Coulomb dissociation of ^{23}O within the quark-meson coupling model

R. Chatterjee[1*] and R. Shyam[2†]
[1] *Department of Physics, Indian Institute of Technology, Roorkee - 247667, INDIA and*
[2] *Theory Group, Saha Institute of Nuclear Physics,*
1/AF Bidhan Nagar, Kolkata - 700064, INDIA

Introduction

The region around the 'near drip-line' nucleus ^{23}O has been the focus of many recent studies. It has been observed, for example, that the neutron drip-line for the oxygen isotopes is located at ^{24}O and not at ^{28}O, the doubly magic nucleus that has been found to be unbound. There has also been disagreements among various authors [1, 2] on the ground state spin-parity assignment of ^{23}O ($J^{\pi} = 5/2^{+}$or $1/2^{+}$) and as to whether it is a halo nucleus or not.

Therefore, there is a need for a more rigorous theoretical investigation of ^{23}O ground state configuration and analysis of the ^{23}O breakup reaction data within a more microscopic theoretical model than has been done so far.

In this contribution we study the ground-state structure of ^{23}O within the latest version of the quark-meson coupling model (QMC-III), which is a quark-based model for nuclear matter, finite nuclei and hypernuclei [3]. The wave function describing the valence neutron-core relative motion obtained within this model, has been used to calculate the Coulomb dissociation of ^{23}O on a lead target at a beam energy of 422 MeV/nucleon [4]. The experimental neutron-core relative energy spectrum and the total one-neutron removal cross sections are well described by our calculations. The widths of the longitudinal momentum distributions (LMD) of the ^{22}O fragment are found to be broad, which do not support the formation of a neutron halo in this nucleus.

*Electronic address: rcfphfph@iitr.ernet.in
†Electronic address: radhey.shyam@saha.ac.in

Formalism

We consider a breakup reaction ($a + A \rightarrow b+c+A$), where the projectile a breaks up into fragments b (charged) and c (uncharged) in the Coulomb field of a target A. This theory [5] is formulated within the post-form finite range distorted wave Born approximation, where the electromagnetic interaction between the fragments and the target nucleus is included to all orders and the breakup contributions from the entire nonresonant continuum corresponding to all the multipoles and the relative orbital angular momenta between the fragments are taken into account. Only the full ground state wave function of the projectile, of any orbital angular momentum configuration, enters in this theory as input, thereby making it is free from the uncertainties associated with the multipole strength distributions that may exist in many of the other theories.

The ground state wave function, in our case, is obtained from the QMC-III model. It should be mentioned here that the the QMC-III model leads to a remarkably realistic Skyrme force in a non-relativistic approximation. However, unlike the non-relativistic Skyrme force based calculation, where the experimental values for the binding energy and the radii are included in the fitting procedure for determining the corresponding parameters, in QMC-III calculations these quantities are actually predicted by the model without changing any parameters. Therefore, QMC-III model contains features that make it more appealing and suitable for the description of the structure of the drip line nuclei thereby opening new vistas in the description of the structure of such nuclei.

The QMC-III model predicts a ^{22}O$(0^{+}) \otimes 2s_{1/2}\nu$ configuration for the ground state of ^{23}O, with a one neutron separation energy

(S_n) of 2.86 MeV, in close agreement with the corresponding experimental value of 2.74 MeV. We have also tried a scheme to get a valence neutron spin-parity of $5/2^+$ by filling the last neutron orbit ($2s_{1/2}$) with two neutrons. This, however, makes the ^{23}O isotope unstable in our model. Therefore, we confirm that the ground state of this nucleus is consistent with a $^{22}\mathrm{O}(0^+) \otimes 2s_{1/2}\nu$ configuration with $S_n = 2.86$ MeV.

In our breakup calculations we have also used a single particle wave function from a Woods-Saxon (WS) potential, which has been parameterized by adjusting its depth to reproduce the experimental value of S_n with the radius and diffuseness parameters of 1.15 fm and 0.5 fm, respectively.

Results and discussions

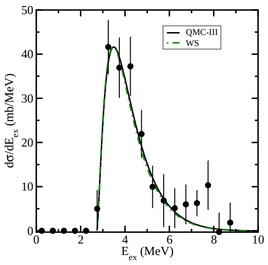

FIG. 1: The calculated excitation energy spectra in the Coulomb dissociation of ^{23}O on a Pb target at 422 MeV/u beam energy obtained with QMC-III (solid line) and WS (dashed line) wave function. Data are from Ref. [2].

In Fig. 1, the calculated energy differential cross section ($d\sigma/dE_{ex}$) is shown as a function of the excitation energy ($E_{ex} = E_{bc} + S_n$, where E_{bc} is the $n-^{22}$O relative energy). In order to compare the calculations with the data of Ref. [2], the calculated cross sections need to be convoluted with the detector response function of the experiment. Since this is not available to us we have normalized our cross sections to the peak of the experimental $d\sigma/dE_{ex}$ in each case. This may be viewed as an alternative to the convolution procedure.

In Fig. 2, we show the calculated LMD for the ^{22}O fragment emitted in the Coulomb dissociation of ^{23}O on a Pb target at 422 MeV/c beam energy, calculated with QMC-III and WS ground state wave functions. The full width at half maximum (FWHM) of the LMD is about 85 MeV/c in both cases. This value is more than a factor 2 larger than the FWHM of the LMD of the core fragment observed in reactions induced by established one-neutron halo nuclei like ^{11}Be and ^{19}C. Although there are no data available for the LMD of the ^{22}O fragment in the ^{23}O induced reaction on a heavier target like Pb, the FWHM of the LMD of ^{22}O have been measured in the ^{23}O induced breakup reaction on light targets like carbon, where they have been found to lie around 100 MeV/c. Therefore, these results almost rule out the development of a one-neutron halo structure in ^{23}O, even though the valence neutron occupies an s-orbit in this nucleus.

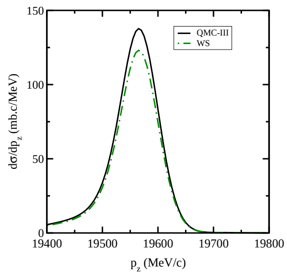

FIG. 2: The calculated longitudinal momentum distribution of ^{22}O fragment in the Coulomb dissociation of ^{23}O on a Pb target at 422 MeV/u beam energy obtained with QMC-III (solid line) and WS (dotted line) wave function.

References

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