

APPENDIX A

CROSS SECTIONS USED IN THE CR MODEL

Elastic cross sections

The e-ArI cross section for momentum transfer used in the solution of the Boltzmann equation are taken from a report by M. Hayashi, "Bibliography of Electron and Photon Cross Sections with Atoms and Molecules Published in the 20th Century - Argon", National Institute For Fusion Science, Report No. **NIFS-DATA-72**, Jan. 2003 and are shown in table A.1.

The ArII-e and ArIII-e are collisions between charged particles, so the cross sections for momentum transfer are given by [3]:

$$Q(v) = 4\pi b_0^2 \ln \left[1 + \left(\frac{\lambda_D}{b_0} \right)^2 \right]^{1/2} \quad (\text{A.1})$$

where $\lambda_D = \left(\frac{\epsilon_0 kT}{n_e e^2} \right)^{1/2}$ is the Debye length and

$$b_0 = \frac{Ze^2/4\pi\epsilon_0}{m_{12}v^2} \quad (\text{A.2})$$

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
0	6.30	1.0	1.42
0.01	4.20	1.2	1.70
0.012	4.00	1.5	2.09
0.015	3.69	2.0	2.84
0.02	3.20	2.5	3.56
0.025	2.80	3.0	4.31
0.03	2.48	4.0	5.78
0.035	2.20	5.0	7.68
0.04	1.98	6.0	9.71
0.05	1.59	8.0	13.7
0.06	1.32	10	16.1
0.08	0.913	12	16.4
0.10	0.599	15	13.7
0.125	0.391	20	9.30
0.15	0.255	25	6.68
0.175	0.162	30	5.16
0.20	0.108	40	3.59
0.225	0.0808	50	2.90
0.23	0.0781	60	2.54
0.235	0.0763	80	2.14
0.24	0.0765	100	1.91
0.245	0.0786	120	1.71
0.25	0.0816	150	1.46
0.275	0.103	200	1.12
0.3	0.139	250	0.873
0.35	0.216	300	0.713
0.4	0.310	400	0.518
0.5	0.507	500	0.397
0.6	0.690	600	0.315
0.7	0.888	800	0.219
0.8	1.07	1000	0.161
0.9	1.25	10000	0.00

Table A.1 – *e-ArI cross section for momentum transfer*

Inelastic cross sections

As for the momentum transfer, the excitation and ionization cross sections for ArI are taken by the same report.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
11.55	0.00	16	0.0466
11.6	0.00543	17	0.05
11.61	0.00643	18	0.0495
11.64	0.00699	19	0.0482
11.75	0.00714	20	0.0464
11.77	0.00815	25	0.0347
11.8	0.00832	30	0.0253
11.81	0.0084	35	0.018
12.1	0.00889	40	0.0132
12.2	0.0105	50	0.00694
12.4	0.015	60	0.00375
12.6	0.0191	70	0.00222
12.7	0.0204	80	0.00141
12.74	0.0208	100	0.000652
13.23	0.0221	150	0.00017
13.6	0.0251	175	0.0001
14	0.0265	200	0.000001
15	0.0369	1000	0.00

Table A.2 – Excitation ArI cross section for $E_L = 11.55$ eV.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
11.62	0.00	14.25	0.0292
11.81	0.00494	14.5	0.0322
11.90	0.00495	15.0	0.0373
11.94	0.00500	16	0.0449
12.00	0.00520	17	0.0520
12.04	0.00530	18	0.0565
12.1	0.00550	19	0.0608
12.2	0.00570	20	0.0658
12.4	0.00730	22	0.0700
12.5	0.00790	25	0.0740
12.6	0.00850	30	0.0760
12.65	0.00860	35	0.0770
12.7	0.00880	40	0.0765
12.74	0.00900	50	0.0743
12.8	0.00920	60	0.0715
12.9	0.00970	70	0.0685
13.00	0.0103	80	0.0650
13.29	0.0112	100	0.0585
13.30	0.0115	150	0.0480
13.4	0.0138	200	0.0410
13.5	0.0158	300	0.0320
13.82	0.0219	400	0.0262
14.0	0.0255	500	0.0222

Table A.3 – Excitation ArI cross section for $E_L = 11.62$ eV.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
11.72	0.00	14.0	0.00446
11.75	0.000202	15.0	0.00641
11.80	0.000378	16	0.00837
11.81	0.000400	17	0.0100
11.88	0.000431	18	0.0103
11.94	0.000473	19	0.0100
12.00	0.000579	20	0.00923
12.10	0.000837	22	0.00800
12.20	0.00108	25	0.00650
12.40	0.00174	30	0.00475
12.60	0.00248	35	0.00360
12.70	0.00276	40	0.00290
12.74	0.00287	50	0.00200
12.77	0.00291	60	0.00149
12.80	0.00292	70	0.00116
13.24	0.00325	80	0.000930
13.38	0.00330	100	0.000656
13.40	0.00341	150	0.000339
13.44	0.00354	200	0.000212
13.6	0.00396	300	0.000110

Table A.4 – Excitation ArI cross section for $E_L = 11.72$ eV.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
11.83	0.00	16	0.0947
12.00	0.00357	17	0.114
12.1	0.00400	18	0.130
12.2	0.00570	19	0.142
12.4	0.00870	20	0.154
12.5	0.0106	22	0.172
12.6	0.0125	25	0.197
12.65	0.0133	30	0.233
12.7	0.0140	35	0.263
12.74	0.0145	40	0.288
12.8	0.0154	50	0.313
12.9	0.0167	60	0.318
13.0	0.0184	70	0.311
13.08	0.0186	80	0.296
13.16	0.0192	100	0.266
13.25	0.0229	150	0.197
13.4	0.0265	200	0.160
13.5	0.0306	300	0.119
13.82	0.0432	350	0.106
14.5	0.0648	400	0.0963
15.0	0.0757	500	0.0822

Table A.5 – Excitation ArI cross section for $E_L = 11.83$ eV.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
14.71	0.00	50	0.178
15	0.00200	60	0.178
16	0.0100	80	0.165
18	0.0300	100	0.146
20	0.0480	150	0.112
22	0.0650	200	0.0930
25	0.0910	300	0.0690
30	0.124	500	0.0470
35	0.150	800	0.0330
40	0.165	1000	0.0280

Table A.6 – Excitation ArI cross section for $E_L = 14.71$ eV.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
15.20	0.00	50	0.193
16	0.00900	60	0.194
18	0.0320	80	0.173
20	0.0630	100	0.152
22	0.0850	150	0.115
25	0.112	200	0.0950
30	0.148	300	0.0710
35	0.170	500	0.0480
40	0.183	800	0.0330

Table A.7 – Excitation ArI cross section for $E_L = 15.20$ eV.

Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)	Energy (eV)	Cross section (10 ⁻¹⁶ cm ²)
15.76	0.00	30	1.80	75	2.82
16	0.0202	32	1.96	80	2.84
17	0.134	34	2.11	85	2.85
18	0.294	36	2.24	90	2.86
19	0.460	38	2.33	100	2.85
20	0.627	40	2.39	120	2.81
21	0.787	42.5	2.45	130	2.76
22	0.933	45	2.49	150	2.68
23	1.06	50	2.53	160	2.62
24	1.18	55	2.60	180	2.52
25	1.30	60	2.66	200	2.39
26	1.41	65	2.73	250	2.17
28	1.60	70	2.77	300	1.98

Table A.8 – Ionization ArI cross section from the ground level.

The other cross sections of the ArII levels used in the resolution of the Boltzmann equation are reported in the references [42]-[50].

The ArII cross section for excitation, ionization and radiative recombination used in the CR model are reported in reference [13].

Oscillator strength

The oscillator strengths used in the CR model are taken from the reference [35]. If any data are not available the following formulae are applied:

$$f_{pq} = 1.52 p^{-5} q^{-3} (p^{-2} - q^{-2})^{-3} \quad \text{if } \Delta p / p \ll 1 \quad (\text{A.3})$$

$$f_{pq} = 1.95 p^{-5} q^{-3} (p^{-2} - q^{-2})^{-3} \quad \text{if } \Delta p / p \gg 1 \quad (\text{A.4})$$