PROCEEDINGS OF SCIENCE

Analysis of the ^{16}O(d,p)^{17}O and ^{16}O(d,n)^{17}F transfer reactions to determine astrophysical direct capture cross sections

Marlete Assunção[*†]
Universidade Federal de São Paulo, Campus Diadema, 09941-510 Diadema/SP, Brazil
E-mail: mpmeira@if.usp.br

Rubens Lichtenthäler,Valdir Guimarães, Alinka Lépine-Szily, Antônio M. Moro[1]
Instituto de Fisica da Universidade de São Paulo, CP 66318, 05315-970 São Paulo/SP, Brazil
[1]*Departamento de Física, Instituto Superior Técnico, Taguspark, 2780-990 Porto Salvo, Portugal*

Coupled Reaction Channel Calculations have been performed for transitions to ground and first excited states of ^{17}F and ^{17}O at deuteron incident energies from E_d=2.279 MeV up to 3.186 MeV. The n+^{16}O and p+^{16}O astrophysical direct capture cross sections have been calculated using the spectroscopic factors obtained from ^{16}O(d,p)^{17}O and ^{16}O(d,n)^{17}F transfer reactions. The astrophysical S-factors are compared to recent experimental data. The Maxwellian-averaged neutron capture cross section at kT=30 keV is obtained as 22(3)μ barn.

International Symposium on Nuclear Astrophysics - Nuclei in the Cosmos - IX
25-30 June 2006
CERN

[*]Speaker.
[†]The authors would like to thank FAPESP for the support. Projeto temático 01/06676-9 and FINEP.

PoS(NIC-IX)071

1. Introduction

Proton and neutron capture cross sections at the astrophysical energies are important for nucleosynthesis theories. The direct measurements of these reactions are, in some cases, nearly impossible due to low reaction yield, especially if the capture involves exotic nuclei. Alternative indirect methods such as the asymptotic normalization coefficient (ANC) method, based on the analysis of breakup [1] or transfer reaction [2] have been used for obtaining astrophysical S-factors [2, 3, 4, 5, 6]. The advantage of the indirect approach comes from the fact that the transfer and breakup reactions can be measured at higher energies, where the cross sections are much larger. However, in order to obtain useful information from transfer reactions, one needs to understand the reaction mechanism therein involved. We investigate the importance of considering the coupled reaction channel (CRC) calculation in the analysis of the ^{16}O(d,n)^{17}F and ^{16}O(d,p)^{17}O transfer reactions, at low incident deuteron energies from E_d=2.279 MeV to E_d=3.155 MeV, for which experimental data are available [7]. The full CRC calculation provides more realistic spectroscopic factors in comparasion to a DWBA analysis which resulted spectroscopic factor lower than one.The spectroscopic factors were used to evaluate the p+^{16}O and n+^{16}O direct capture cross sections [8]. The large ^{16}O(n,γ)^{17}O cross section has implications to nucleosyntesis theories, especially in metal-defficient massive stars as an important neutron poison [9].

2. CRC Analysis

In a previous work [8], we have analyzed angular distributions of the of ^{16}O(d,n)^{17}F and ^{16}O(d,p)^{17}O peripheral tranfer reactions using DWBA, CCBA and CRC calculations and we have concluded that the CRC formalism describes very well these experimental data at foward angles. The optical potentials used in our analysis are listed in Table 1 and the spin-orbit contributions are V_{so}=6.0 MeV, r_{so}=1.4 fm and a_{so}=0.7 fm for the d+^{16}O system. For both n+^{17}F and p+^{17}O systems we have considered the values of V_{so}=5.5 MeV, r_{so}=1.25 fm and a_{so}=0.65 fm. For the p-n binding potential, V_{pn}, a Gaussian form V_{pn}(r)=- v_0 exp(r^2/a^2) with a=1.484 fm and v_0=72.15 MeV was used. These parameters were chosen to reproduce the rms and binding energy of the deuteron (see figure 1.).

Table 1: Optical potential parameters used in CRC analysis. All potentials have a Woods-Saxon derivative imaginary potential

System	V_0 (MeV)	r_0 (fm)	a_0 (fm)	W_d (MeV)	r_i (fm)	a_i (fm)	Ref.
d+^{16}O	110.0	1.012	0.876	9.3	1.837	0.356	[10]
n+^{17}F	-49.3+0.33$E_{c.m.}$	1.25	0.65	5.75	1.25	0.70	[11]
p+^{17}O	54.77-0.701E_p^{lab}	1.25	0.65	0.501+0.80E_p^{lab}	1.25	0.70	[12]
Set I (CRC)	102.0	1.25	0.65	20.2	1.25	0.232	[8]
Set II (CRC)	104.0	1.25	0.65	24.9	1.25	0.233	[8]

We used the search version SFRESCO code [13] to determine the bare potential in the entrance channel by varying V_0, W_d, a_i, and the spectrosopic amplitude in order to simultaneously fit the

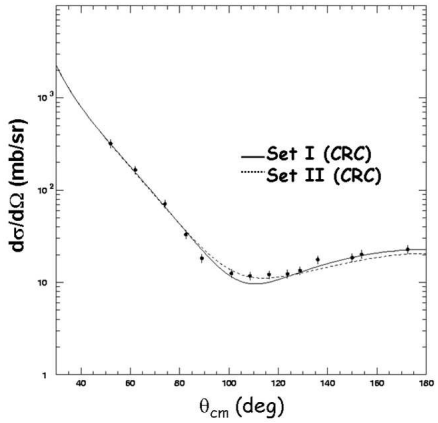

Figure 1: Experimental and calculated elastic angular distributions for d+^{16}O at E_d=2.85MeV

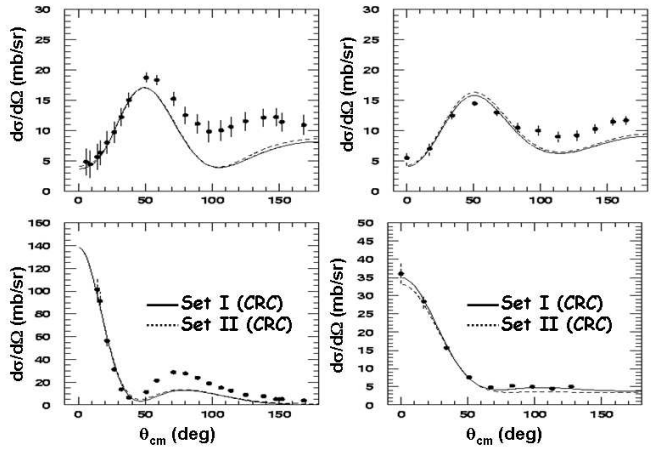

Figure 2: CRC calculations for the ^{16}O(d,n)^{17}F and (b) ^{16}O(d,p)^{17}O reactions for the ground (upper pannels) and first excited (lower pannels) states at 2.85 MeV, using the parameters list in Table 1). Experimental data were obtained by Dietzsch et al. [7].

elastic (d+^{16}O) data and transfer channels. The obtained values V_0, W_d and a_i are listed in Table 1. The optical potential in the n+^{17}F exit channel was kept fixed to the Rosen parametrization [11]. Results using different sets of parameters are presented in Figure 2 at 2.85 MeV deuteron incident energy. Futhermore, the CRC calculation using the potential for p+^{17}O, obtained from the experimental data [12], leads to a reduction of the calculated cross section at forward angles for both reactions, significantly improving the agreement with the experimental data using spectroscopic factors close to one. The small values for the $\langle^{17}O^*|^{16}O\rangle$ spectroscopic factor was obtained for the (d,p_1) channel. In all calculations, a compound nucleus contribution obtained by Dietzsch et al. [7] was subtracted from the experimental data. We have extended the CRC analysis to other energies, i.e., from E_d= 2.279 to E_d= 3.186 MeV for the (d,n) reaction and from E_d= 2.279 to E_d= 3.155 MeV for the (d,p) reaction. The average spectroscopic factors and ANC values range

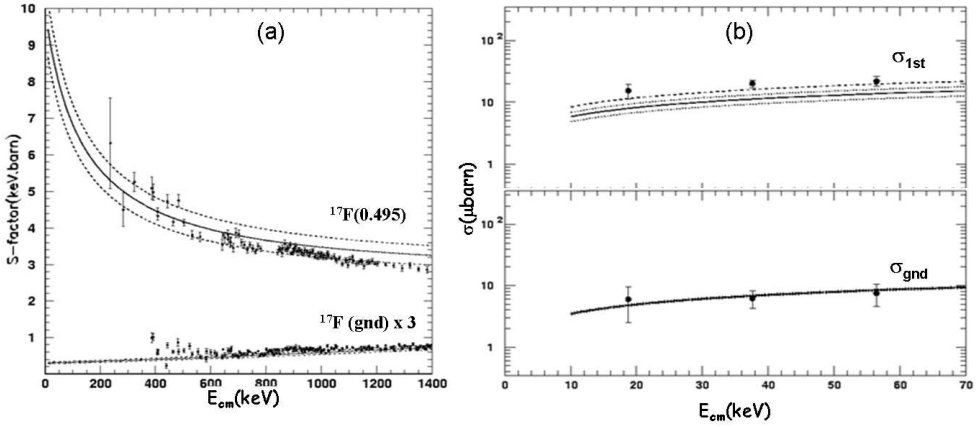

Figure 3: Astrophysical S- factor from ^{16}O(d,n)^{17}F transfer reaction and (b) neutron capture cross section from ^{16}O(d,p)^{17}O transfer reaction performed by CRC analysis. The solid lines are our results and the dashed lines are error bands. The dotted line in (b) was obtained using the spectroscopic factor equal to one. The experimental data were obtained by Morlock et al. [15] and by Igashira et al.[9], respectively.

obtained from this analysis are summarized in Table 2. The standart deviation specified as the error of the spectroscopic factors were obtained from the average of four analyzed energies.

Table 2: Average spectroscopic factor (S) and ANC values range from CRC calculations.

	(d,p_0)	(d,p_1)	(d,n_0)	(d,n_1)
S (Set I)	0.96(14)	0.66(14)	0.95(10)	0.93(11)
S (Set II)	1.00(7)	0.62(14)	0.91(10)	0.92(15)
ANC (Set I) (fm^{-1})	0.99-0.74	4911-3192	0.79-0.64	9-7
ANC (Set II) (fm^{-1})	0.96-0.84	4666-2947	0.76-0.61	9-7

3. Proton and Neutron Capture Cross Sections

The astrophysical S-factors for the ^{16}O(p,γ)^{17}F and ^{16}O(n,γ)^{17}O capture cross sections were determined using the Radcap code [14]. The results are shown in Figure 3 (a) and (b) compared to the experimental data of Morlock et al. [15], and Igashira et al. [9], respectively. The zero energy S-factor for the first excited state ^{16}O(p,γ)^{17}F was obtained as 9.6 ± 0.8 keV.b and it is in agreement with the value of 9.8 ± 1.0 keV.b obtained by Gagliardi et al [4]. For the ground state ^{16}O(p,γ)^{17}F, a 0.28 ± 0.03 keV.b S-factor was obtained. The Gagliardi et al [4] calculations also underestimate the experimental data, however, Morlock et al. [15] suggest that the ground experimental data could have been contaminated by the background [15].

The neutron captures to the ground and first excited states of the ^{17}O nucleus are shown in Figure 3 (b). The Maxwellian-averaged direct cross section at kT=30 keV was calculated to 22 ± 3 μbarn from our transfer reaction analysis. Igashira et al. [9] reported a 34 ± 4 μbarn from the

experimental data with the resonance effect subtracted. This large cross section has implications on the nucleosynthesis theories and inhomogeneous models [9].

4. Conclusions

We calculate the astrophysical S-factors for the $^{16}O(p,\gamma)^{17}F$ and $^{16}O(n,\gamma)^{17}O$ capture reactions using the spectroscopic factors obtained by performing the CRC calculation from transfer reactions. Our results are in good agreement with the experimental proton capture cross sections. We determine the Maxwellian-averaged cross section at kT=30keV for the total (gs+1st$_{exc}$) $^{16}O(n,\gamma)^{17}O$ capture to 22(3)μb. This large cross section has implications to nuclesynthesis theories of s and p processes, especially in metal-deficient massive stars, which may be seen as important neutron poisson.

References

[1] N. Imai et al., *Nucl. Phys.Phys.* **A688** (2001) 281c-284c

[2] H.M. Xu et al., *Phys. Rev. Lett.*, **73**,(1994), 2027

[3] A.M. Mukhamedzhanov et al., *Phys. Rev.* **C56**,(1997) 1302

[4] J. C. Fernandes, R. Crespo, and F. M. Nunes, *Phys. Rev.* **C64**, (2001) 062801(R)

[5] C.A. Gagliardi et al., *Phys. Rev.* **C59**,(1999) 1149

[6] L.Trache et al., *Phys. Rev. Lett.* **87** (2001) 271102

[7] O. Dietzsch et al., *Nucl. Phys.* **A114** (1968) 330

[8] M. Assunção et al., *Phys. Rev.* **C70** (2004) 054601

[9] M. Igashira et al., *ApJ*, **441** (1995) L89-L92

[10] G.R. Satchler, *Nucl.Phys.* **85**(1966) 273

[11] L. Rosen *Proceedings of the 2nd International Symposium on Polarization Phenomena of Nucleons*, Birkhauser Verlag, Basel, (1966) 253

[12] K. C. C. Pires , *Master Thesis* IFUSP, Universidade de São Paulo (2006)

[13] I.J. Thompson, *Computer Physics Reports* **7** (1988) 167-212

[14] C. A. Bertulani, *MSUCL* **1267** (2003)

[15] R. Morlock et al., *Phys. Rev. Lett.* **79** (1997) 3837