Determination of the ^{59}Fe level density from proton evaporation spectra

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1. Introduction

The observation of excess ^{60}Fe in deep ocean crusts, sediments, lunar soils and galactic cosmic rays highlight the importance of accurate knowledge on the stellar nucleosynthesis (formation) and destruction of ^{60}Fe. The primary production mechanism of ^{60}Fe occurs in massive stars through the weak s-process component, and it is released into the interstellar medium during subsequent core-collapse supernova explosions. Hence, the processes that form ^{60}Fe provide an opportunity to test stellar models that describe the evolution of massive stars [1]. Stellar model calculations of astrophysical phenomenon take nuclear reaction rates as input. The rate of the reaction (^{59}Fe(n,γ), in present case) is calculated using a statistical model (SM) where nuclear level density (NLD, ρ) is an important parameter. The NLD determines the number of states accessible in the decay of the compound nucleus via a particular particle or γ-ray emission. It plays a crucial role in the radiative capture of neutrons by short-lived nucleus ^{59}Fe which is responsible for the synthesis of ^{60}Fe. Since the target nucleus ^{59}Fe is short lived (44.5 d), it is naturally unavailable, hence direct measurement of ^{59}Fe(n,γ) becomes difficult. Therefore, we have employed an indirect measurement, known as surrogate technique [2], to determine ρ for ^{59}Fe nucleus.

2. Experiment & Results

The experiment was performed by bombarding ^{7}Li beams of energies $E_{\rm lab}$ = 30 MeV, on freshly prepared self-supporting targets of ^{57}Fe (enrichment≈95%, thickness ≈ 852 μg/cm^2) at BARC-TIFR Pelletron Linac Accelerator Facility, Mumbai. The experimental setup consists of four Si strip telescopes (ΔE and E), each positioned at 17.6 cm from the target center. Two telescopes were placed at forward angles covering an angular range of $\theta_{\rm lab} = 32^\circ - 72^\circ$ to detect the projectile-like fragments (PLFs), and the other two telescopes were placed in the backward angles ($\theta_{\rm lab} = 150^\circ - 170^\circ$) for detecting the evaporated protons from the compound nucleus. Each strip telescope, having total active area of 50 × 50 mm^2, is made of 16 segmented ΔE (thickness ≈ 55 μm) and 16 segmented E detectors (thickness ≈ 1500 μm). Energy calibrations of all the ΔE and E detectors were performed using ^{229}Th alpha source that emits α particles of five different known energies in the range of 4.6 − 8.7 MeV. Figure 1 shows the energy calibrated two dimensional (2D) correlation plot of ΔE versus E$_{\rm total}$ which clearly distinguishes different PLFs, i.e., p, d and t particles. Events within the banana gate represented by the red dotted line in Fig. 1 were of our interest to generate the desired proton spectra. Similar 2D plots for the forward telescopes were also obtained where all the above particles as well as α particles were clearly observed (not shown here). By identifying the α band from the latter 2D plot and collecting proton events in coincidence with the α particles, one can confirm that the protons are emitted from the compound nucleus (CN) ^{60}Co* populated in the transfer reaction ^{57}Fe(^{7}Li,α).

By putting an 1D gate on α spectrum as shown by two dotted lines within the inset

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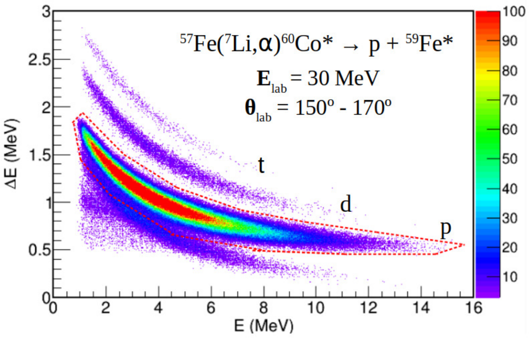

FIG. 1: A Typical energy calibrated 2D spectrum of ΔE versus E$_{\text{total}}$ (total energy) for outgoing particles in ^{7}Li + ^{57}Fe reaction at $E_{\text{lab}} = 30$ MeV, acquired at backward angle placed at $\theta_{\text{lab}} = 150^\circ - 170^\circ$ (see text).

of Fig. 2, only a narrow range of CN excitation energy (E*=25-27 MeV) was selected. The proton spectrum was obtained in coincidence with the above gate in α spectrum as well as a gate in the time correlation peak of the TDC (Time to Digital Converter) spectrum. The coincidence yield was converted to cross section in center-of-mass and the final proton evaporation spectrum is as shown in Fig. 2.

In order to determine the nuclear level density, we compared the experimentally measured proton spectrum with the ones predicted by the statistical model code CASCADE [3] by using proton energy and angular momentum dependent NLD prescription with level density parameter A/8.5 MeV^{-1}. By varying the inverse NLD parameter K=8-9.5 with step 0.5, it was found that a value of K=8.5 provides best reproduction of the measured evaporation spectra. Figure 2 shows a comparison of the measured proton spectrum with CASCADE results.

3. Summary

An exclusive experiment was carried out to measure the protons evaporated from the compound nucleus ^{60}Co populated in the transfer reaction ^{57}Fe(^{7}Li,α), in coincidence with projectilelike α particles. The evaporated proton spectra were compared with SM calculation by varying the inverse level density parameter for ^{59}Fe. The inverse NLD parameter K=8.5 MeV was obtained for ^{59}Fe. This result is very important for obtaining accurate rates of nuclear reactions involving ^{59}Fe nucleus and Maxwellian averaged cross-section (MACS) for improving the current stellar model calculations for the abundance of ^{60}Fe.

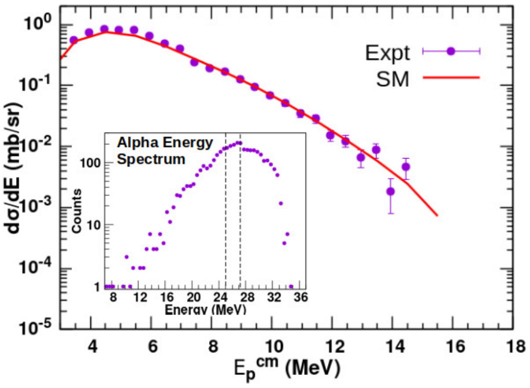

FIG. 2: Comparison of experimental cross sections for proton evaporation with the statistical model calculations. The inset picture corresponds to the α spectrum measured in a forward telescope (see text).

References

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