Microscopic (n, γ) rates with astrophysical relevance near the $N = 50$ neutron core

Saumi Dutta[1],* G. Gangopadhyay[2], and Abhijit Bhattacharyya[3]
Department of Physics, University of Calcutta,
92, Acharya Prafulla Chandra Road, Kolkata-700009, India

Introduction

The weak s-process component, that takes place in He core and C-burning shell of massive stars, produces elements in the mass range $56 < A < 90$ from iron up to Sr-Y-Mo region. Neutron capture rates are crucial in the study of weak s-process nucleosynthesis via classical or model-based network calculations. The nuclei in the vicinity of shell closures have very small capture cross sections and hence, act as bottlenecks to the reaction chain. The (n, γ) rates of s-only isotopes are crucial to test the validity of local approximation. Precise neutron capture rates have also consequences for s-process branching analysis that can predict various constraints about the astrophysical medium. The neutron capture rates are also important for p-process study. The rates of the (γ, n) reactions can be deduced from (n, γ) rates via detailed balance. The nuclei, for which experimental data do not exist, a good theoretical model can predict the values.

Theory

The present study deals with the theoretical calculation of (n, γ) cross sections and reaction rates for temperatures relevant to s- and p-processes. The semi-microscopic optical model potential is formulated in folding model technique by convoluting radial matter densities of the target with the DDM3Y NN interaction [1, 2]. The cross sections and rates are calculated with the statistical reaction code TALYS1.8 [3]. The nuclear level densities and E1 γ-ray strength functions are taken from Refs. [4, 5].

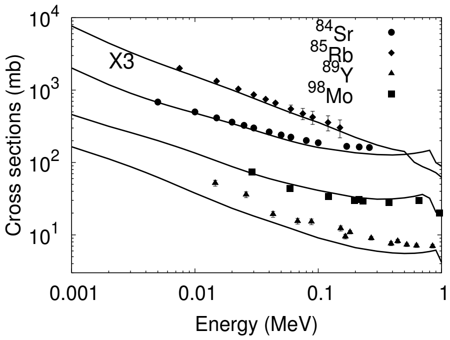

FIG. 1: Comparison of results of the present calculation (solid lines) with measurements. For the convenience of viewing, cross-sections for ^{85}Rb have been multiplied by a factor of 3.

TABLE I: MACS values at $kT = 30$ keV for a few nuclei near the $N = 50$ shell closure.

	MACS (mb)		
Nucleus	Pres.	Exp.	MOST
$^{85}_{37}$Rb	259	234±7	197
$^{86}_{37}$Rb	206		226
$^{87}_{37}$Rb	17.6	15.7±0.8	18.8
$^{86}_{38}$Sr	54.5	64±3	51.0
$^{87}_{38}$Sr	139	92±0.4	72.2
$^{89}_{39}$Y	19.0	19±0.6	16.6
$^{90}_{40}$Zr	18.4	19.3±0.9	13.7
$^{91}_{40}$Zr	62.3	62.0±3.4	53.7
$^{92}_{40}$Zr	28.1	30.1±1.7	25.5
$^{93}_{41}$Nb	224	266±5	241
$^{92}_{42}$Mo	53.2	70±10	45.5

In the high-temperature stellar environment, all the rates are thermalized and hence, cross sections, in general, are averaged over the MB distribution as, $< \sigma >=$

---

*Electronic address: saumidutta89@gmail.com

$\frac{2}{\sqrt{\pi}} \frac{\int_0^\infty E\sigma(E) e^{-E/kT} dE}{\int_0^\infty E e^{-E/kT} dE}$. While classical s-process prefers MACS at 30 keV, recent codes coupled with stellar models demand at several other energies. Hence, we have calculated the MACS values, first at 30 keV and then over a range of energies of astrophysical interests. We have also calculated the (n, γ) rates over a range of temperatures suitable for s-process.

TABLE II: MACS values over a range of energies for ^{88}Sr and ^{92}Mo.

kT (MeV)	MACS (mb)			
	^{88}Sr		^{92}Mo	
	Pres.	Expt.	Pres.	Expt.
0.005	18.0	10.88	144	277
0.010	11.3	11.86	96.4	158
0.015	8.63	9.88	76.6	115
0.020	7.16	8.21	65.5	93
0.025	6.22	7.02	58.4	79
0.030	5.55	6.13	53.2	70
0.040	4.67	5.04	46.2	59
0.050	4.12	4.35	41.6	53
0.060	3.73	3.95	38.3	49
0.080	3.25	3.25	34.0	45
0.100	2.96	3.36	31.4	43

TABLE III: The (n, γ) reaction rates for ^{90}Zr and ^{94}Mo over a range of stellar temperature ($T_9 = 1GK$). The rates are in the order of 10^5.

T_9 (GK)	$N_A < \sigma v >$ ($cm^3 mol^{-1} s^{-1}$)			
	^{90}Zr		^{94}Mo	
	Pres.	Expt.	Pres.	Expt.
0.1	29.156	28.013	130.40	128.86
0.2	27.279	23.876	126.39	113.37
0.3	26.746	22.340	126.14	105.82
0.4	26.533	21.670	126.81	101.66
0.5	26.455	21.399	127.78	99.332
0.6	26.479	21.358	128.98	98.216
0.7	26.589	21.646	130.42	97.957
0.8	26.774	21.670	132.07	98.325
0.9	27.020	21.944	133.92	99.164
1.0	27.318	22.266	135.95	100.36

Results

Fig. 1 shows the (n, γ) cross sections for ^{84}Sr, ^{85}Rb, ^{89}Y, and ^{98}Mo from 1 keV to 1 MeV. The experimental values are from Refs. [6, 7, 8, 9], respectively. Table I lists the MACS values at 30 keV of stellar energy for a number of nuclei near the $N = 50$ closed shell. MACS values over an energy range from 5 to 100 keV for ^{88}Sr and ^{92}Mo are given in Table II. Our calculated values are compared to available experimental values recommended by Bao *et al.*[10] and theoretical MOST code predicted values. MOST is a Hauser-Feshbach code that derives all inputs from global models. Both the experimental values and MOST values are listed in KADoNiS database [11]. The (n, γ) rates for ^{90}Zr and ^{94}Mo at astrophysically important temperatures are given in Table III along with the rates available in BRUSLIB database [12] for the sake of comparison.

Acknowledgments

Authors acknowledge UGC and AvH Foundation for providing financial support.

References

[1] S. Dutta *et al.*, Phys. Rev. C **93**, 024602, (2016).

[2] S. Dutta *et al.*, Phys. Rev. C **94**, 024604, (2016).

[3] A. Koning *et al.*, in *Proc. of the Int. Conf. on Nucl. Data for Sci. and Technol., April 22-27, 2007, Nice, France*, edited by O. Bersillon *et al.*, (EDP Sciences, Cedex, France, 2008), p. 211.

[4] S. Goriely *et al.*, Phys. Rev. C **78**, 064307 (2008).

[5] R. Capote *et al.*, Nucl. Data Sheets **110**, 3107 (2009).

[6] Dillmann *et al.*, Phys. Rev. C **73**, 015803 (2006).

[7] M. Heil *et al.*, Phys. Rev. C **78**, 025802 (2008).

[8] D. Stupegia *et al.*, Jour. of Nucl. Energy **22**, 267 (1968).

[9] W. Chunhao *et al.*, Conf. on Nucl. Data for Sci. and Technol., Jülich, Germany, 13-17 May 1991, edited by S. Qaim (Springer, Berlin, 1992), p.370.

[10] Z. Y. Bao *et al.*, At. Data. Nucl. Data Tables **76**, 70 (2000).

[11] I. Dillmann *et al.*, KADoNiS v0.3 - The third update of the "Karlsruhe Astrophysical Database of Nucleosynthesis in Stars" in *EFNUDAT Fast Neutrons, Proc. of the Sci. Workshop on Neutron Measurements, Theo., and Appl.* 28 - 30 April 2009, Geel, Belgium, edited by F. -J. Hambsch (Publications Office of the European Union, Luxembourg, 2010) p. 55 ; http//www.kadonis.org

[12] http//www.astro.ulb.ac.be/bruslib/