Indirect Experimental Techniques for Nuclear Astrophysics

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Introduction

The subject 'Nuclear Astrophysics' is an overlay area of nuclear physics and astrophysics. It integrates the information like isotopic abundances, masses, half-lives, nuclear reaction cross-section from nuclear physics with the models of stellar and other astrophysical environments. Astronomy deals with the observations of the objects of the universe. To explain and validate the observations of Astronomy one needs nuclear astrophysics, one needs to study the microscopic processes taking place inside the stars. In the stellar environment, the energy at which the majority of capture reactions occur makes it difficult or sometimes impossible to probe in the laboratory using the present experimental facility. Techniques have been developed to determine the cross-sections of this reaction and to estimate the corresponding reaction rates by the indirect method [1].

The thesis explores some of the experimental techniques of nuclear reactions as indirect methods in the study of astrophysical capture reactions. The work deals with the modeling of the astrophysical capture cross sections with relevant quantities extracted from the nuclear reaction studies. Three different astrophysical capture reactions viz. ^{22}Ne(p,γ)^{23}Na of Ne-Na cycle, ^{68}Zn(n,γ)^{69}Zn of s-process nucleosynthesis path and αα(n,γ)^{9}Be of r-process nucleosynthesis path have been studied.

Discussion

Asymptotic normalization constants of the bound states [1] of ^{23}Na were estimated from finite range DWBA analysis of ^{22}Ne(^{3}He, d)^{23}Na transfer reaction data[2]. A consistent analysis of the direct capture component of ^{22}Ne(p, γ)^{23}Na reaction was performed within the R-matrix framework, constrained with the asymptotic normalization constants of the bound states of ^{23}Na obtained from the transfer reaction calculation[2]. The contribution of capture through the sub-threshold resonance at 8664 keV excitation in the total capture to the ground state of ^{23}Na was also determined shown in **Fig.1**.

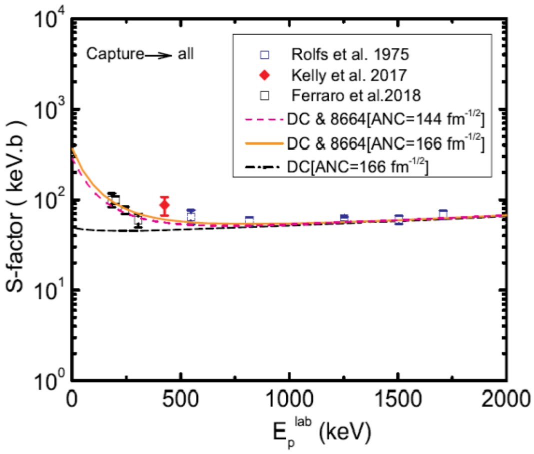

Fig. 1 R-matrix fit to the data of total direct capture in ^{23}Na.

The observed rise in the astrophysical S-factor data for ground state capture, including the effect of capture through sub-threshold state, was reproduced nicely. The total direct capture S-factor at zero relative energy was found to be 48.8 ± 9.5 keV b, having less uncertainty [2]. The value corroborates with the recent measurements. The total reaction rate obtained as a function of temperature differs from the recent estimations by Ferraro et al. in the temperature window of $0.1 \leq T \leq 0.2$ GK[2].

In the ^{68}Zn(n, γ)^{69}Zn reaction study, the thesis attempts the extraction of nuclear level density (NLD) of ^{69}Zn experimentally. Evaporated α-spectra have been measured in coincidence with the low energy γ-rays from the purely compound nuclear reaction ^{64}Ni(^{9}Be,αn)^{68}Zn at E(^{9}Be)=30 MeV[3]. The first chance α-emission spectrum, producing ^{69}Zn, have been compared with statistical model calculation to extract the asymptotic value of NLD. Subsequently, with the asymptotic NLD, the NLD parameter at neutron separation energy of ^{69}Zn has been evaluated and used in the TALYS reaction code to calculate the ^{68}Zn(n, γ)^{69}Zn capture cross-sections shown in **Fig. 2**. Excellent agreement with the measured (n, γ) cross-section[3], does highlight the objective of direct experimental determination of the parameters of statistical model for more accurate description of astrophysical reactions.

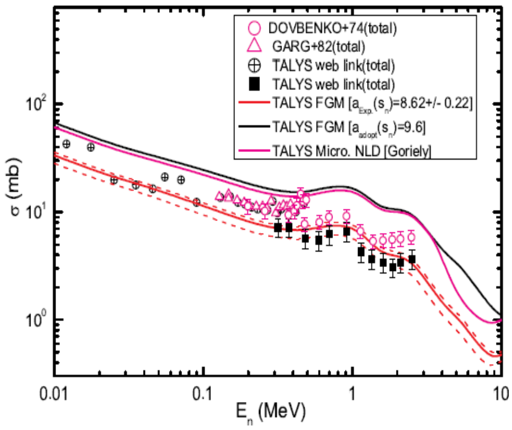

Fig. 2 The ^{68}Zn(n, γ)^{69}Zn capture data are compared with TALYS calculation using the present NLD parameter.

To investigate the formation of ^{9}Be in the explosive astrophysical scenario, we studied the population of near threshold states of ^{9}Be by inelastic α scattering and their decay by emission of two. As the 1/2^{+} state at 1.68 MeV is of particular interest as a doorway for formation of ^{9}Be, the scattered α-particles from the state in singles and in coincidence with the two decay α-s were detected. The FWHM of the corresponding peaks in the α-energy spectrum provide the measure of the total width (shown in **Fig. 3**) and the neutron decay width of the state.

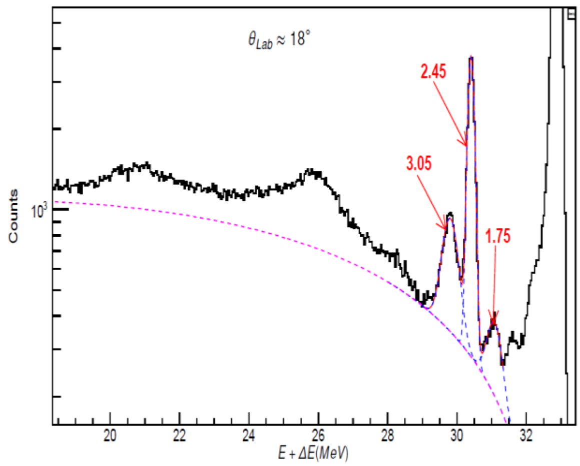

Fig. 3 The scatter α-particles energy spectrum at 18° lab angle.

References

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[2] Rajkumar Santra *et. al.*, Phys. Rev. C, 101 (2020), 025802.

[3] Rajkumar Santra *et. al.*, Physics Letters B, (806) 2020, 135487.