Lifetime of the 6792 keV state in ^{15}O

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Introduction

Being the slowest process of the CNO cycle, study of the ^{14}N(p, γ)^{15}O (Q = 7297 keV) capture reaction is of high astrophysical interest [1]. This reaction plays an important role to regulate the rate of energy production for main sequence stars with M>1.5M$_{solar.}$ This study is also important for detailed understanding of the neutrino spectrum of our sun.

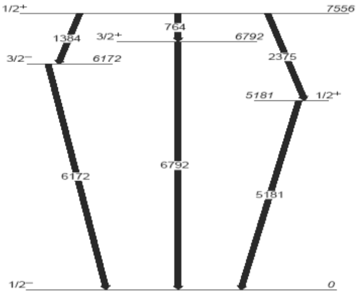

Fig 1 Partial level scheme of ^{15}O.

The reaction cross section for ^{14}N(p,γ)^{15}O reaction has been measured down to 70 keV [2]. So extrapolation is needed to get the cross section at Gamow peak (~30 keV). It has been found that the ^{14}N+p ground state capture cross-section is strongly influenced by a sub-threshold resonance (E$_{CM}$ = -507 keV), corresponding to the 3/2$^+$ state at 6792 keV in ^{15}O. Therefore, the major source of uncertainty in the extrapolation is the width of this sub-threshold resonance. Many attempts have been made to estimate either the lifetime or the width of this level [2], but the errors are still large. Most of the uncertainty arises from the estimates of stopping powers of the recoils atoms at this low energy (recoil energy is around 19-20 keV).

In the present work, we have determined a preliminary estimate of the lifetime of this state using Doppler shift attenuation method (DSAM). We have used an implanted Nitrogen target [3] on Ta backing. For these targets, the stopping power strongly depends on their composition stoichiometry, which therefore should be determined experimentally. We have used Rutherford Backscattering Spectroscopy (RBS) to measure the implanted dose and composition stoichoimetry of the target.

Experiment

The ^{14}N distribution in the Ta was investigated using the E_{CM} = 259 keV (E_{LAB} =278 keV) resonance of ^{14}N(p, γ)^{15}O to populate the 7556 keV level in ^{15}O. The proton beam (I_p=7~15 μA) was delivered from an ECR based 400 KV accelerator [4] at TIFR, Mumbai. The estimated energy spread of the ion beam was ~ 1 keV. We have used a 30% HPGe detector placed at two different angles (0^o and 90^0) with respect to the beam line to measure the gamma rays emitted from excited ^{15}O recoils. The target was produced by implanting 75 keV ^{14}N ions into a thick tantalum backing. The details of the target preparation, detector characterization and the experimental setup have been discussed in Ref. [3]. This resonance reaction also populated the 6792, 6172 and 5181 keV states (Fig 1) in ^{15}O.

The target thickness and the distribution of ^{14}N inside the backing were estimated using this resonance reaction [3]. We have estimated that the ^{14}N atoms are distributed from the surface of the Ta to a depth of 30 keV energy-loss of protons. The maximum amount of ^{14}N ions exist at a depth of ~15 keV from the surface.

Therefore, for the present study, the proton energy of E_{LAB} = 293 keV was chosen.

A 3.682 MeV ^{4}He^{++} beam delivered from 1.7 MV Pelletron accelerator at IUAC, New Delhi, was used for RBS measurement. The scattered He ions were detected by a Si surface barrier detector placed at 166^0 with respect to the beam line. The beam intensity was ~12.2 nA. The composition of the target has been obtained by comparing experimental data with SIMNRA [5] simulation. The implanted target has been found to contain 0.35 part of Ta and 0.65 part of N. The number of implanted ^{14}N atoms is 7.8×10^{17} atoms/cm^2. This corresponds to 18.1 μg/cm^2 thickness of ^{14}N in this target. These results are in good agreement with estimations made from data of previous nuclear resonance reaction measurement [3].

Results and Discussion

The experimental spectra of 1384, 6172 and 6792 keV gamma transitions, which decay from 7556, 6172 and 6792 keV levels, respectively, are fully shifted (Fig 2) in the detector placed at 0^o to the beam direction, indicating very short half-lives of the levels. The stopping time of ^{15}O inside the target is < 26 *fs*. Therefore the lifetime of these states must be shorter than 26 *fs*.

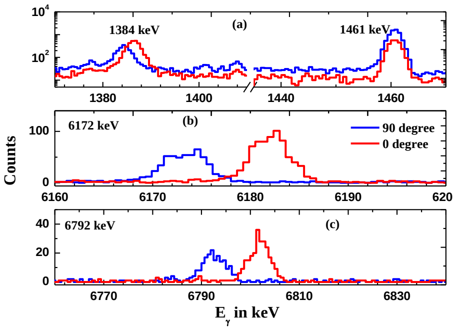

Fig 2 Relevant gammas (a) 1384 keV, (b) 6172 keV and (c) 6792 keV emitted from ^{15}O in spectra at 90^o and 0^o. The room background 1461 keV gamma shown in (a) indicates similar gains of the two spectra taken at these two angles.

In this preliminary experiment, we took data for only two angles (θ). The recoil (^{15}O) velocity (β=*v/c)* has been calculated classically. The stopping powers were obtained from SRIM [6] with density calculated by providing the measured stoichiometry of the target. We have determined the experimental F(τ) from the centroids of the shifted and un-shifted γ-peaks. The correction factor for finite opening angle of the detector indicated as *P* has been obtained from Ref. [2]. We have determined F(τ) values for the gamma transitions of our interest using the following relationship.

$$E_\gamma(\theta) = E^0_\gamma(1+\beta PF(\tau)\cos\theta)$$

Precise calibration and proper extraction of centroid positions at these angles have played an important role in the analysis. Proper estimation of nuclear stopping powers for slow moving recoils (E_{recoil}(^{15}O)~19 keV) needed special attention. Finally a preliminary estimation of the lifetimes have been obtained, which appears to be reasonable.

We have tested the sensitivity of our results with respect to the uncertainties in various input quantities. We hope our present endeavour will be helpful to design a better experiment to extract more precise lifetime for this important state.

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