Measurement of cross sections and S factors for d(p,γ)^{3}He at astrophysically relevant energies

M. Dhibar[1], G. Anil Kumar[1], I. Mazumdar[2,*] A. K. Rhine Kumar[2], S. M. Patel[2], P. B. Chavan[2], C. D. Bagdia[2], K. V. Thulasi Ram[2], W. A. Fernandes[2], and L. C. Trivedi[2]
[1]Department of Physics, Indian Institute of Technology Roorkee, Uttarakhand - 247 667, INDIA and
[2]Deptartment of Nuclear and Atomic Physics,
Tata Institute of Fundamental Research, Mumbai - 400005, INDIA

Introduction

Low energy proton-deuteron radiative capture reaction has astrophysical importance to understand the stellar evolution process and big-bang nucleosynthesis model[1, 2]. In the low mass star like Sun, the main source of energy production is proton-proton chain (pp-chain) as more than 98% energy is produced via this chain. Among all reactions happening inside the pp-chain process, *pd* reaction is the key reaction for the net energy production. The *pd* reaction and the other chain reactions inside the pp-process are the doorsteps, for the production of the light nuclei. The study of pd reaction is also important to estimate D/H abundance ratio in order to understand the big bang nucleosynthesis model [3]. In the present work, we report our measurements of cross-section and S-factors for d(p,γ)^{3}He reaction at astrophysically relevant energies. The cross-section is defined in terms of S-factor, S_{cm} as follows [1]

$$\sigma_{cm} = \frac{S_{cm}e^{-2\pi\eta}}{E_{cm}} \quad (1)$$

where $2\pi\eta = 31.29Z_1Z_2(\frac{\mu}{E})^{1/2}$ and η is the Sommerfeld parameter. μ is the reduced mass of the system.

Experimental Details

We have carried out the experiment using 14.5 GHz 300 W ECR based low energy ion-accelerator (ECRIA) at DNAP, TIFR [4]. The minimum extraction voltage of the accelerator is 30 kV and the voltage of the deck can be raised up to 400 kV to accelerate the ion further. The incident proton beam was accelerated at 100, 175 and 250 keV by the accelerator. The proton beam was allowed to fall on a deuterated polyethylene (CD_2) target with an areal density $\sim 10^{17}$atoms/cm^2. The γ-rays with energy $E_{cm} = E_\gamma + Q$ (5.493MeV) produced from the reaction were detected using a large volume cylindrical ($3.5'' \times 6''$) LaBr$_3$(Ce) detector The detailed studies of low to high energy gamma response of the detector were reported in our earlier paper [5].The total cross section can be written as

$$\sigma_{cm} = \frac{Yield}{n_1n_2(\epsilon d\Omega)} \quad (2)$$

where n_1 is areal density of the target, n_2 is number of incident protons and $(\epsilon d\Omega)$ is intrinsic photo-peak efficiency times solid angle subtended by the detector.

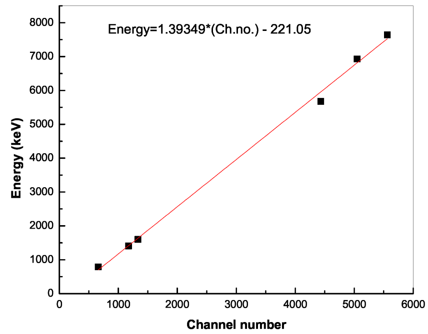

FIG. 1: Energy calibration curve.

*Electronic address: indra@tifr.res.in

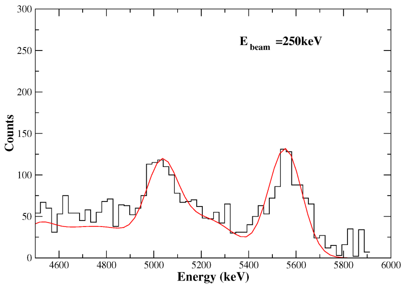

FIG. 2: A typical spectrum for captured d(p,γ)^{3}He γ-ray at E_p = 250 keV.

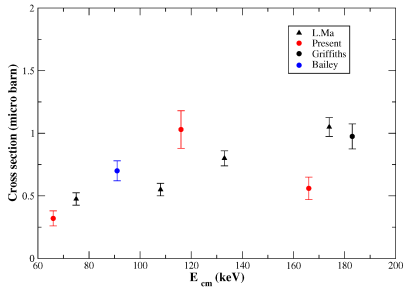

FIG. 3: Plot of cross-section vs E_{cm}.

Results and Discussion

Here we present some preliminary results of the measurements of d(p,γ)^{3}He reaction. Table-1 show the capture gamma energies corresponding to the incident proton energy.

Fig.1 shows energy calibration plot obtained using calibrated gamma sources of ^{137}Cs, ^{60}Co, Am-Be and also using 5.559 MeV γ-ray produced from the *pd* reaction. The figure clearly shows an excellent linearity. GEANT4 simulations [6] were used in order to calculate efficiencies. Fig.2 shows the measured and

TABLE I: Captured gamma energies corresponding to the three beam energies.

E_p (keV)	$E_{cm} = (2/3)E_p$ (keV)	$E_\gamma = E_{cm} + Q$ (keV)
250	166.66	5.659
175	116.66	5.609
100	66.66	5.559

simulated capture γ-ray spectrum for E_p = 250 keV. Fig.3. presents our measured cross-sections at three different energies along with the other data taken from literature [7–9]. The results of measurements and simulations will be presented and discussed in detail.

References

[1] C. Rolfs and W. S. Rodney, Cauldrons in the Cosmos (The University of Chicago Press, Chicago, 1988).
[2] K.M. Burbidge *et al.*, Rev. Mod. Phys. **29**, 4 (1952).
[3] D. Tytler *et al.*, Nature (London) **381**, 207 (1996).
[4] Aditya Agnihotri *et al.*, Phys. Scr. T **144**, 014038 (2011).
[5] I. Mazumdar *et al.*, Nucl. Instr. Meth. A **705**, 82 (2013).
[6] http://geant4.cern.ch/.
[7] L. Ma.*et al.*, Phys. Rev. C **55**, 2 (1997).
[8] G.M. Balliey *et al.*, Can. J. Phys. **48**, 3059 (1963) .
[9] G.M. Griffiths *et al.*, Can. J. Phys. **41**, 724 (1963) .