Coulomb dissociation of ^{15}C and the neutron capture cross section of ^{14}C

P. Banerjee[1],* R. Chatterjee[2], and R. Shyam[3]
[1] Department of Physics, Presidency College, 86/1 College Street, Kolkata -700 073
[2] Department of Physics, Indian Institute of Technology, Roorkee -247 667 and
[3] Theory Group, Saha Institute of Nuclear Physics, Kolkata - 700064

I. INTRODUCTION

A lot of interest has been generated in the ground state structure of ^{15}C as it has a moderate sized neutron halo with a neutron separation energy of 1.218 MeV. Coulomb dissociation experiments, both at medium (RIKEN [1]) and high (GSI [2]) beam energies have been performed to investigate the structure of ^{15}C. However, there appears to be a disagreement over the peak positions in the relative energy spectra obtained in the above mentioned experiments. This is something interesting because the relative energy spectra calculated for the breakup process should, in principle, be independent of the incident beam energy.

Furthermore, the neutron capture by ^{14}C is an important ingredient in several nucleosynthesis processes. The ^{14}C(n,γ)^{15}C radiative capture reaction (i) is the slowest in the neutron induced CNO cycle that takes places in AGB stars and thus controls the cycle, (ii) it has impact on the abundances of the heavy elements produced by inhomogeneous big bang models, and (iii) it modifies the abundances resulting from the r-process in massive Type II supernovae.

The purpose of this work is thus twofold. Firstly, we wish to calculate the Coulomb breakup of ^{15}C on a Pb target and compare our results with the most recent data [1]. Our calculation would thus be an arbitrator for the seemingly different relative energy spectra obtained from experiments in Refs. [1, 2]. Secondly, we wish to use the power of the Coulomb dissociation method as an indirect tool in nuclear astrophysics and calculate the ^{14}C(n,γ)^{15}C radiative capture reaction.

II. FORMALISM

Recently, we have presented a theory to describe the Coulomb breakup reactions of one-nucleon halo nuclei within the finite range post-form DWBA (FRDWBA) framework, where the breakup contributions from the entire continuum corresponding to all the multipoles and the relative orbital angular momenta between the valence nucleon and the core fragment are included [3]. Full ground state wave function of the projectile, of any angular momentum structure, enters as an input to this theory. In the particular case of neutron halo breakup reactions we can factorise the breakup transition amplitude into two parts - one containing the structure information and the other containing the dynamics part, which can be analytically expressed in terms of the bremmstrahlung integral.

Consider the reaction $a+t \rightarrow b+c+t$, where the projectile a breaks up into fragments b (charged) and c (uncharged) in the Coulomb field of a target t.

The relative energy spectra for the reaction is given by

$$\frac{d\sigma}{dE_{rel}} = \int_{\Omega_{bc},\Omega_{at}} d\Omega_{bc} d\Omega_{at} \times \left\{ \sum_{lm} \frac{1}{(2l+1)} |\beta_{lm}|^2 \right\} \times \frac{2\pi}{\hbar v_{at}} \frac{\mu_{bc}\mu_{at} p_{bc} p_{at}}{h^6} , \quad (1)$$

*Electronic address: banprabir@gmail.com

where v_{at} is the a–t relative velocity in the entrance channel, Ω_{bc} and Ω_{at} are solid angles, μ_{bc} and μ_{at} are reduced masses, and p_{bc} and p_{at} are appropriate linear momenta corresponding to the b–c and a–t systems, respectively. β_{lm} is the reduced amplitude in the FRDWBA.

III. RESULTS

^{15}C has a relatively large value for the one-neutron separation energy (1.218 MeV) and a ground state spin-parity of $1/2^+$. We consider it primarily to be a $1s_{1/2}$ neutron coupled to a ^{14}C (0^+) core and the single particle relative motion wave function for the neutron is constructed by assuming a Woods-Saxon interaction between the valence neutron and the charged core whose depth (for fixed values of the radius and diffuseness parameters) is adjusted to reproduce the binding energy. The depth turns out to be 57.21 MeV for a radius and diffuseness parameters of 1.2 fm and 0.5 fm, respectively. We also tried using a spin-orbit term in our potential [4], but then it seems it have no effect on the calculated relative energy spectra.

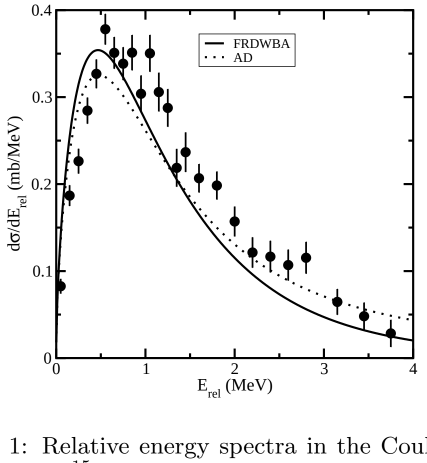

FIG. 1: Relative energy spectra in the Coulomb breakup of ^{15}C on Pb target at 68 MeV/A beam energy. Solid and dotted lines show FRDWBA and Adiabatic model (AD) calculations. Data are from [1].

In Fig. 1, we show results for the relative energy spectra in the Coulomb breakup of ^{15}C on a Pb target at 68 MeV/A beam energy. Solid and dotted lines show FRDWBA and Adiabatic model (AD) calculations. The center of mass angles in both these calculations have been integrated from $0° - 180°$.

It is interesing to note that for the RIKEN experiment (beam energy = 68 MeV/A) the peak of the relative energy spectra comes at a relative energy of 0.6 MeV or a little more. In the GSI experiment (beam energy = 500-600 MeV/A) the peak of the excitation energy spectra comes for excitation energy = 1.6 MeV. So if we subtract the one-neutron separation energy (= 1.2 MeV) of ^{15}C from this excitation energy, we would correspondingly expect the relative energy spectra to peak at the relative energy of 0.4 MeV. This peak position is clearly different from the experiment at 68MeV/A. However it is in agreement with what our calculations suggest.

Studies of Coulomb dissociation are also of great interest due to their application in determining the cross sections of astrophysically interesting radiative capture reactions, which forms the second part of our work. We will relate the cross section in Eq. (1) to the photodissociation cross section, $\sigma^a_{\gamma n}$, for the reaction $a + \gamma \rightarrow b + c$ and then calculate the the radiative capture cross section, $\sigma^a_{n\gamma}$, for the reaction, $b + c \rightarrow a + \gamma$, by the principle of detailed balance. For more details of the theory one is referred to Ref. [5].

References

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