The study of the ANC and spectroscopic factor of the ^{16}O ground state using breakup reactions

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Introduction

In nuclear astrophysics, the charged particle thermonuclear reactions occurring in the stars are difficult to be reproduced in the laboratory. This is because the energies at which the rates or cross sections of these reactions are required to be measured are much below the Coulomb barrier of the interacting nuclei. As such very low cross sections are involved complicating the process of measurement and analysis. In the direct measurement [1] of the cross section or reaction rates the laboratory measurement of the actual reaction under study is performed at a higher energy (where cross sections are higher) and then extrapolated to the desired energy by some extrapolation technique. The other alternative is to use indirect method where instead of the actual reaction a different reaction is chosen in such a way so as to extract the rate conveniently. The indirect measurements generally use standard nuclear physics experimental techniques. Some of the well known indirect methods are the Coulomb dissociation [2], ANC [3] and the Trojan Horse method. The first two methods are suitable to study capture reactions whereas the latter method is suitable for strong interactions. The ANC method generally utilizes peripheral transfer reactions to extract the spectroscopic information. Recently, breakup reactions [4] have been also used to extract the spectroscopic factor and ANC of loosely bound nuclei such as ^{8}B, ^{7}Be etc. in order to study the rates of ^{7}Be(p,γ), ^{3}He(α,γ) astrophysical reactions. The feasibility of this method lies in the peripheral nature of the reaction under study and how well the breakup process is analyzed by some appropriate theory. The Continuum Discretized Coupled Channel (CDCC) method describes breakup reactions in the most complete way by treating the coulomb and nuclear contributions to breakup on an equal footing. However, the breakup method has not been applied to compact systems. It is well known that the ^{12}C(α,γ) reaction is a very important alpha capture process in the helium burning stage of a star. The R matrix calculation of the E2 part of the capture cross section of this reaction requires the reduced alpha width and spectroscopic factors of the 2^{+} states (both unbound and sub threshold) and ground state of ^{16}O. It is possible to extract the spectroscopic information of the unbound and the ground state of ^{16}O from the breakup-CDCC method. In this work we study the ground state spectroscopic factor and ANC of ^{16}O from the breakup method using a recent sequential breakup data of ^{16}O at intermediate energies.

The breakup-CDCC method

In the breakup-CDCC method one needs a good quality breakup angular distribution data of the nucleus of interest. The ratio of the experimental to the theoretical cross section or yield is the spectroscopic factor *S*. In this work we have used the CDCC code FRESCO [5] to calculate the theoretical breakup cross section.

In the FRESCO formalism, the breakup of the projectile having a two-body structure (such as α+^{12}C for ^{16}O) is described in terms of the interactions between core (^{12}C)-target, valence (α)-target and core-valence interactions. The core-target and the valence-target interactions are described by complex (optical) potentials whereas the binding potential is considered to be real. The breakup continuum is described in terms of energy or momentum bins and is defined keeping in mind the presence of any resonances. The ANC (C^2) of a nuclear state is the normalization constant of the overlap function (overlap integral of the projectile state of interest (here ground state) and the product of the constituents wave functions at large radial

distance. The overlap function is a many body function and is generally approximated by the single particle wave function of the bound state with a constant defined by the square root of *S*. The normalization (b^2) of the bound state wave function is obtained at large distance as the latter can there be approximated as a Whittaker function. This gives the unique relation between C^2 and S i.e $C^2=S\,b^2$.

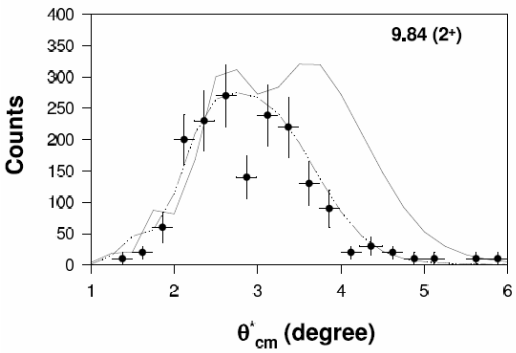

Fig.1 The comparison of FRESCO (CDCC) calculations with the data using two different a widths for the 9.84 MeV.

Results of calculation and discussions

In this work we analyze a recent ^{16}O sequential breakup data through two 2^+ unbound states of ^{16}O [6]. In fig.1 we show a comparison of our FRESCO calculation with the data for resonance breakup through the 9.84 MeV state. The calculation is sensitive to the reduced alpha width of the state. Calculations with two different widths are shown in the figure. The spectroscopic factor is evaluated with an uncertainty of about 21%. The uncertainty in the spectroscopic factor arises from the uncertainty in the theoretical cross section and error in the experimental cross section. The uncertainty in the theoretical cross section (estimated 19% in our case) is estimated from a variation of the geometrical factors (radius and diffuseness) of the core-valence binding potential. In earlier calculations for ^{8}B [4] the Glauber model calculations show a much larger uncertainty. This has been the problem with also with DWBA calculations while extracting spectroscopic factor from transfer reactions. In fig.2 we study the peripheral aspect of resonance breakup. It has been pointed out by earlier studies that resonance breakup is not peripheral in nature. However we see from figure 2 that resonance breakup in the present case has a substantial contribution from the peripheral region.

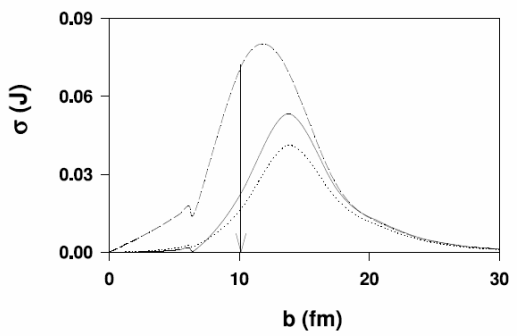

Fig. 2 Peripheral aspect of ^{16}O resonance breakup (FRESCO calculations). The touching radius (10.1 fm) is shown by an arrow.

Calculations with different width and binding potentials (Woods Saxon and Gaussian) are shown. The single particle ANC (*b*) is evaluated by comparing the single particle wave function with the Whittaker function. The ANC extracted in the present case is not very stable with respect to variation in b, probably due to the contribution from the non-peripheral region.

Conclusions

We have studied the CDCC-ANC method in relation to the breakup of a compact nucleus ^{16}O. The method seems to have a smaller uncertainty in the spectroscopic factor than from other models. The ground state ANC is however not stable due to the non-peripheral contributions in the breakup reaction analyzed in our case.

References

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