Study of low energy resonances in ^{23}Na from transfer reaction ^{22}Ne (^{3}He, d) ^{23}Na and astrophysical implication

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Introduction

Peripheral transfer reaction has evolved as an indirect experimental technique to obtain the relevant quantities required to estimate the rate of astrophysical capture cross section [1].

In the present work, we re-investigate the existing data of one-proton transfer reaction (^{3}He, d), a surrogate to (p,γ) capture reaction, on ^{22}Ne [2] populating E_x = 8828, 8945 and 8972 keV (E_r = 36, 151 and 178 keV) states of the residual nucleus ^{23}Na above the proton threshold of 8794 keV. Recent direct measurement of ^{22}Ne(p,γ)^{23}Na [3], reports a significant change in the resonance strengths for these low-lying resonances compared to those predicted by the indirect (^{3}He,d) transfer study [2]. One major source of the discrepancies is the assignment of spin-parity (J^{π}) of some of these near threshold resonance states [4].

In this context, we re-analyzed the angular distribution data from (^{3}He,d) reaction to these *unbound* states and estimated the particle decay widths (Γ_p) of these states. Corresponding resonant reaction rates of ^{22}Ne (p, γ) ^{23}Na capture reaction at low energies have been calculated. We also evaluated the Asymptotic Normalization Constants (ANC) of the low lying bound states in order to determine the direct capture contribution.

Model

Angular distribution data from Refs [2,5] have been analyzed within the Zero Range Distorted Wave Born Approximation formalism using the code DWUCK4 [6]. The model cross section $(d\sigma/d\Omega)_{\rm DWBA}$ from DWUCK4 is related to the measured cross section $(d\sigma/d\Omega)_{\rm expt}$ as

$$\left(\frac{d\sigma}{d\Omega}\right)_{\rm expt} = N\frac{(2J_f+1)}{(2J_i+1)(2j+1)}C^2S\left(\frac{d\sigma}{d\Omega}\right)_{\rm DWBA}$$

where the constant N=4.42 for (^{3}He,d). J_i, J_f are the initial channel spin and spin of the final state, respectively and j_i is the spin of the proton orbital in the final nucleus. C^2S is the ^{22}Ne+p spectroscopic factor of the states in ^{23}Na. It is related to proton partial width (Γ_p) as $\Gamma_p = C^2S\ \Gamma_{sp}$, where the single particle width (Γ_{sp}) is obtained from proton bound state wave function and the irregular Coulomb function. The ANCs are related to spectroscopic factors of bound states as $(ANC) = \sqrt{(C^2S)}.b$ with b as the single particle asymptotic coefficient. Both Γ_{sp} and b depend on the choice of the nuclear potential parameters.

Results and Discussions

Optical potential parameters were taken from Ref [2]. The parameters of bound state potentials were varied from 1.125 to 1.375 fm and from 0.39 to 0.89 fm for radius and diffuseness parameters, respectively keeping the resonance energies fixed.

Table 1: Summary of proton widths (Γ_p) and resonance strengths.

E_x (E_r) keV	Γ_p (keV)	ωγ (eV)	ωγ (eV) (Indirect)	ωγ (eV) (Direct)
8830 (36) *1/2+*	1.04E-14 ± 1.32E-15	1.04E-14 ± 1.32E-15	3.6E-15*[2]* 6.8E-15[1]	—
8945 (151) *3/2+*	4.02E-07 ± 1.27E-07	8.04E-07 ± 2.55E-07	≤9.23E-9[2]	3.0E-07[6]
8972 (178) *5/2+*	2.06E-06 ± 4.41E-07	6.18E-06 ± 1.32E-06	3.4E-06*[2]*	2.32E-06*[10]*
9211 (417) *7/2+*	12.8 ± 0.6	0.108 ± 0.08	—	0.082 *[10]*

Fig.1 shows a comparison of the fits to the resonance state at Ex=8945 MeV with *l=2* ($J^{\pi}=3/2^{+}$) and *l=3* ($J^{\pi}=7/2^{-}$) transfers. The proton partial widths and strengths (ωγ) of the resonances obtained from the analyses are listed in Table 1. Corresponding reactions rates are estimated from the code system STARLIB [7]. The rates of respective of resonant captures as a function of temperature are shown in Fig.2. Total reaction rate at T_9=0.1 from the present analysis is about 30% higher than previously reported in Ref [2].

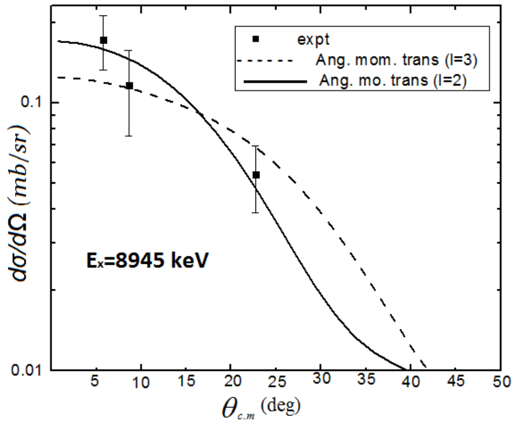

Fig.1: *DWBA predictions of cross sections for 8945 MeV state in ^{23}Na.*

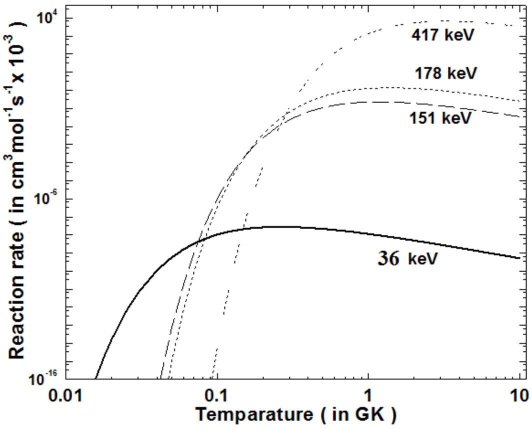

Fig.2: *Resonant reaction rates using the resonance strengths of present calculation.*

References

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