Reactions studies in relation to upcoming FRENA facility: Indirect Method & R-matrix phenomenology

Sucheta Adhikari*
Physics Department, Techno India University, EM 4, Sector-V, SaltLake, Kolkata-700091, INDIA
** email: suchetaadhikari@gmail.com*

Introduction

A 3 MV high current Tandetron accelerator facility (FRENA) [1] is being installed at the Saha institute of Nuclear Physics, Kolkata to pursue low energy nuclear reactions relevant to nuclear astrophysics. The energy region corresponding to the temperature of stars is very low (of the order tens to hundreds of keV). We know that at such low energies the nuclear reaction cross section is very sensitive to the energy and decreases exponentially as one goes towards lower energy making it very difficult to measure with reasonable accuracy. Extrapolations are therefore done in the framework of the R-matrix theory using the cross-section data at higher energy. Phenomenological R-matrix extrapolations require spectroscopic inputs in the form of reduced particle width and/or Asymptotic Normalization Constant (ANC). These inputs can be constrained by the so called Indirect method. In this method, elastic scattering, transfer or breakup reactions have been used to extract the spectroscopic information.

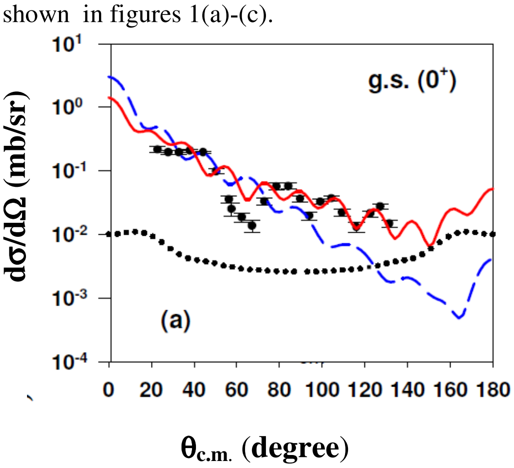
The main purpose of the FRENA facility is to perform direct measurements. However direct measurements are more tedious and not all reactions particularly those with very low Gamow Energy are feasible without an underground facility. Thus to study intricacies of varied astrophysical reactions, to start with the facility can be utilized for Indirect method through the study of resonant elastic scattering, sub-Coulomb transfer reactions, reaction mechanisms of (p,α) and (α,p) reactions etc.

As potential users of the facility, we as various groups have carried out experimental Indirect method studies utilizing the higher energy accelerator facilities in the country and theoretical works on the R-matrix method. These works are providing us with necessary experience to work in the lower energy framework with the FRENA machine.

Indirect method

We determined the ANC of ^{16}O states particularly for the 6.92 MeV (2^+) and 7.12 MeV (1^-) from α-transfer reactions ^{12}C(^{6}Li,d)^{16}O and ^{12}C(^{7}Li,t)^{16}O at above barrier energy (20 MeV). Several experiments in this direction have been carried out at various energies for these two reactions. Most of these experiments are at above barrier energies [2-4] and only two measurements are at sub-Coulomb energies [5,6] as the former is easier to execute experimentally due to higher cross-sections. However, the extraction of ANC requires a peripheral reaction and this is ensured in a sub-Coulomb reaction rather than at higher energies. Experiments were carried out using 20 MeV ^{6}Li and ^{7}Li beam from 15 UD Pelletron facility at Inter University Accelerator Centre, New Delhi. The deuteron and triton angular distributions were measured at closely spaced angles in the range 18-112 degrees in the laboratory using the 1.5 m General purpose scattering chamber (GPSC) facility.

The angular distributions for the 6.92 and 7.12 states and the ground state population of ^{16}O from the ^{12}C(^{6}Li,d) and ^{12}C(^{7}Li,t) reactions are shown in figures 1(a)-(c).



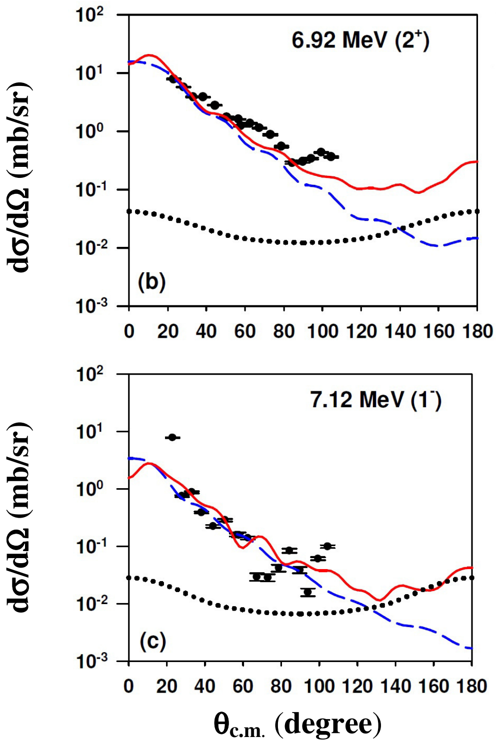


Fig.1(a)-(c) The comparison of the measured angular distributions [2] of the α-bound states of ^{16}O from ^{12}C(^{7}Li,t) with FRDWBA calculations (blue dashed lines), Hauser-Feshbach calculations (black dotted lines), and CDCC-CRC (red solid lines) calculations, where all the bound states and unbound resonance states of ^{16}O are considered.

The present work besides the extraction of the spectroscopic properties of the states of ^{16}O important for astrophysical calculations, investigated the breakup effect on the alpha transfer process in the two reactions for the first time. This effect is found to be most prominent at above barrier energies for the population of the ground state. The Continuum-Discretized Coupled Reaction Channel (CDCC-CRC) theory is used over the usual Finite Range Distorted wave Born approximation (FRDWBA) to study the breakup effect.

R-matrix phenomenology

R-matrix phenomenology [7] has been also undertaken to study several astrophysical reactions. S. Roy and his group at SINP has carried out studies on the important CNO cycle reaction ^{13}C(p,γ) [8]. The low energy astrophysical S-factor of this reaction is dominated by two resonance states at 8.06 MeV ($J^{\pi}=1^{-}$, T=1) and 8.78 MeV ($J^{\pi}=0^{-}$, T=1) and the direct capture process. The extrapolated values of S(0) i.e the S-factor at zero relative energies by different measurements differ by 30%. In this scenario Roy et al has looked into the discrepancies through a detailed R-matrix analysis with an emphasis on the associated uncertainties. Simultaneous analysis of the capture data with ^{13}C(p,p$_0$) elastic data has been carried out. The external capture model along with background poles to simulate the internal capture were used to estimate the direct capture contribution. The ANCs for all ^{14}N states were also extracted from capture data. The multichannel multilevel R-matrix code AZURE2 has been used for this calculations. The ANCs for all ^{14}N states were also extracted from capture data and they corroborate with those extracted using transfer reactions by Mukhamedzhanov et al [9]. The values of the S-factor at zero relative energy was found to be consistent within error bars for the two sets of capture data used. The reaction rates were also calculated and they compare well with NACRE I compilation and are 10-15% lower than the values of NACRE II.

A preliminary R-matrix analysis of ^{12}C(α,γ) reaction based on ANC extracted from ^{12}C(^{6}Li,d) reaction at 20 MeV is reported in the 2015 symposium.

References

[1] N.C. Podaru et al, NIM B 273 (2012) 231

[2] S.Adhikari et al, Phys. Rev. C 89 (2014) 044618

[3] S. Adhikari et al, Jour. Phys. G (2016) (in press)

[4] N. Oulebsir et al, Phys. Rev. C 85 (2012) 035804

[5] C. Brune et al, Phys. Rev. Lett. 83 (1999) 4025.

[6] M.L. Avila et al, Phys. Rev. Lett. 114 (2015) 071101

[7] R. J. deBoer et al, Phys. Rev. C 87 (2013)

[8] Suprita Chakraborty et al, Phys. Rev. C 91 045801 (2015)

[9] A. M. Mukhamedzhanov et al, Nucl. Phys. A 725 (2003) 279