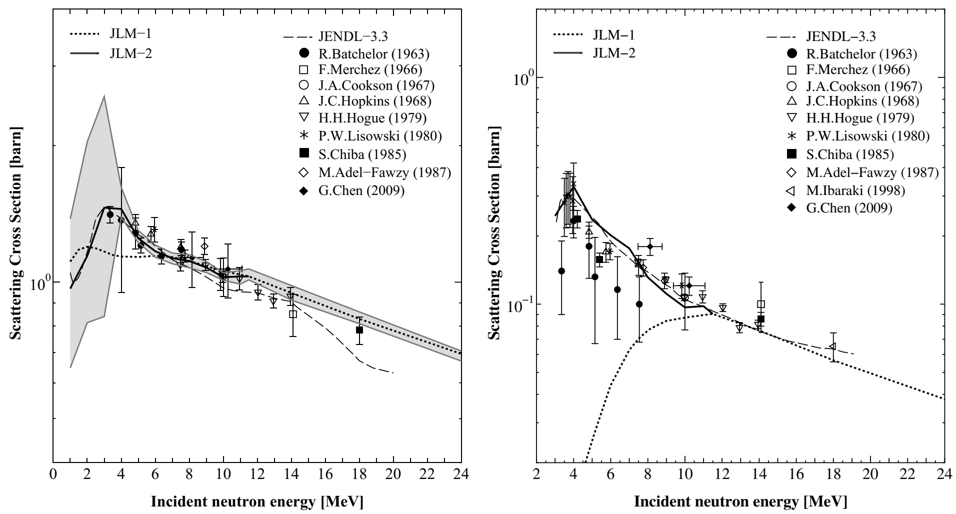

Figure 2: The integrated (left) elastic cross sections of the $n+{}^{6}$Li scattering, (Right) inelastic $n+{}^{6}$Li scattering cross sections, for the excited 3^{+} state at the excitation energy of 2.18 MeV of ^{6}Li in comparison with the evaluated data and experimental data.

experimental data without any additional parameters. The calculated results [6] are presented in Figure 2. The CDCC calculation gives a satisfactorily good agreement with the experimental data. We also purpose to extend the CDCC analysis of the scattering cross section of ^{16}O target with incident proton.First, we investigated the elastic scattering cross section of ^{16}O $+p$ reactions with ^{15}N $+p$ cluster model. The current calculated results of elastic scattering cross section data are shown to reproduce the observed data. The next purpose of our work is to calculate ^{16}O(p,pn) ^{15}O positron source, detailed information on the energy spectrum, angular distribution and production cross section. This kind of research is applicable to the PET (positron emission therapy) and nuclear reaction data fields.

4 Continuum excitations in the Borromean systems and the unbound 2n-systems

In recent years, there has been rapidly increasing interest in the study of the Borromean nuclei sitting right on the top of neutron drip-lines and two-neutron decays of unbound systems beyond the neutron drip-line. This study demands a three-body description with proper treatment of continuum, whereas the conventional shell-model assumptions are being insufficient. Recently we have developed a simple nuclear structure model for ground and continuum states of the Borromean nuclei [7–11]. Initially it is tested for ^{6}He, the states of which are built by starting from the continuum single-particle spd-states of ^{5}He. The role of different continuum components in the weakly bound nucleus ^{6}He is studied by coupling unbound spd-waves of ^{5}He by using simple pairing contact-delta interaction. Our results show that the ^{6}He ground state 0^{+} displays collective nature by taking contribution from five different oscillating continuum states,that are summed up to give an exponentially decaying bound wavefunction. In summary, the electric multipole response of ^{6}He has been investigated by using a simple structure model and the role of different configurations has been explored in each case. Fig. (3), shows our predictions for the response of ^{6}He to electromagnetic excitations of different multipolarity by showing the centroid of each state and the width on horizontal scale. We expect that our efforts might be of help to unravel the

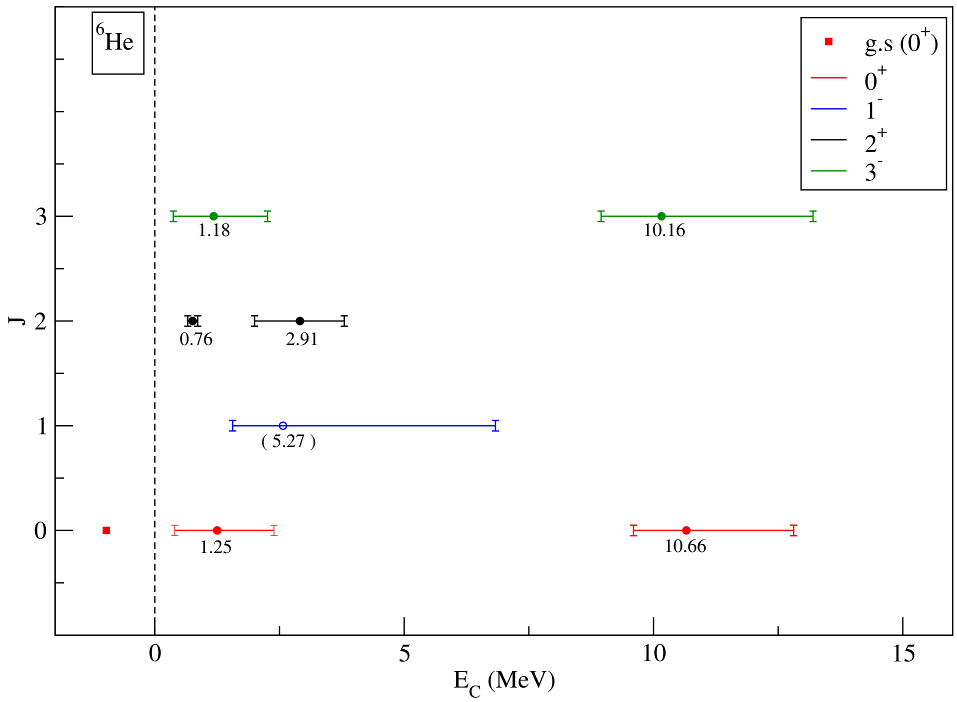

Figure 3: Schematic representation of the spectrum of ^{6}He predicted by our simple model. The parenthesis in the J $= 1^-$ response indicates the uncertainty on the position of the peak. The lines correspond to the widths [11].

complex patterns seen in the continuum spectrum of ^{6}He.
Recently in 2016 a high precision interaction cross section (σ_I) for ^{22}C, was measured on a carbon target at 235 MeV/nucleon at RIKEN [16]. This higher-precision measurement is the motivation of selecting the $2n-$ halo ^{22}C, for extending our study in this fiscal year. We have also planned the possibility of extension of our simple model from Borromean systems to the two-neutron unbound systems beyond the neutron drip-line i.e. ^{26}O [17]. This study will help to unravel the complex patterns seen in the continuum spectrum of these systems and assigning spin and parity to newly measured low lying excited states.

5 Summary

In summary, we have investigated the amplitude of octupole correlation in ^{144}Ba and ^{220}Rn for multi-octupole deformation with the constraint three-dimensional Skyrme Hartree-Fock+BCS model. For the study of ^{6,7}Li $+n$ reactions, by introducing normalization factors using CDCC, the calculated elastic and inelastic scattering cross sections gives a satisfactorily good agreement with the experimental data. For study of Borromean systems and the unbound 2n-systems, the electric multipole response of ^{6}He has been investigated by using a simple structure model and the role of different configurations has been explored in each case. These theoretical approaches are still in progress to implement the possible extensions discussed in the text to provide further new information on nuclear structure and nuclear reactions in near future.

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