Analysis of Coulomb breakup of ^{15}C for astrophysical applications

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The well known ways responsible for production of energy in stars are Hydrogen and Carbon-Nitrogen-Oxygen (CNO) cycles. During the hydrogen cycle mainly the four protons transform into an α -particle with a certain amount of energy. But at high temperature if the gases which originate the star contain heavier elements then Carbon-Nitrogen-Oxygen cycle plays more important role in stars. In this ,^{14}C(n, γ)^{15}C(β^-)^{15}N(n, γ)^{16}N(β^-)^{16}O(n, γ)^{17}O(n, α)^{14}C, cycle the neutron capture reaction ^{14}C(n, γ)^{15}C needs sincere attention because of its considerable contribution in the synthesis of heavier elements[1, 2]. But for obtaining the considerable information regarding ^{14}C(n, γ)^{15}C reaction one has to made precise measurement of the rate of this reaction.

Secondly the nuclear capture reactions play major role in defining our universe and the primary goal in nuclear astrophysics is to determine the rates of different capture reactions which is essentially needed for better understanding of the evolution of stellar system. For the purpose the rate of such reactions is to be measured directly inside the laboratory. However the capture reactions often involve a radioactive target which makes the measurement quit difficult or even it seems impossible due to unattained physical condition like high temperature and density in the laboratory.

Hence during the few last decades the techniques have been developed for determining the rates of capture reactions through indirect methods [3]. The Coulomb dissociation is one of the method which is being used frequently for obtaining the capture cross section pertaining to nuclear astrophysical problems. But this method will be useful only if the higher order effects are under control. Therefore prior to exploit this channel for obtaining reliable information regarding astrophysical problems one has to estimate the relative share of higher order terms especially of electric quadrupole (E2) and dipole-quadrupole interference (E1-E2) terms in Coulomb breakup process[4,5].

As far as theoretical formulism is concerned, in the energy range of interest the eikonal approximation is the most appropriate method for describing the Coulomb breakup process. In this formulism the final expressions for calculating the integrated cross section and cross section differential in relative energy of core fragments emerging out from the Coulomb breakup of ^{15}C on Pb target, corresponding to E1(electric dipole), E2 and E1-E2 electric transitions may be expressed as [6-8]

$$\frac{d\sigma_{E1}}{dE_{rel}} = \int_0^{\pi} \frac{4Z_t^2 (Z_1^{eff})^2 \alpha^2}{3\gamma^2\beta^2} \xi^2 I_{011}^2$$
$$\left[(K_1^2 - K_0^2)\left\{(1+2P_2) - (1-P_2)\gamma^2\right\} + \frac{2}{\xi} K_0 K_1 (1-P_2)\gamma^2 \right]$$
$$\times \sqrt{2E_{rel}\left(\frac{\mu}{\hbar^2}\right)^3} \;\sin\theta\, d\theta .$$

$$\frac{d\sigma_{E2}}{dE_{rel}} = \int_{|q_z|}^{\infty} \frac{Z_t^2 (Z_2^{eff})^2 \alpha^2}{105\gamma^2\beta^4} \left(\frac{\omega}{c}\right)^2 \xi^2 I_{022}^2$$
$$\left[\frac{4}{\xi^2} K_1^2 (7 - 10P_2 + 3P_4) + \right.$$
$$(K_1^2 - K_0^2)(28 + 20P_2 + 57P_4) + (7 + 5P_2 - 12P_4)\gamma^2 (2-\beta^2)^2$$
$$\left. \times \left(\frac{2}{\xi} K_0 K_1 - (K_1^2 - K_0^2) \right) \right] \times \sqrt{2E_{rel}\left(\frac{\mu}{\hbar^2}\right)^3} \;\sin\theta\, d\theta$$

$$\frac{d\sigma_{E1-E2}}{dE_{rel}} = \int_{|q_z|}^{\infty} \frac{4Z_t^2 Z_1^{eff} Z_2^{eff} \alpha^2}{5\gamma^2\beta^3} \left(\frac{\omega}{c}\right) \xi^2 I_{011} I_{022}$$
$$\times \left[(K_1^2 - K_0^2)(2P_1 + 3P_3) + [\frac{2}{\xi} K_0 K_1 - (K_1^2 - K_0^2)](P_1 - P_3)\gamma^2 (2-\beta^2) \right]$$
$$\times \sqrt{2E_{rel}\left(\frac{\mu}{\hbar^2}\right)^3} \;\sin\theta\, d\theta .$$

respectively. Here K_0, K_1, P_1, P_2 and ξ are represents the modified Bessel functions with order one and two, Legendre polynomial of order one and two with argument $\cos\theta$ and adiabaticity parameter given as $\xi = \frac{\omega R}{\gamma v}$.

For numerical calculations the ingredients required is the radial part of the ground state wave function of the projectile which strongly depends on the orbital occupancy of valence neutron. Here we have consider the dominating spin coupling, ^{14}C(0^+)$\otimes$2$s_{1/2}$, configuration with spectroscopic factor 0.91 for ^{15}C, wherein ^{14}C is attached with a s-orbital valence neutron[9]. The radial part of the wave function corresponding to this configuration is constructed by solving the radial part of Schrodinger equation in Woods-Saxon potential. The range [2.34fm] and diffuseness [0.60fm] parameters of the potential are tuned locally while the depth [76MeV] is adjusted to reproduce ground state binding energy of valence neutron [1.218MeV]. Now the wave function so obtained is used for calculating the integrated Coulomb breakup cross section and cross section differential in relative energy of core fragments. The values of integrated Coulomb breakup cross sections calculated for breakup of ^{15}C on Pb target at 550AMeV as the incident beam energy corresponding to electric dipole and quadrupole transitions are 254 mb and 2.2 mb respectively. It shows that the contribution of *E*2 transition in total cross section is very small (approximately 0.9% of *E*1). While the total Coulomb breakup cross section is remains insensitive towards the *E*1-*E*2 interference term [8]. Therefore in order to predict the contribution of interference terms in Coulomb breakup process, the cross section differential in relative energy of core fragments has also been calculated. Figure 1 depicts the relative energy spectrum for the ^{208}Pb(^{15}C, ^{14}C + n)^{208}Pb reaction at 68AMeV beam energy along with the data taken from ref [9]. The different curves shown are depicts the contribution of *E*1 (dotted), *E*2 (dashed), *E*1-*E*2(dot-dashed) transitions while the solid curve was obtained by the inclusion of effects of quadrupole and dipole-quadrupole terms in *E*1 contribution .

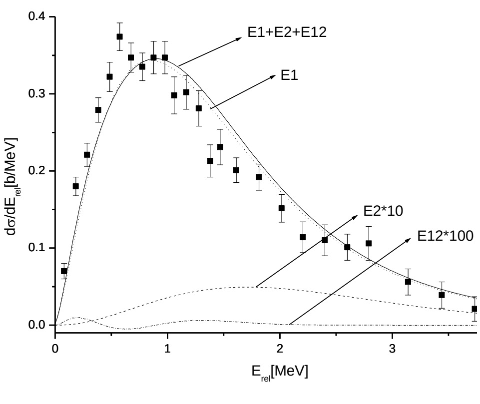

Fig.1. Relative energy spectrum of ^{14}C and n emerging from the Coulomb breakup of ^{15}C on Pb target at 68 MeV/u beam energy corresponding to electric dipole (*E*1)(dotted line), quadrupole (*E*2)(dashed line), electric dipole quadrupole interference terms (*E*1-E2)(dash-dotted line) and combination of all these(solid line). Data points are taken from ref [9].

The results corresponding to *E*2 and *E*1-*E*2 terms are multiplied by a factor of 10 and 100 respectively for the sake of clarity. It has been found that the inclusion of *E*2 and *E*1-*E*2 terms slightly increases the peak height while the shape of spectrum remains the same.

In summary, the electric quadrupole term shows their presence in integrated Coulomb breakup cross section however it is very small (0.9% of *E*1. The inclusion of *E*2 and *E*1-*E*2 terms just increases the peak height of the relative energy spectrum. Hence it seems that the contribution of *E*2 and *E*1-*E*2 terms in the Coulomb breakup of ^{15}C is very small and this mechanism may be used undoubtedly for investigating astrophysical problems involving ^{15}C.

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