

## STARK BROADENING PARAMETER TABLES FOR Rb I LINES

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**SUMMARY:** Using a semiclassical approach, we have calculated electron-, proton-, and ionized argon-impact line widths and shifts for 24 Rb I multiplets as a function of temperature for perturber densities  $10^{14}$  and  $10^{16} - 10^{18} \text{ cm}^{-3}$ .

### 1. INTRODUCTION

Rubidium lines have been observed in Solar and stellar spectra (see e.g. Merrill, 1945; Davis, 1947) and consequently their Stark broadening parameters are of interest to astrophysicists. Neutral Rubidium Stark-broadening parameters are of interest for laboratory plasma spectroscopy as well, and have been investigated several times (Lakićević et al, 1975; Purić et al, 1977; Dimitrijević and Konjević, 1983).

In order to provide reliable data for Rb I lines broadened by collisions with charged perturbers in stellar and laboratory plasmas, we have calculated electron-, proton- (for stellar plasma research) and ionized argon- (for laboratory plasma investigations) impact line widths and shifts for 24 Rb I multiplets, using the semiclassical-perturbation formal-

ism (Sahal-Bréchet, 1969ab). The obtained results for perturber density of  $10^{15} \text{ cm}^{-3}$ , together with discussion, analysis and comparison with existing theoretical and experimental data will be published in the principal article elsewhere (Dimitrijević, and Sahal-Bréchet, 1993). Since data are not linear with perturber density ( $N$ ), due to the Debye screening effect, we will present here the data for  $N = 10^{14}$  and  $10^{16} - 10^{18} \text{ cm}^{-3}$ .

### 2. RESULTS AND DISCUSSION

All details of the calculation procedure has been described in Dimitrijević and Sahal-Bréchet (1984) and will not be repeated here. Energy levels for Be II lines have been taken from Moore (1971). Oscillator strengths have been calculated using the



Table 1. This table gives electron-, proton-, and ionized-argon- impact broadening parameters for Rb I lines, for perturber densities  $10^{14}$  and  $10^{16} - 10^{18} \text{ cm}^{-3}$  and temperatures from 2,500 K to 50,000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. By dividing  $c$  by the electron-impact full halfwidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5.

PERTURBER DENSITY= 0.1E+15 cm-3							
TRANSITION	PERTURBERS ARE: T(K)	ELECTRONS WIDTH(A)	SHIFT(A)	PROTONS WIDTH(A)	SHIFT(A)	IONIZED ARGON WIDTH(A)	SHIFT(A)
4D - 8P 9529.3 Å C= 0.39E+17	2500.	0.708E-01	0.502E-01	0.203E-01	0.125E-01	*0.170E-01	*0.685E-02
	5000.	0.797E-01	0.569E-01	0.215E-01	0.144E-01	*0.175E-01	*0.804E-02
	10000.	0.885E-01	0.564E-01	0.229E-01	0.164E-01	*0.181E-01	*0.928E-02
	20000.	0.988E-01	0.450E-01	0.246E-01	0.186E-01	0.188E-01	0.106E-01
	30000.	0.107	0.375E-01	0.257E-01	0.200E-01	0.192E-01	0.114E-01
50000.	0.116	0.298E-01	0.273E-01	0.218E-01	0.199E-01	0.125E-01	
5P - 6D 6276.9 Å C= 0.23E+17	2500.	0.129E-01	0.856E-02	0.364E-02	0.218E-02	*0.314E-02	*0.122E-02
	5000.	0.149E-01	0.917E-02	0.383E-02	0.249E-02	0.321E-02	0.141E-02
	10000.	0.175E-01	0.863E-02	0.406E-02	0.282E-02	0.329E-02	0.161E-02
	20000.	0.210E-01	0.712E-02	0.433E-02	0.318E-02	0.340E-02	0.182E-02
	30000.	0.230E-01	0.615E-02	0.452E-02	0.341E-02	0.347E-02	0.196E-02
50000.	0.249E-01	0.494E-02	0.478E-02	0.372E-02	0.357E-02	0.214E-02	
6S - 8P 10292.8 Å C= 0.46E+17	2500.	0.822E-01	0.582E-01	0.239E-01	0.145E-01	*0.202E-01	*0.793E-02
	5000.	0.926E-01	0.650E-01	0.252E-01	0.166E-01	*0.207E-01	*0.931E-02
	10000.	0.104	0.642E-01	0.268E-01	0.190E-01	*0.214E-01	*0.107E-01
	20000.	0.117	0.501E-01	0.288E-01	0.215E-01	0.221E-01	0.123E-01
	30000.	0.127	0.408E-01	0.301E-01	0.231E-01	0.226E-01	0.132E-01
50000.	0.138	0.331E-01	0.319E-01	0.252E-01	0.234E-01	0.145E-01	
6P - 6D 20344.9 Å C= 0.24E+18	2500.	0.126	0.805E-01	0.341E-01	0.208E-01	0.292E-01	0.116E-01
	5000.	0.151	0.767E-01	0.359E-01	0.236E-01	0.299E-01	0.134E-01
	10000.	0.186	0.643E-01	0.381E-01	0.268E-01	0.307E-01	0.153E-01
	20000.	0.238	0.481E-01	0.408E-01	0.302E-01	0.317E-01	0.173E-01
	30000.	0.267	0.434E-01	0.425E-01	0.324E-01	0.324E-01	0.187E-01
50000.	0.293	0.321E-01	0.450E-01	0.354E-01	0.334E-01	0.204E-01	
6D - 7P 120891.2 Å C= 0.86E+19	2500.	4.12	0.253	1.03	-0.126	1.02	-0.718E-01
	5000.	6.09	0.605	1.03	-0.142	1.03	-0.815E-01
	10000.	8.58	0.863	1.03	-0.160	1.03	-0.921E-01
	20000.	11.3	0.788	1.03	-0.180	1.03	-0.104
	30000.	12.9	0.775	1.03	-0.193	1.03	-0.111
50000.	14.4	0.795	1.03	-0.212	1.03	-0.121	
6D - 8P 86166.8 Å C= 0.32E+19	2500.	5.73	3.60	1.38	0.852	*1.17	*0.470
	5000.	6.96	3.59	1.46	0.978	*1.20	*0.549
	10000.	8.57	3.41	1.56	1.11	*1.24	*0.632
	20000.	10.6	2.54	1.67	1.26	1.28	0.720
	30000.	11.8	2.11	1.75	1.35	1.31	0.776
50000.	12.9	1.68	1.86	1.48	1.36	0.850	



STARK BROADENING PARAMETER TABLES FOR Rb I LINES

PERTURBER DENSITY= 0.1E+15 cm <sup>-3</sup>							
PERTURBERS ARE:	ELECTRONS	PROTONS		IONIZED ARGON			
TRANSITION	T(K)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)
7S - 7P	2500.	1.05	0.664	0.350	0.166	*0.325	*0.933E-01
64519.9 A	5000.	1.26	0.620	0.360	0.188	0.329	0.107
C= 0.34E+19	10000.	1.59	0.547	0.373	0.214	0.333	0.122
	20000.	2.08	0.430	0.390	0.241	0.338	0.138
	30000.	2.39	0.376	0.401	0.258	0.341	0.148
	50000.	2.71	0.310	0.417	0.281	0.347	0.162
7S - 8P	2500.	0.608	0.430	0.176	0.104	*0.151	*0.571E-01
28267.4 A	5000.	0.689	0.435	0.186	0.120	*0.155	*0.670E-01
C= 0.35E+18	10000.	0.798	0.413	0.197	0.136	*0.159	*0.773E-01
	20000.	0.941	0.310	0.211	0.155	0.164	0.882E-01
	30000.	1.05	0.239	0.220	0.166	0.168	0.950E-01
	50000.	1.15	0.198	0.232	0.181	0.173	0.104
7P - 8S	2500.	2.02	0.919	0.577	0.234	*0.551	*0.132
84354.7 A	5000.	2.79	0.917	0.589	0.265	0.555	0.151
C= 0.57E+19	10000.	3.95	0.776	0.604	0.300	0.559	0.172
	20000.	5.46	0.622	0.622	0.338	0.564	0.195
	30000.	6.33	0.558	0.636	0.363	0.568	0.209
	50000.	7.29	0.436	0.655	0.395	0.574	0.228
8S - 8P	2500.	10.8	6.40	3.17	1.63	*2.86	*0.902
124647.9 A	5000.	13.4	6.51	3.30	1.87	*2.91	*1.05
C= 0.67E+19	10000.	16.9	5.01	3.45	2.13	*2.96	*1.21
	20000.	22.0	3.70	3.63	2.41	3.03	1.38
	30000.	24.9	2.94	3.76	2.59	3.07	1.48
	50000.	27.7	1.81	3.94	2.83	3.14	1.63
PERTURBER DENSITY= 0.1E+17 cm <sup>-3</sup>							
4D - 5P	2500.	0.367	0.122	0.122	0.309E-01	*0.117	*0.170E-01
15156.1 A	5000.	0.403	0.150	0.123	0.356E-01	*0.120	*0.199E-01
C= 0.10E+21	10000.	0.479	0.149	0.124	0.405E-01	0.121	0.230E-01
	20000.	0.616	0.143	0.126	0.460E-01	0.122	0.262E-01
	30000.	0.722	0.123	0.127	0.494E-01	0.122	0.283E-01
	50000.	0.872	0.102	0.128	0.539E-01	0.122	0.310E-01
4D - 6P	2500.	4.29	2.74	*1.31	*0.620		
22634.0 A	5000.	4.91	3.35	*1.39	*0.762		
C= 0.99E+20	10000.	5.51	3.56	1.47	0.903		
	20000.	6.29	3.44	1.56	1.05	*1.26	*0.581
	30000.	6.82	3.02	1.62	1.14	*1.28	*0.636
	50000.	7.68	2.57	1.71	1.25	*1.32	*0.707
4D - 7P	2500.	4.03	2.60				
11756.1 A	5000.	4.61	3.19				
C= 0.11E+20	10000.	5.13	3.19	*1.36	*0.811		
	20000.	5.73	3.00	*1.46	*0.973		
	30000.	6.20	2.70	*1.52	*1.07		
	50000.	6.82	2.19	*1.61	*1.19		



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PERTURBER DENSITY= 0.1E+17 cm <sup>-3</sup>							
PERTURBERS ARE:	ELECTRONS	PROTONS	IONIZED ARGON				
TRANSITION	T(K)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)
4D - 8P	2500.	7.07	4.25				
9529.3 A	5000.	7.96	5.18				
C= 0.39E+19	10000.	8.85	5.36				
	20000.	9.88	4.41				
	30000.	10.7	3.69				
	50000.	11.6	2.97				
5S - 6P	2500.	0.141	0.942E-01	*0.495E-01	*0.216E-01		
4206.4 A	5000.	0.162	0.113	*0.523E-01	*0.266E-01		
C= 0.34E+19	10000.	0.182	0.123	0.549E-01	0.315E-01		
	20000.	0.206	0.121	0.578E-01	0.366E-01	*0.483E-01	*0.203E-01
	30000.	0.222	0.106	0.598E-01	0.396E-01	*0.491E-01	*0.222E-01
	50000.	0.248	0.897E-01	0.626E-01	0.437E-01	*0.502E-01	*0.247E-01
5S - 7P	2500.	0.370	0.237				
3589.2 A	5000.	0.424	0.297				
C= 0.11E+19	10000.	0.472	0.298	*0.130	*0.757E-01		
	20000.	0.527	0.277	*0.139	*0.908E-01		
	30000.	0.568	0.240	*0.144	*0.997E-01		
	50000.	0.623	0.205	*0.152	*0.111		
5S - 8P	2500.	0.869	0.526				
3350.2 A	5000.	0.979	0.641				
C= 0.48E+18	10000.	1.09	0.663				
	20000.	1.21	0.548				
	30000.	1.31	0.463				
	50000.	1.42	0.372				
5P - 5D	2500.	0.620	0.398	*0.175	*0.859E-01		
7724.8 A	5000.	0.694	0.428	*0.187	*0.107		
C= 0.65E+19	10000.	0.806	0.413	0.199	0.128		
	20000.	0.977	0.331	0.213	0.148	*0.167	*0.819E-01
	30000.	1.09	0.291	0.222	0.161	*0.171	*0.899E-01
	50000.	1.21	0.258	0.235	0.178	*0.176	*0.100
5P - 6D	2500.	1.28	0.803				
6276.9 A	5000.	1.48	0.858				
C= 0.23E+19	10000.	1.75	0.831	*0.401	*0.239		
	20000.	2.10	0.655	*0.431	*0.287		
	30000.	2.31	0.575	*0.450	*0.316		
	50000.	2.52	0.459	*0.476	*0.352		
6S - 6P	2500.	5.27	3.03	*1.98	*0.708		
27474.6 A	5000.	6.04	3.22	*2.06	*0.858		
C= 0.15E+21	10000.	7.51	3.06	2.13	1.01		
	20000.	9.69	2.22	2.20	1.16	*1.98	*0.650
	30000.	11.3	1.89	2.25	1.26	*2.00	*0.709
	50000.	13.3	1.71	2.32	1.39	*2.02	*0.786

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PERTURBER DENSITY= 0.1E+17 cm <sup>-3</sup>							
PERTURBERS ARE:		ELECTRONS		PROTONS		IONIZED ARGON	
TRANSITION	T(K)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)
6S - 7P	2500.	4.77	3.05				
12940.3 A	5000.	5.46	3.62				
C= 0.14E+20	10000.	6.19	3.73	*1.65	*0.952		
	20000.	7.07	3.05	*1.77	*1.14		
	30000.	7.82	2.70	*1.84	*1.25		
	50000.	8.72	2.28	*1.94	*1.39		
6S - 8P	2500.	8.20	4.94				
10292.8 A	5000.	9.25	5.88				
C= 0.46E+19	10000.	10.3	6.05				
	20000.	11.7	4.86				
	30000.	12.7	3.98				
	50000.	13.8	3.30				
6P - 8S	2500.	12.8	8.11				
18962.7 A	5000.	14.4	9.96				
C= 0.29E+20	10000.	16.9	10.3	*3.30	*2.51		
	20000.	19.9	8.52	*3.68	*3.04		
	30000.	22.8	7.22	*3.93	*3.34		
	50000.	26.2	6.44	*4.27	*3.73		
6P - 6D	2500.	12.6	7.32				
20344.9 A	5000.	15.1	7.23				
C= 0.24E+20	10000.	18.6	6.25	*3.78	*2.31		
	20000.	23.8	4.78	*4.07	*2.76		
	30000.	26.7	4.32	*4.25	*3.03		
	50000.	29.3	3.20	*4.50	*3.37		
PERTURBER DENSITY= 0.1E+18 cm <sup>-3</sup>							
4D - 5P	2500.	3.67	1.17	*1.15	*0.264		
15156.1 A	5000.	4.03	1.47	1.21	0.324		
C= 0.10E+22	10000.	4.78	1.47	1.23	0.383		
	20000.	6.16	1.42	1.25	0.443	*1.20	*0.246
	30000.	7.22	1.23	1.26	0.480	*1.21	*0.269
	50000.	8.72	1.02	1.28	0.529	*1.22	*0.299
5S - 5P	2500.	0.722	0.422	*0.306	*0.922E-01		
7838.7 A	5000.	0.782	0.517	0.323	0.115		
C= 0.41E+21	10000.	0.877	0.527	0.333	0.138		
	20000.	1.09	0.457	0.343	0.160	*0.316	*0.883E-01
	30000.	1.26	0.377	0.349	0.174	*0.319	*0.970E-01
	50000.	1.54	0.297	0.358	0.192	*0.322	*0.108
5S - 6P	2500.	1.41	0.819				
4206.4 A	5000.	1.62	1.04				
C= 0.34E+20	10000.	1.82	1.17				
	20000.	2.06	1.17				
	30000.	2.22	1.03	*0.595	*0.361		
	50000.	2.48	0.884	*0.625	*0.409		



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PERTURBER DENSITY= 0.1E+18 cm <sup>-3</sup>							
PERTURBER TRANSITION	SARE: T(K)	ELECTRONS WIDTH(A)	SHIFT(A)	PROTONS WIDTH(A)	SHIFT(A)	IONIZED ARGON WIDTH(A)	SHIFT(A)
5S - 7P 3589.2 A C= 0.11E+20	2500.	*3.66	*1.75				
	5000.	4.23	2.53				
	10000.	4.72	2.67				
	20000.	5.26	2.56				
	30000.	5.68	2.26				
	50000.	6.23	1.98				
5S - 8P 3350.2 A C= 0.48E+19	2500.						
	5000.	*9.54	*4.66				
	10000.	*10.7	*5.39				
	20000.	12.0	4.65				
	30000.	13.1	4.04				
	50000.	14.1	3.44				
5P - 6S 13556.7 A C= 0.67E+21	2500.	6.89	4.20	*1.55	*.728		
	5000.	7.92	5.32	*1.75	*1.06		
	10000.	8.89	6.45	*1.93	*1.37		
	20000.	10.3	6.48	*2.14	*1.66		
	30000.	11.2	5.80	2.26	1.83		
	50000.	12.9	4.87	2.44	2.04	*1.57	*1.12
5P - 7S 7377.7 A C= 0.84E+20	2500.	7.48	4.15				
	5000.	8.59	5.46				
	10000.	9.28	6.29				
	20000.	10.4	6.44				
	30000.	11.0	5.82				
	50000.	12.6	5.01	*2.61	*2.17		
5P - 8S 6138.9 A C= 0.30E+20	2500.	*14.0	*6.32				
	5000.	*16.4	*9.27				
	10000.	17.1	9.99				
	20000.	19.1	9.85				
	30000.	21.0	8.97				
	50000.	23.8	7.50				
5P - 5D 7724.8 A C= 0.65E+20	2500.	6.19	3.42				
	5000.	6.94	3.88				
	10000.	8.06	3.89				
	20000.	9.77	3.20				
	30000.	10.9	2.83	*2.21	*1.45		
	50000.	12.1	2.56	*2.35	*1.65		
5P - 6D 6276.9 A C= 0.23E+20	2500.	*12.6	*5.99				
	5000.	14.7	7.12				
	10000.	17.4	7.29				
	20000.	21.0	6.19				
	30000.	23.1	5.46				
	50000.	25.2	4.53				



## STARK BROADENING PARAMETER TABLES FOR Rb I LINES

PERTURBER DENSITY = $0.1E+19 \text{ cm}^{-3}$							
PERTURBERS ARE:		ELECTRONS		PROTONS		IONIZED ARGON	
TRANSITION	T(K)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)	WIDTH(A)	SHIFT(A)
5S - 5P	2500.	7.17	3.61				
7838.7 A	5000.	7.81	4.75				
C = $0.41E+22$	10000.	8.76	4.97				
	20000.	10.9	4.35	*3.35	*1.39		
	30000.	12.6	3.61	*3.45	*1.56		
	50000.	15.4	2.90	*3.56	*1.78		
	5S - 6P	2500.	*13.2	*4.14			
4206.4 A	5000.	*16.0	*7.52				
C = $0.34E+21$	10000.	18.1	9.68				
	20000.	20.6	10.3				
	30000.	22.2	9.29				
	50000.	24.7	8.39				

method of Bates and Damgaard (1949) and tables of Oertel and Shomo (1968). For the transitions including higher atomic energy levels, the method described by Van Regemorter et al. (1979) has been used.

Our results are shown in Table 1 for perturber densities  $10^{14}$  and  $10^{16} - 10^{18} \text{ cm}^{-3}$  and temperatures of  $T = 2,500; 5,000; 10,000; 20,000; 30,000$  and  $50,000 \text{ K}$ . We also specify a parameter  $c$  (Dimitrijević and Sahal-Bréchet, 1984) which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the electron-impact full width at half maximum. The presented data, together with the data published in the principal article (Dimitrijević and Sahal-Bréchet, 1993) enable a good interpolation for densities when a departure from the linear behaviour with  $N$  exists.

For each value given in Table 1, the collision volume ( $V$ ) multiplied by the perturber density ( $N$ ) is much less than one and the impact approximation is valid (Sahal-Bréchet, 1969 a b). Values for  $NV > 0.5$  are not given in Table 1; values for  $0.1 < NV \leq 0.5$  are denoted by an asterisk. When the impact approximation is not valid, the ion broadening contribution may be estimated by using quasistatic formulae (cf. Sahal-Bréchet (1991) or Griem (1974)).

The analysis of present results and comparison with available experimental and theoretical data is given in Dimitrijević and Sahal - Bréchet (1992 b).

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ТАБЕЛЈЕ ПАРАМЕТАРА ШТАРКОВОГ ШИРЕЊА ЛИНИЈА Rb I

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