Abstract

We present in this work energy levels, oscillator strengths, radiative decay rates and fine structure collision strengths for the Mg III and Al IV ions. The 11 configurations:(1s²) 2s²2p⁶, 2s²2p³3l, 2s²p⁶3l, 2s²2p⁵4l (l ≤ n − 1, where n is the principal quantum number), yielding the lowest 75 levels are used. The collisional data for these two ions are missing in the literature, especially the database CHIANTI, this is the principal motivation behind the present work. Calculations have been performed using the AUTOSTRUCTURE code. AUTOSTRUCTURE treats the scattering problem in the distorted wave approach. Fine structure collision strengths are calculated for a range of electron energies from 10 Ry to 240 Ry. The atomic structure data are compared to available experimental and theoretical results.

Keywords: plasma diagnostics; X-ray spectra; atomic structure; impact excitation by electrons; line broadening

1. Introduction

Neon-like ions have a high abundance over a wide range of electron temperatures and densities because of their closed-shell configuration ground state. Due to its various applications in astrophysics, plasma physics and spectroscopy, they have been the subject of investigation for many years. The ions of this sequence play an important role in the diagnostics of a wide variety of laboratory and astrophysical plasmas. For example, the energies and transition rates are used for the determination of radiative opacities of stellar envelopes, the Opacity Project (Seaton, 1987), for spectral diagnostics of solar, stellar and laboratory plasmas, for plasma modelling and for laser research, particularly in the soft X-ray region (Lee et al., 1987; Elton, 1990; Matthews et al., 1985; Feldman et al., 1984). They are used to study transport and confinement of high-Z impurity ions in tokamaks. Furthermore, oscillator strengths are important for the study of laboratory and solar spectra (Borges et al., 2004). Mg III and Al IV are two ions belonging to the neon-like sequence.

The Mg III spectrum was extensively studied by Anderson (1971). Later, an experimental work on this spectrum was published by Lundström (1973). An extensive level classification and wavelengths have been compiled by Kaufman & Martin (1991a). Hibbert et al. (1993) have calculated configuration-interaction wave functions in intermediate coupling for the states 2s²2p⁶, 2s²2p³3l (l = 0, 1, 2), and 2s²2p⁶3l (l = 0, 1, 2) of neon-like ions Ne I through Kr XXVII, incorporating variationally optimized orbitals and a modified Breit-Pauli Hamiltonian into the code CIV3. They have presented the percentage LS compositions of the LSJ levels, together with their energies, oscillator strengths, and probabilities of transition between them. Lifetimes of 2s²2p⁵3l levels have been also presented. More recently and using the multi-configuration Hartree-Fock (MCHF) method with relativistic effects, Froese Fischer & Tachiev (2004) have obtained energy levels and transitions probabilities for transitions between computed levels for the Be-like (4 ≤ Z ≤ 12) to Ne-like (10 ≤ Z ≤ 24) sequences including the Mg III and Al IV ions (Z is the nuclear charge). A recent experimental study of Mg III was published (Brown et al., 2009). Further analyzes of the Mg III spectra have been performed and about 60 unobserved levels have been predicted (Liang et al., 2010) using the multichannel quantum defect theory (MQDT). The most recent results are those of Beiersdorfer et al. (2011), where the radiative decay rates of the (2s²2p⁵5l)⁰ = 0 level in neon-like ions have been calculated for nuclear charges ranging from Z = 10 to Z = 110.

In Artru & Kaufman (1975), a total of 225 new lines of Al IV have been observed in the wavelength range of 400–4700 Å, leading to the determination of all of the levels of the 2p⁵4p, 4d, 4f, 5s, 5f, and 5g configurations. Martin & Zalubas (1979) have published energy levels for the atom and all positive ions of aluminium, where the authors have critically compiled their data using the published material on measurements and analyzes of the optical spectra. An extensive level classification and wavelengths for Al IV have been compiled by Kaufman & Martin (1991b). A more recent compilation of atomic transition probabilities for about 5000 lines of aluminium in all its ionization stages (except the hydrogenic one) has been published by

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Kelleher & Podobedova (2008).

To our best knowledge, there are no distorted wave fine structure collision strengths for the Mg III and Al IV ions to compare with. Although the number of published papers dedicated to the atomic structure of Mg III and Al IV is important, the only published electron scattering calculations are those of Ganas & Green (1980) and Liang & Badnell (2010). In Ganas & Green (1980), integrated cross sections for incident electron energies ranging from threshold to 5 keV were calculated for the 2p3s resonance transition along the neon-like sequence. The authors in Ganas & Green (1980) used an analytic atomic independent particle model potential adjusted to experimental energy levels to generate wave functions for the ground and excited states of the considered ions. The obtained wave functions are used in conjunction with the Born approximation and the LS-coupling scheme to obtain generalized oscillator strengths, which are used to calculate integrated cross sections. The method of deriving generalized oscillator strengths and the formula used to obtain cross sections may be found in Ganas (1998). In Liang & Badnell (2010), electron impact excitation data were calculated for Ne-like ions from Na II to Kr XXVII using the intermediate-coupling frame transformation R-matrix approach, and the results of effective collision strengths were presented.

The principal motivation behind the present work is the missed collisional data for the two ions Mg III and Al IV in many databases. These data can be useful for many astrophysical investigations. Besides the importance of the structural and collisional data of multicharged ions in astrophysical and laboratory plasmas investigations, collision strengths have another importance which is related to another field of investigation: the comparison of these data to the accuracy of the atomic and collisional ones. This represents an other motivation and interest of the present work. Indeed, our line broadening method is ab initio, this means that all the parameters required for the line broadening calculations such as radiative atomic data (energy levels, oscillator strengths...) and collisional data (collision strengths or cross sections, scattering matrices...) are evaluated during the calculation and not taken from other data sources. Consequently, the accuracy of our broadening parameters is strongly related to the accuracy of the atomic and collisional ones. This represents an other motivation and interest of the present work.

The aim of this paper is to provide fine structure collision strengths for Mg III and Al IV transitions in the distorted wave approximation. The atomic structure has been calculated for the 75 levels arising from the eleven configurations \((1s^2)\ 2s^2 2p^6, 2s^2 2p^5 3l, 2s2p^63l, 2s^2 2p^5 4l (l \leq n - 1)\). Collision strengths have been computed for transitions from the ground and the four first excited levels to all the levels. The incoming electron energies used in our calculations are between 10 Ry and 240 Ry. Discussions and investigations of convergence of collision strengths with energy and with total angular momentum \(J^T\) are also given. Only the atomic structure data are compared to available experimental and theoretical results.

2. Atomic structure and electron-ion scattering

The atomic structure has been calculated using the AUTOSTRUCTURE (AS) code (Badnell, 1986, 1997) by constructing target wavefunctions using radial wavefunctions calculated in a scaled Thomas-Fermi-Dirac-Amaldi statistical model potential using the Breit-Pauli intermediate coupling (Bethe & Salpeter, 1957). The radial scaling parameters \(\lambda_{nl}\) (depending on \(n\) and \(l\)) are determined by minimizing the sum of the energies of all the target terms, computed in \(LS\) coupling, i.e. neglecting all relativistic effects. In this code, besides the one-body and the two-body fine structure interactions, the two-body non-fine structure operators of the Breit-Pauli Hamiltonian, namely contact spin-spin, two-body Darwin and orbit-orbit are incorporated. More details of how these interactions are incorporated are reported in Badnell (1997).

Recently, the Breit-Pauli Distorted Wave (BPDW) approach for electron impact excitation of atomic ions has been implemented in the AS code (Badnell, 2011), which we use for the scattering problem in the present paper. We note that the distorted wave approximation (DW) is adequate for moderately and highly charged ions and the agreement between the DW and more sophisticated methods (close coupling for example) is good. Collision strengths are calculated at the same set of final scattered energies for all transitions: zero gives all threshold transitions, for example. For large \(l\) values, a ‘top up’ for dipole transitions makes use of the sum rule of Burgess (1974). For higher multipoles, a geometric series in energy in combination with the degenerate energy limit (Burgess, 1970) is used to take into account of large \(l\) contributions to collision strengths.

3. Results and discussions

3.1. Structure

Eleven configurations: \((1s^2)\ 2s^2 2p^6, 2s^2 2p^5 3l, 2s2p^63l, 2s^2 2p^5 4l (l \leq n - 1)\) have been used in AUTOSTRUCTURE to study the atomic structure of the Mg III and Al IV ions. This set of configurations gives rise to 75 fine structure levels. The radial scaling parameters \(\lambda_{nl}\) used in the code AUTOSTRUCTURE for the two ions are listed in the Table 1. The energy levels of Mg III are listed in Table 2. We have presented a comparison of our Mg III energies with the NIST (Kramida et al., 2012) values, with those of Froese Fischer & Tachiev (2004) and with the results of Liang & Badnell (2010). The wavefunctions in Froese Fischer & Tachiev (2004) were determined using the multi-configuration HartreeFock (MCHF) method with relativistic effects included through the BreitPauli Hamiltonian,
where only the orbit-orbit interaction was omitted. In Liang & Badnell (2010), the authors used the code AUTOSTRUCTURE but with a 31-configuration model. Our ground level 1s22s2p5 1S0 energy has been shifted by +24993 cm\(^{-1}\). This shift is obtained by the difference between the center of gravity of levels 2−27 for calculated and compiled energies by NIST (Kramida et al., 2012). After adjustment, our results become in an excellent agreement (less than 1\% with those of Froese Fischer & Tachiev (2004) and Liang & Badnell (2010). It is important to note that, even the authors in Liang & Badnell (2010) used more configurations than we used in the present work, we prefer to present our energy levels and compare them with other results. This is because the collision strengths presented in the next subsection are calculated using our 11-configuration model energies. So, it is better to present coherent structural and collisional data derived from the same model. We present in Table 3 our line strengths, oscillator strengths and transition probabilities for spontaneous emission for the Mg III allowed transitions (E1). The comparison between our results and those of the MCHF calculations shows that the relative differences between them are about 12\% for line strengths, 11\% for oscillator strengths and 10\% for transition probabilities. Our Al IV adjusted energies are also compared with the MCHF (Froese Fischer & Tachiev, 2004) results and results of Liang & Badnell (2010) in Table 4. The same procedure of the ground level adjustment has been adopted as for Mg III, and we have shifted the ground level energy by +22339 cm\(^{-1}\). Excellent agreement has been found between our results and the two other ones. Line strengths, oscillator strengths and transition probabilities of Al IV are presented in Table 5. The relative differences between our results and those of Froese Fischer & Tachiev (2004) are of the same order of magnitude as those of the Mg III ion. The averaged relative difference between the two methods is about 10\%. In the following, some common remarks of the two ions will be drawn. Firstly, an inversion of some levels is found between our energies and those of NIST (Kramida et al., 2012) and Froese Fischer & Tachiev (2004). The inverted levels are denoted by asterisks in Tables 2 and 4. Secondly, our adjusted energies have been used (instead of the calculated ones) to evaluate the present radiative data (line strengths, oscillator strengths and transition probabilities). Thirdly, the worse disagreement for level energies is about 1.6\% and has been found for the level 2s22p53p 1S0 (level 15 in Tables 2 and 4). We found that the energy of level 15 before the adjusting process had the best agreement with the MCHF results of Froese Fischer & Tachiev (2004) (about 1.6\%), and all the other energies have a relative difference of about 3\%. After adjustment of our ground level, all the level energies become in agreement with the MCHF results except the energy of the level 15. Finally, we found that the highest difference (about 30\%) between our results and those of the MCHF method (Froese Fischer & Tachiev, 2004) has been found for the two transitions 2s22p53s 1P1−2s22p53p 3D2 and 2s22p53s 1P1−2s22p53p 3D1 (transitions 5−8 and 5−9 in Tables 3 and 5).

3.2. Collision problem

Collision problem has been treated in the distorted wave approximation using the AUTOSTRUCTURE code. We present in Tables 6, 7, 8, 9 and 10 Mg III collision strengths from the ground level and from the first four excited levels to all the other levels. Our collision strengths have been computed for five energies 10, 20, 40, 80 and 160 Ry. In Tables 11, 12, 13, 14 and 15 Al IV collision strengths from the ground level and from the first four excited levels to all the other levels are presented. The incoming electron energies used are 15, 30, 60, 120 and 240 Ry. To our best knowledge, there are no distorted wave collision strengths for Mg III or Al IV to compare with. In Liang & Badnell (2010), electron impact excitation data were calculated for Ne-like ions from Na II to Kr XXVII using the intermediate-coupling frame transformation R-matrix approach, and only the results of effective collision strengths were presented. Any other collision calculations for these two ions will be very helpful for two reasons. Firstly, to compare with our results and to decide about their applicability in astrophysics and plasma diagnostics. Secondly, since collision strengths (and other collisional parameters like scattering matrices, cross sections...) are used in our line broadening calculations, their comparison with collision strengths derived from other different methods will be very interesting for the evaluation of our line broadening results. We hope that the structural and collisional data presented in this paper will be useful in spectral diagnostics and modelling of astrophysical and laboratory plasmas, laser development and tokamaks research.

4. Conclusion

We have calculated energy levels, oscillator strengths and radiative decay rates for the two neon-like ions Mg III and Al IV. We have used eleven configurations: (1s2) 2s22p6, 2s22p53l, 2s2p63l, 2s2p54l (l \leq n − 1) yielding 75 fine structure levels. The atomic structure has been studied using the AUTOSTRUCTURE code. We have compared our level energies with the NIST values and with the multiconfiguration Hartree-Fock ones. We find that the agreement (after adjustment of the ground level energy) is much better than 1\%. The agreement for the oscillator strengths and the radiative decay rates is about 12\%.

Fine structure collision strengths have been calculated in the distorted wave approximation using the AUTOSTRUCTURE code at five electron energies: 10, 20, 40, 80 and 160 Ry for Mg III and 15, 30, 60, 120 and 240 Ry for Al IV. We have presented our collision strengths between the ground and the four first excited levels to all other
Acknowledgments

This work has been supported by the Tunisian research unit 05/UR/12-04.

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Table 1: Radial scaling parameters $\lambda_{nf}$ used in AUTO Structure.

| Ion | 1s   | 2s   | 2p   | 3s   | 3p   | 3d   | 4s   | 4p   | 4d   | 4f   |
|-----|------|------|------|------|------|------|------|------|------|------|
| Mg  | 1.6229 | 1.1129 | 1.0581 | 0.9879 | 0.9582 | 0.9140 | 1.0035 | 0.9466 | 0.9115 | 0.8629 |
| Al  | 1.6596 | 1.1231 | 1.0641 | 1.0068 | 0.9709 | 0.9411 | 1.0243 | 0.9599 | 0.9401 | 0.9034 |

Table 2: Mg III energy levels in cm$^{-1}$. $E$: present results, $E_{\text{NIST}}$: energies reported by NIST (Kramida et al., 2012) and taken from Martin & Zalubas (1980), $E_{\text{MCHF}}$: Hartree-Fock energies (Froese Fischer & Tachiev, 2004), $E_{\text{LB10}}$: energies calculated in Liang & Badnell (2010) by AUTO Structure using 31 configurations. Levels denoted by asterisks (*) are inverted compared to our values.

| $l$ | $\text{Conf.}$ | $\text{Level}$ | $E$  | $E_{\text{NIST}}$ | $E_{\text{MCHF}}$ | $E_{\text{LB10}}$ |
|-----|----------------|----------------|------|-------------------|-------------------|------------------|
| 1   | $2s^22p^6$     | $1S_0$         | 0    | 0                 | 0                 | 0                |
| 2   | $2s^22p^3$3s   | $3P_2$         | 426260 | 425640.3          | 425638.16         | 424178.0         |
| 3   | $2s^22p^3$3s   | $3P_1$         | 427481 | 426868.1          | 426861.97         | 425391.0         |
| 4   | $2s^22p^3$3s   | $3P_0$         | 428462 | 427852.1          | 427834.77         | 426313.0         |
| 5   | $2s^22p^3$3s   | $1P_1$         | 432100 | 431530.0          | 431569.27         | 430399.0         |
| 6   | $2s^22p^3$3p   | $3S_1$         | 468025 | 467378.5          | 467378.97         | 465349.0         |
| 7   | $2s^22p^3$3p   | $3D_3$         | 474034 | 474053.2          | 474052.45         | 472851.0         |
| 8   | $2s^22p^3$3p   | $3D_2$         | 474656 | 474655.0          | 474651.63         | 473453.0         |
| 9   | $2s^22p^3$3p   | $3D_1$         | 475504 | 475502.9          | 475492.16         | 474277.0         |
| 10  | $2s^22p^3$1D_2 | 477190         | 478846.1 | 477440.27      | 476441.0         |
| 11  | $2s^22p^3$1D_2 | 478245         | 479456.0 | 478376.48      | 477572.0         |
| 12  | $2s^22p^3$1D_2 | 478609         | 479265.3 | 478844.95      | 477886.0         |
| 13  | $2s^22p^3$1D_2 | 479049         | 479435.7 | 479272.29      | 478393.0         |
| 14  | $2s^22p^3$1D_2 | 479238         | 478374.5 | 479455.80      | 478598.0         |
| 15  | $2s^22p^3$1D_2 | 505651         | 496012.1 | 496012.43      | 505219.0         |
| 16  | $2s^22p^3$3P_0 | 529081         | 530178.2 | 530181.62      | 528446.0         |
| 17  | $2s^22p^3$3P_1 | 529326         | 530420.6 | 530422.66      | 528695.0         |
| 18  | $2s^22p^3$3P_2 | 529869         | 530962.9 | 530961.40      | 529244.0         |
| 19  | $2s^22p^3$3P_3 | 530598         | 531563.0 | 531563.27      | 530078.0         |
| 20  | $2s^22p^3$3P_3 | 530931         | 531833.1 | 531828.43      | 530383.0         |
| 21  | $2s^22p^3$3P_3 | 531752         | 532725.7 | 532715.89      | 531233.0         |
| 22  | $2s^22p^3$3P_3 | 532080         | 532971.2 | 532973.68      | 531550.0         |
| 23  | $2s^22p^3$3P_3 | 533321         | 534197.7 | 534771.87      | 532853.0         |
| 24  | $2s^22p^3$3D_2 | 533807         | 534776.9 | 534205.42      | 533310.0         |
| 25  | $2s^22p^3$3D_2 | 533931         | 534923.6 | 534918.56      | 533429.0         |
| 26  | $2s^22p^3$3D_2 | 534164         | 535179.6 | 535173.97      | 533690.0         |
| 27  | $2s^22p^3$3P_1 | 535401         | 536152.0 | 536156.03      | 534805.0         |
| 28  | $2s^22p^3$3P_0 | 534510         | 545813.46 | 545193.0      |
| 29  | $2s^22p^3$3P_1 | 545231         | 546532.94 | 545933.0      |
| 30  | $2s^22p^3$3P_0 | 546705         | 548017.37 | 547312.0      |
| 31  | $2s^22p^3$3P_0 | 547412         | 548720.99 | 548088.0      |
| 32  | $2s^22p^3$3P_1 | 559232         | 559009.0 |
| 33  | $2s^22p^3$3P_0 | 560481         | 560898.0 |
| 34  | $2s^22p^3$3P_0 | 560788         | 561268.0 |
| 35  | $2s^22p^3$3P_0 | 561227         | 561793.0 |
| 36  | $2s^22p^3$3P_0 | 561434         | 562149.0 |
| 37  | $2s^22p^3$3P_0 | 562890         | 563533.0 |
| 38  | $2s^22p^3$3D_2 | 562912         | 563365.0 |
| 39  | $2s^22p^3$3D_2 | 563205         | 563767.0 |
| 40  | $2s^22p^3$3P_1 | 563262         | 563854.0 |
| 41  | $2s^22p^3$3P_0 | 576696         | 574235.0 |
| 42  | $2s^22p^3$3D_2 | 579959         | 580886.0 |
| i  | Conf. | Level | $E_{\text{NIST}}$ | $E_{\text{MCHF}}$ | $E_{\text{LB10}}$ |
|----|-------|-------|-------------------|-------------------|-----------------|
| 43 | $2s^22p^34d$ | $^3P_1^0$ | 580127 | 580886.0 |
| 44 | $2s^22p^34d$ | $^3P_2^0$ | 580457 | 581443.0 |
| 45 | $2s^22p^34d$ | $^3F_4^0$ | 580476 | 581590.0 |
| 46 | $2s^22p^34d$ | $^3F_3^0$ | 580662 | 581800.0 |
| 47 | $2s^22p^34d$ | $^1D_2^0$ | 581092 | 582275.0 |
| 48 | $2s^22p^34d$ | $^3D_3^0$ | 581187 | 582408.0 |
| 49 | $2s^22p^34d$ | $^3D_1^0$ | 581937 | 583236.0 |
| 50 | $2s^22p^34f$ | $^3D_1^0$ | 582249 | 583537.0 |
| 51 | $2s^22p^34f$ | $^3D_2^0$ | 582260 | 583549.0 |
| 52 | $2s^22p^34f$ | $^3G_5^0$ | 582394 | 583687.0 |
| 53 | $2s^22p^34f$ | $^1G_4^0$ | 582397 | 583688.0 |
| 54 | $2s^22p^34f$ | $^3D_3^0$ | 582477 | 583775.0 |
| 55 | $2s^22p^34f$ | $^1D_2^0$ | 582486 | 583781.0 |
| 56 | $2s^22p^34f$ | $^1F_3^0$ | 582614 | 583917.0 |
| 57 | $2s^22p^34f$ | $^3F_4^0$ | 582616 | 583920.0 |
| 58 | $2s^22p^34d$ | $^3F_3^0$ | 582953 | 584052.0 |
| 59 | $2s^22p^34d$ | $^1F_3^0$ | 583068 | 584189.0 |
| 60 | $2s^22p^34d$ | $^3D_2^0$ | 583071 | 584184.0 |
| 61 | $2s^22p^34d$ | $^1P_1^0$ | 584053 | 585339.0 |
| 62 | $2s^22p^34f$ | $^3F_3^0$ | 584676 | 585905.0 |
| 63 | $2s^22p^34f$ | $^3G_3^0$ | 584682 | 585907.0 |
| 64 | $2s^22p^34f$ | $^3F_2^0$ | 584683 | 585910.0 |
| 65 | $2s^22p^34f$ | $^3G_4^0$ | 584685 | 585911.0 |
| 66 | $2s^2p^53s$ | $^3S_1^0$ | 760404 | 761263.0 |
| 67 | $2s^2p^53s$ | $^1S_0^0$ | 771523 | 771417.0 |
| 68 | $2s^2p^53p$ | $^3P_0^0$ | 807679 | 807900.0 |
| 69 | $2s^2p^53p$ | $^3P_1^0$ | 807716 | 807979.0 |
| 70 | $2s^2p^53p$ | $^3P_2^0$ | 807801 | 808146.0 |
| 71 | $2s^2p^53p$ | $^1P_1^0$ | 810617 | 812511.0 |
| 72 | $2s^2p^53d$ | $^3D_2^0$ | 862962 | 865827.0 |
| 73 | $2s^2p^53d$ | $^3D_1^0$ | 862962 | 865822.0 |
| 74 | $2s^2p^53d$ | $^3D_3^0$ | 862962 | 865835.0 |
| 75 | $2s^2p^53d$ | $^1D_2^0$ | 863989 | 866676.0 |
Table 3: Line strengths ($S$), oscillator strengths ($f_{ij}$), and radiative decay rates ($A_{ji}$) for some Mg III lines. Our results (Present) are compared with the Hartree-Fock (MCHF) values (Froese Fischer & Tachiev, 2004).

| Transition | $S$       | $f_{ij}$       | $A_{ji}$ (s$^{-1}$) |
|------------|-----------|----------------|---------------------|
| $i - j$    | Present   | MCHF           | Present             | MCHF                |
| 1 - 3      | 1.22E−02  | 8.946E−03      | 1.594E−02           | 1.160E−02           | 6.477E+08 | 4.700E+08 |
| 1 - 5      | 2.113E−01 | 1.687E−01      | 2.773E−01           | 2.212E−01           | 1.151E+10 | 9.160E+09 |
| 1 - 17     | 2.424E−03 | 1.931E−03      | 3.897E−03           | 3.111E−03           | 2.428E+08 | 1.946E+08 |
| 1 - 23     | 1.367E−01 | 1.220E−01      | 2.215E−01           | 1.980E−01           | 1.401E+10 | 1.257E+10 |
| 2 - 6      | 3.792E+00 | 3.404E+00      | 9.621E−02           | 8.631E−02           | 1.866E+08 | 1.672E+08 |
| 2 - 7      | 1.390E+01 | 1.282E+01      | 4.035E−01           | 3.772E−01           | 4.388E+08 | 4.212E+08 |
| 2 - 8      | 3.494E+00 | 3.226E+00      | 1.027E−01           | 9.605E−02           | 1.605E+08 | 1.539E+08 |
| 2 - 9      | 4.523E−01 | 3.980E−01      | 1.353E−02           | 1.205E−02           | 3.648E+07 | 3.331E+07 |
| 2 - 10     | 3.438E+00 | 3.015E+00      | 1.064E−01           | 9.489E−02           | 1.840E+08 | 1.698E+08 |
| 2 - 11     | 5.234E−01 | 4.240E−01      | 1.653E−02           | 1.359E−02           | 4.966E+07 | 4.201E+07 |
| 2 - 12     | 2.862E+00 | 2.885E+00      | 9.102E−02           | 9.326E−02           | 1.664E+08 | 1.761E+08 |
| 2 - 14     | 1.183E+00 | 1.219E+00      | 3.809E−02           | 3.985E−02           | 1.188E+08 | 1.283E+08 |
| 3 - 6      | 1.703E+00 | 1.539E+00      | 6.990E−02           | 6.314E−02           | 7.663E+07 | 6.914E+07 |
| 3 - 8      | 6.289E+00 | 5.821E+00      | 3.004E−01           | 2.817E−01           | 2.675E+08 | 2.575E+08 |
| 3 - 9      | 3.325E+00 | 3.024E+00      | 1.616E−01           | 1.489E−01           | 2.486E+08 | 2.349E+08 |
| 3 - 10     | 1.054E+00 | 9.421E−01      | 5.304E−02           | 4.825E−02           | 5.245E+07 | 4.940E+07 |
| 3 - 11     | 3.869E−01 | 3.543E−01      | 1.989E−02           | 1.848E−02           | 3.418E+07 | 3.271E+07 |
| 3 - 12     | 2.561E+00 | 2.401E+00      | 1.326E−01           | 1.264E−01           | 1.387E+08 | 1.367E+08 |
| 3 - 13     | 1.873E+00 | 1.767E+00      | 9.785E−02           | 9.379E−02           | 5.207E+08 | 5.155E+08 |
| 3 - 14     | 5.431E−01 | 5.568E−01      | 2.846E−02           | 2.965E−02           | 5.085E+07 | 5.470E+07 |
| 4 - 6      | 4.969E−01 | 4.531E−01      | 5.972E−02           | 5.443E−02           | 2.078E+07 | 1.892E+07 |
| 4 - 9      | 2.149E+00 | 2.056E+00      | 3.070E−01           | 2.976E−01           | 1.511E+08 | 1.503E+08 |
| 4 - 11     | 1.769E+00 | 1.398E+00      | 2.674E−01           | 2.146E−01           | 1.474E+08 | 1.219E+08 |
| 4 - 14     | 1.515E+00 | 1.570E+00      | 2.337E−01           | 2.462E−01           | 1.339E+08 | 1.459E+08 |
| 5 - 6      | 3.399E−02 | 3.114E−02      | 1.236E−03           | 1.129E−03           | 1.064E+06 | 9.658E+05 |
| 5 - 8      | 1.735E−01 | 1.365E−01      | 7.477E−03           | 5.953E−03           | 5.419E+06 | 4.422E+06 |
| 5 - 9      | 3.238E−02 | 2.219E−02      | 1.423E−03           | 9.868E−04           | 1.788E+06 | 1.270E+06 |
| 5 - 10     | 5.574E+00 | 5.409E+00      | 2.545E−01           | 2.512E−01           | 2.071E+08 | 2.116E+08 |
| 5 - 11     | 3.270E+00 | 3.404E+00      | 1.528E−01           | 1.613E−01           | 2.170E+08 | 2.357E+08 |
| 5 - 12     | 4.479E+00 | 3.932E+00      | 2.109E−01           | 1.882E−01           | 1.826E+08 | 1.683E+08 |
| 5 - 13     | 7.555E−02 | 5.492E−02      | 3.591E−03           | 2.653E−03           | 1.584E+07 | 1.208E+07 |
| 5 - 14     | 2.659E+00 | 2.169E+00      | 1.269E−01           | 1.051E−01           | 1.881E+08 | 1.608E+08 |
| i   | Conf. | Level   | E   | E_{\text{NIST}} | E_{\text{MCHF}} | E_{\text{LB10}} |
|-----|-------|---------|-----|-----------------|-----------------|-----------------|
| 1   | 2s^22p^6 | ^1S_0   | 0   | 0               | 0               | 0               |
| 2   | 2s^22p^3s^1 | ^3P_0 | 616706 | 616644.2 | 616643.56 | 615386.0 |
| 3   | 2s^22p^3s^3 | ^3P_2 | 618536 | 618473.9 | 618470.83 | 617213.0 |
| 4   | 2s^22p^3s^3 | ^3P_0 | 620113 | 620060.1 | 620050.63 | 618711.0 |
| 5   | 2s^22p^3s^1 | ^1P_1 | 624841 | 624717.5 | 624721.95 | 623896.0 |
| 6   | 2s^22p^3p^3 | ^3P_1 | 671875 | 671632.5 | 671634.22 | 669906.0 |
| 7   | 2s^22p^3p^3 | ^3D_1 | 680859.8 | 680859.51 | 679917.0 |
| 8   | 2s^22p^3p^3 | ^3D_0 | 681390 | 681683.3 | 681680.35 | 680740.0 |
| 9   | 2s^22p^3p^3 | ^3D_1 | 682981.8 | 682968.11 | 682025.0 |
| 10  | 2s^22p^3p^3 | ^3P_0 | 685179 | 687830.5 | 687823.79* | 687014.0 |
| 11  | 2s^22p^3p^3 | ^1P_1 | 686612 | 686959.1* | 686959.06* | 686396.0 |
| 12  | 2s^22p^3p^0 | ^3P_0 | 687302 | 688309.6 | 688303.59* | 687617.0 |
| 13  | 2s^22p^3p^3 | ^1D_2 | 687816 | 685752.8* | 685732.60* | 684895.0 |
| 14  | 2s^22p^3p^3 | ^3P_1 | 688162 | 688649.4 | 688642.76 | 687988.0 |
| 15  | 2s^22p^3p^3 | ^1S_0 | 725669 | 714096.9 | 714097.28 | 724385.0 |
| 16  | 2s^22p^3d^3 | ^3P_0 | 757933 | 759193.4 | 759195.79 | 758177.0 |
| 17  | 2s^22p^3d^3 | ^3P_1 | 758340 | 759566.8 | 759566.88 | 758595.0 |
| 18  | 2s^22p^3d^3 | ^3P_0 | 759218 | 760472.3 | 760466.93 | 759487.0 |
| 19  | 2s^22p^3d^0 | ^3P_0 | 760660 | 761688.4 | 761689.66 | 761052.0 |
| 20  | 2s^22p^3d^3 | ^3P_1 | 761318 | 762272.5 | 762273.51 | 761666.0 |
| 21  | 2s^22p^3d^3 | ^3P_0 | 762575 | 763613.6 | 763602.97 | 762953.0 |
| 22  | 2s^22p^3d^3 | ^1P_1 | 763443 | 764297.1 | 764302.67 | 763801.0 |
| 23  | 2s^22p^3d^3 | ^3D_1 | 765871 | 766880.8 | 766881.57* | 766393.0 |
| 24  | 2s^22p^3d^3 | ^1D_2 | 766039 | 767035.7* | 767032.92* | 766489.0 |
| 25  | 2s^22p^3d^3 | ^3D_0 | 766293 | 767345.5 | 767340.51 | 766741.0 |
| 26  | 2s^22p^3d^3 | ^3D_1 | 766675 | 767750.6 | 767748.86 | 767164.0 |
| 27  | 2s^22p^3d^3 | ^1P_1 | 7700620 | 770836.9 | 770841.05 | 770877.0 |
| 28  | 2s^22p^4s^3 | ^3P_0 | 799949 | 801874.46 | 801987.0 |
| 29  | 2s^22p^4s^1 | ^3P_1 | 800994 | 802909.49 | 803031.0 |
| 30  | 2s^22p^4s^3 | ^3P_0 | 803354 | 805291.23 | 805296.0 |
| 31  | 2s^22p^4s^1 | ^3P_1 | 804316 | 806233.72 | 806284.0 |
| 32  | 2s^22p^4p^4 | ^3S_1 | 820251 | 821115.0 |
| 33  | 2s^22p^4p^3 | ^3D_1 | 822296 | 823847.0 |
| 34  | 2s^22p^4p^3 | ^3D_0 | 822647 | 824347.0 |
| 35  | 2s^22p^4p^1 | ^1P_1 | 823307 | 825112.0 |
| 36  | 2s^22p^4p^3 | ^3P_2 | 823639 | 825604.0 |
| 37  | 2s^22p^4p^3 | ^3P_0 | 825834 | 827700.0 |
| 38  | 2s^22p^4p^3 | ^3D_1 | 825921 | 827570.0 |
| 39  | 2s^22p^4p^1 | ^1D_2 | 826403 | 828182.0 |
| 40  | 2s^22p^4p^3 | ^3P_1 | 826453 | 828262.0 |
| 41  | 2s^22p^4p^1 | ^1S_0 | 843570 | 842124.0 |
| 42  | 2s^22p^4d^3 | ^3P_0 | 849638 | 851762.0 |

Table 4: Al IV energy levels in \(\text{cm}^{-1}\). \(E\): present results, \(E_{\text{NIST}}\): energies reported by NIST (Kramida et al., 2012) and taken from Martin & Zaubas (1979), \(E_{\text{MCHF}}\): Hartree-Fock energies (Froese Fischer & Tachiev, 2004), \(E_{\text{LB10}}\): energies calculated in Liang & Badnell (2010) by AUTOSTRUCTURE using 31 configurations. Levels denoted by asterisks (*) are inverted compared to our values.
| \(i\) | Conf. | Level | \(E\) | \(E_{\text{NIST}}\) | \(E_{\text{MCHF}}\) | \(E_{\text{LB10}}\) |
|-----|-------|-------|-----|-------|-------|-------|
| 43  | \(2s^22p^54d\) | \(^3\)P\(_1\) | 849921 | 852068.0 |
| 44  | \(2s^22p^54d\) | \(^3\)P\(_2\) | 850465 | 852670.0 |
| 45  | \(2s^22p^54d\) | \(^3\)F\(_3\) | 850529 | 852914.0 |
| 46  | \(2s^22p^54d\) | \(^3\)F\(_3\) | 850896 | 853306.0 |
| 47  | \(2s^22p^54d\) | \(^3\)D\(_3\) | 851575 | 854328.0 |
| 48  | \(2s^22p^54d\) | \(^1\)D\(_2\) | 851804 | 854036.0 |
| 49  | \(2s^22p^54d\) | \(^3\)D\(_1\) | 853286 | 855841.0 |
| 50  | \(2s^22p^54d\) | \(^3\)F\(_3\) | 854430 | 856796.0 |
| 51  | \(2s^22p^54f\) | \(^3\)D\(_1\) | 854579 | 857299.0 |
| 52  | \(2s^22p^54f\) | \(^3\)D\(_2\) | 854613 | 857331.0 |
| 53  | \(2s^22p^54d\) | \(^3\)D\(_2\) | 854654 | 857045.0 |
| 54  | \(2s^22p^54d\) | \(^1\)F\(_3\) | 854677 | 857077.0 |
| 55  | \(2s^22p^54f\) | \(^3\)G\(_5\) | 854871 | 857595.0 |
| 56  | \(2s^22p^54f\) | \(^1\)G\(_4\) | 854880 | 857598.0 |
| 57  | \(2s^22p^54f\) | \(^3\)D\(_3\) | 854999 | 857733.0 |
| 58  | \(2s^22p^54f\) | \(^1\)D\(_2\) | 855031 | 857756.0 |
| 59  | \(2s^22p^54f\) | \(^1\)F\(_3\) | 855271 | 858008.0 |
| 60  | \(2s^22p^54f\) | \(^3\)F\(_3\) | 855275 | 858016.0 |
| 61  | \(2s^22p^54d\) | \(^1\)P\(_1\) | 857213 | 859776.0 |
| 62  | \(2s^22p^54f\) | \(^3\)F\(_3\) | 858421 | 861072.0 |
| 63  | \(2s^22p^54f\) | \(^3\)G\(_3\) | 858439 | 861078.0 |
| 64  | \(2s^22p^54f\) | \(^3\)F\(_2\) | 858443 | 861086.0 |
| 65  | \(2s^22p^54f\) | \(^3\)G\(_4\) | 858447 | 861088.0 |
| 66  | \(2s^22p^53s\) | \(^3\)S\(_1\) | 999258 | 1000574.0 |
| 67  | \(2s^22p^53s\) | \(^1\)S\(_0\) | 1013660 | 1014285.0 |
| 68  | \(2s^22p^53p\) | \(^3\)P\(_0\) | 1062257 | 1062181.0 |
| 69  | \(2s^22p^53p\) | \(^3\)P\(_1\) | 1062339 | 1062321.0 |
| 70  | \(2s^22p^53p\) | \(^3\)P\(_2\) | 1062525 | 1062625.0 |
| 71  | \(2s^22p^53p\) | \(^1\)P\(_1\) | 1066573 | 1068018.0 |
| 72  | \(2s^22p^53d\) | \(^3\)D\(_2\) | 1140513 | 1143486.0 |
| 73  | \(2s^22p^53d\) | \(^3\)D\(_1\) | 1140513 | 1143471.0 |
| 74  | \(2s^22p^53d\) | \(^3\)D\(_3\) | 1140517 | 1143509.0 |
| 75  | \(2s^22p^53d\) | \(^1\)D\(_2\) | 1143020 | 1145678.0 |
Table 5: Line strengths ($S$), oscillator strengths ($f_{ij}$), and radiative decay rates ($A_{ji}$) for some Al IV lines. Our results (Present) are compared with the Hartree-Fock (MCHF) values (Froese Fischer & Tachiev, 2004).

| Transition | $S$ | $f_{ij}$ | $A_{ji}$ ($s^{-1}$) |
|-----------|-----|----------|---------------------|
| $i - j$ | Present | MCHF | Present | MCHF | Present | MCHF |
| 1 - 3 | 1.075E-02 | 9.144E-03 | 2.020E-02 | 1.718E+09 | 1.719E+09 |
| 1 - 5 | 1.391E-01 | 1.177E-01 | 2.640E-01 | 2.324E-01 | 2.291E+10 | 1.939E+10 |
| 1 - 7 | 1.374E-03 | 1.264E-03 | 3.165E-03 | 2.916E-03 | 4.047E+08 | 3.741E+08 |
| 1 - 23 | 5.067E-02 | 5.796E-02 | 1.179E-01 | 1.350E-01 | 1.537E+10 | 1.765E+10 |
| 2 - 6 | 2.546E+00 | 2.322E+00 | 8.533E-02 | 7.756E-02 | 2.887E+08 | 2.607E+08 |
| 2 - 7 | 9.417E+00 | 8.741E+00 | 3.651E-01 | 3.410E-01 | 7.081E+08 | 6.700E+08 |
| 2 - 8 | 2.444E+00 | 2.268E+00 | 9.602E-02 | 8.962E-02 | 2.680E+08 | 2.528E+08 |
| 2 - 9 | 3.828E-01 | 2.956E-01 | 1.191E-02 | 1.191E-02 | 6.373E+07 | 5.824E+07 |
| 2 - 10 | 2.621E+00 | 2.367E+00 | 1.090E-01 | 9.936E-02 | 3.140E+08 | 3.140E+08 |
| 2 - 11 | 3.346E-01 | 2.609E-01 | 1.421E-02 | 1.114E-02 | 7.719E+07 | 6.125E+07 |
| 2 - 12 | 1.622E+00 | 1.612E+00 | 6.955E-02 | 6.969E-02 | 2.312E+08 | 2.355E+08 |
| 2 - 14 | 7.898E-01 | 8.243E-01 | 3.429E-02 | 3.552E-02 | 1.946E+08 | 2.047E+08 |
| 3 - 6 | 1.097E+00 | 9.994E-01 | 5.922E-02 | 5.380E-02 | 1.124E+08 | 1.014E+08 |
| 3 - 8 | 4.210E-01 | 3.919E-01 | 2.679E-01 | 2.508E-01 | 4.236E+07 | 4.010E+07 |
| 3 - 9 | 2.326E+00 | 2.143E+00 | 1.511E-01 | 1.400E-01 | 4.147E+08 | 3.884E+08 |
| 3 - 10 | 9.515E-01 | 9.162E-01 | 6.715E-02 | 6.240E-02 | 1.193E+08 | 1.130E+08 |
| 3 - 11 | 2.774E-01 | 2.521E-01 | 1.912E-02 | 1.748E-02 | 5.911E+07 | 5.470E+07 |
| 3 - 12 | 1.522E+00 | 1.423E+00 | 1.060E-01 | 9.992E-02 | 2.006E+08 | 1.923E+08 |
| 3 - 13 | 1.266E+00 | 1.195E+00 | 8.878E-02 | 8.453E-02 | 8.527E+08 | 8.249E+08 |
| 3 - 14 | 3.161E-01 | 3.244E-01 | 2.229E-02 | 2.305E-02 | 7.206E+07 | 7.571E+07 |
| 3 - 15 | 7.376E-02 | 6.312E-02 | 8.218E-03 | 6.111E-03 | 1.887E+08 | 1.118E+08 |
| 4 - 6 | 3.183E-01 | 2.923E-01 | 5.005E-02 | 4.579E-02 | 2.982E+07 | 2.709E+07 |
| 4 - 9 | 1.365E+00 | 1.298E+00 | 2.594E-01 | 2.481E-01 | 2.258E+08 | 2.184E+08 |
| 4 - 11 | 1.274E+00 | 1.025E+00 | 2.573E-01 | 2.082E-01 | 2.530E+08 | 2.073E+08 |
| 4 - 14 | 1.063E+00 | 1.119E+00 | 2.196E-01 | 2.332E-01 | 2.261E+08 | 2.440E+08 |
| 5 - 6 | 3.226E-02 | 3.163E-02 | 1.536E-03 | 1.502E-03 | 2.267E+06 | 2.205E+06 |
| 5 - 8 | 8.992E-02 | 7.195E-02 | 5.149E-03 | 4.150E-03 | 6.589E+06 | 5.388E+06 |
| 5 - 9 | 1.357E-02 | 1.101E-02 | 9.236E-04 | 6.495E-04 | 2.062E+06 | 1.476E+06 |
| 5 - 10 | 3.203E+00 | 3.087E+00 | 1.957E-01 | 1.907E-01 | 2.851E+08 | 2.846E+08 |
| 5 - 11 | 2.150E+00 | 2.257E+00 | 1.345E-01 | 1.422E-01 | 3.422E+08 | 3.674E+08 |
| 5 - 12 | 3.617E+00 | 3.278E+00 | 2.288E-01 | 2.094E-01 | 3.572E+08 | 3.373E+08 |
| 5 - 13 | 6.899E-02 | 5.450E-02 | 4.399E-03 | 3.508E-03 | 3.491E+07 | 2.838E+07 |
| 5 - 14 | 1.852E+00 | 1.513E+00 | 1.187E-01 | 9.793E-02 | 3.175E+08 | 2.669E+08 |
| 5 - 15 | 1.358E+00 | 1.313E+00 | 1.386E-01 | 1.188E-01 | 2.820E+09 | 1.899E+09 |
Table 6: Fine structure collision strengths from the Mg III ground level $1s^22s^22p^6 \ ^1S_0$ (level 1 in Table 2) to all the other levels.

| $i - j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|---------|-------|-------|-------|-------|--------|
| 1 − 2   | 3.120E-03 | 1.673E-03 | 6.358E-04 | 1.868E-04 | 5.347E-05 |
| 1 − 3   | 2.491E-02 | 3.138E-02 | 3.338E-02 | 3.921E-02 | 4.982E-02 |
| 1 − 4   | 6.223E-04 | 3.338E-04 | 1.269E-04 | 3.726E-05 | 1.065E-05 |
| 1 − 5   | 3.943E-01 | 5.218E-01 | 5.662E-01 | 6.694E-01 | 8.523E-01 |
| 1 − 6   | 9.857E-03 | 4.755E-03 | 1.867E-03 | 6.209E-04 | 1.978E-04 |
| 1 − 7   | 6.458E-03 | 3.060E-03 | 1.137E-03 | 3.450E-04 | 9.508E-05 |
| 1 − 8   | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 9   | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 10  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 11  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| 1 − 12  | 6.879E-03 | 7.025E-03 | 7.689E-03 | 9.523E-03 |
| 1 − 13  | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 14  | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 15  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 16  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| 1 − 17  | 6.879E-03 | 7.025E-03 | 7.689E-03 | 9.523E-03 |
| 1 − 18  | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 19  | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 20  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 21  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| 1 − 22  | 6.879E-03 | 7.025E-03 | 7.689E-03 | 9.523E-03 |
| 1 − 23  | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 24  | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 25  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 26  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| 1 − 27  | 6.879E-03 | 7.025E-03 | 7.689E-03 | 9.523E-03 |
| 1 − 28  | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 29  | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 30  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 31  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| 1 − 32  | 6.879E-03 | 7.025E-03 | 7.689E-03 | 9.523E-03 |
| 1 − 33  | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 34  | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 35  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 36  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| 1 − 37  | 6.879E-03 | 7.025E-03 | 7.689E-03 | 9.523E-03 |
| 1 − 38  | 3.785E-03 | 1.997E-03 | 7.900E-04 | 2.623E-04 | 7.865E-05 |
| 1 − 39  | 2.058E-03 | 8.523E-04 | 2.623E-04 | 6.209E-04 | 1.978E-04 |
| 1 − 40  | 3.359E-01 | 3.294E-01 | 3.346E-01 | 3.429E-01 | 3.631E-01 |
| 1 − 41  | 8.039E-04 | 2.533E-04 | 6.815E-05 | 1.477E-05 | 2.736E-06 |
| $i-j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|-------|-------|-------|-------|-------|--------|
| 1−42  | 3.563E-04 | 1.137E-04 | 3.159E-05 | 7.239E-06 | 1.436E-06 |
| 1−43  | 4.425E-03 | 5.840E-03 | 7.301E-03 | 1.096E-02 |        |
| 1−44  | 1.449E-03 | 4.561E-04 | 1.251E-04 | 2.861E-05 | 5.679E-06 |
| 1−45  | 1.151E-03 | 3.393E-04 | 8.877E-05 | 2.027E-05 | 4.139E-06 |
| 1−46  | 2.133E-03 | 2.553E-03 | 3.331E-03 | 3.822E-03 | 3.844E-03 |
| 1−47  | 4.644E-04 | 1.252E-04 | 2.972E-05 | 6.733E-06 | 1.419E-06 |
| 1−48  | 1.657E-03 | 2.043E-03 | 2.707E-03 | 3.123E-03 | 3.148E-03 |
| 1−49  | 1.280E-01 | 1.979E-01 | 2.165E-01 | 2.735E-01 | 4.110E-01 |
| 1−50  | 3.134E-05 | 6.737E-06 | 1.401E-06 | 2.595E-07 | 4.320E-08 |
| 1−51  | 1.196E-03 | 2.022E-03 | 2.794E-03 | 3.659E-03 | 2.941E-03 |
| 1−52  | 3.531E-05 | 7.621E-06 | 1.759E-06 | 3.513E-07 | 5.822E-08 |
| 1−53  | 2.799E-04 | 3.737E-04 | 4.441E-04 | 4.493E-04 | 3.292E-04 |
| 1−54  | 4.523E-05 | 9.477E-06 | 1.947E-06 | 3.580E-07 | 5.855E-08 |
| 1−55  | 1.154E-03 | 1.979E-03 | 2.741E-03 | 3.590E-03 | 2.888E-03 |
| 1−56  | 1.490E-05 | 2.840E-06 | 5.922E-07 | 1.128E-07 | 1.758E-08 |
| 1−57  | 8.349E-05 | 9.785E-05 | 1.143E-04 | 1.154E-04 | 8.454E-05 |
| 1−58  | 5.171E-04 | 1.444E-04 | 3.574E-05 | 8.151E-06 | 1.707E-06 |
| 1−59  | 1.812E-03 | 2.174E-03 | 2.863E-03 | 3.306E-03 | 3.346E-03 |
| 1−60  | 6.737E-04 | 1.935E-04 | 4.871E-05 | 1.104E-05 | 2.242E-06 |
| 1−61  | 2.511E-01 | 3.903E-01 | 4.276E-01 | 5.387E-01 | 8.071E-01 |
| 1−62  | 3.923E-05 | 8.141E-06 | 1.663E-06 | 3.044E-07 | 4.929E-08 |
| 1−63  | 1.900E-05 | 3.931E-06 | 8.798E-07 | 1.739E-07 | 2.847E-08 |
| 1−64  | 8.642E-04 | 1.483E-03 | 2.059E-03 | 2.697E-03 | 2.183E-03 |
| 1−65  | 1.593E-04 | 2.028E-04 | 2.409E-04 | 2.447E-04 | 1.805E-04 |
| 1−66  | 2.066E-03 | 8.954E-04 | 3.408E-04 | 1.106E-04 | 3.620E-05 |
| 1−67  | 1.126E-01 | 1.155E-01 | 1.207E-01 | 1.272E-01 | 1.390E-01 |
| 1−68  | 3.126E-04 | 1.798E-04 | 7.803E-05 | 2.646E-05 | 8.297E-06 |
| 1−69  | 9.512E-04 | 5.731E-04 | 2.738E-04 | 1.192E-04 | 7.771E-05 |
| 1−70  | 1.580E-03 | 9.098E-04 | 3.952E-04 | 1.342E-04 | 4.219E-05 |
| 1−71  | 2.099E-02 | 5.830E-02 | 6.960E-02 | 7.023E-02 | 9.443E-02 |
| 1−72  | 9.292E-04 | 3.226E-04 | 1.004E-04 | 2.693E-05 | 6.344E-06 |
| 1−73  | 5.570E-04 | 1.932E-04 | 5.994E-05 | 1.586E-05 | 3.474E-06 |
| 1−74  | 1.300E-03 | 4.510E-04 | 1.398E-04 | 3.692E-05 | 8.035E-06 |
| 1−75  | 1.627E-02 | 2.668E-02 | 4.249E-02 | 5.365E-02 | 5.992E-02 |
| $i-j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|------|-------|-------|-------|-------|-------|
| 2−3  | 2.095E-01 | 1.527E-01 | 1.339E-01 | 1.328E-01 | 1.366E-01 |
| 2−4  | 6.579E-02 | 5.879E-02 | 5.861E-02 | 6.109E-02 | 6.375E-02 |
| 2−5  | 1.519E-01 | 7.291E-02 | 3.097E-02 | 1.466E-02 | 9.603E-03 |
| 2−6  | 2.047E+01 | 2.450E+01 | 2.863E+01 | 3.267E+01 | 3.714E+01 |
| 2−7  | 7.013E+01 | 8.451E+01 | 9.973E+01 | 1.147E+02 | 1.313E+02 |
| 2−8  | 1.770E+01 | 2.126E+01 | 2.506E+01 | 2.882E+01 | 3.295E+01 |
| 2−9  | 2.277E+00 | 2.733E+00 | 3.224E+00 | 3.711E+00 | 4.245E+00 |
| 2−10 | 1.702E+01 | 2.047E+01 | 2.421E+01 | 2.792E+01 | 3.198E+01 |
| 2−11 | 2.572E+00 | 3.089E+00 | 3.658E+00 | 4.224E+00 | 4.843E+00 |
| 2−12 | 1.399E+01 | 1.684E+01 | 1.995E+01 | 2.305E+01 | 2.643E+01 |
| 2−13 | 1.114E-03 | 2.449E-04 | 7.291E-02 | 1.466E-02 | 9.603E-03 |
| 2−14 | 5.751E+00 | 6.921E+00 | 8.207E+00 | 9.490E+00 | 1.089E+01 |
| 2−15 | 1.421E-03 | 3.079E-05 | 1.534E-06 | 1.691E-07 | 3.198E+01 |
| 2−16 | 4.829E-01 | 5.766E-01 | 5.225E-01 | 3.416E-01 | 8.565E-01 |
| 2−17 | 1.214E+00 | 1.386E+00 | 1.450E+00 | 1.313E+00 | 8.358E-01 |
| 2−18 | 1.249E+00 | 1.426E+00 | 1.492E+00 | 1.349E+00 | 8.773E-01 |
| 2−19 | 4.116E+00 | 4.718E+00 | 4.936E+00 | 4.449E+00 | 2.857E+00 |
| 2−20 | 1.037E+00 | 1.181E+00 | 1.234E+00 | 1.122E+00 | 7.163E+00 |
| 2−21 | 4.974E-01 | 5.659E-01 | 5.914E-01 | 5.339E+01 | 3.452E-01 |
| 2−22 | 1.525E+00 | 1.746E+00 | 1.876E+00 | 1.648E+00 | 1.062E+00 |
| 2−23 | 1.690E-01 | 1.901E-01 | 1.983E-01 | 1.792E-01 | 1.162E-01 |
| 2−24 | 1.610E-01 | 1.837E-01 | 1.921E-01 | 1.735E-01 | 1.124E-01 |
| 2−25 | 5.185E-01 | 5.964E-01 | 6.245E-01 | 5.635E-01 | 3.635E-01 |
| 2−26 | 3.519E-01 | 4.042E-01 | 4.231E-01 | 3.819E-01 | 2.469E-01 |
| 2−27 | 3.031E-02 | 3.412E-02 | 3.557E-02 | 3.207E-02 | 2.072E+00 |
| 2−28 | 2.841E+00 | 3.001E+00 | 3.123E+00 | 3.314E+00 | 3.606E+00 |
| 2−29 | 3.599E-03 | 2.969E-03 | 2.781E-03 | 2.124E-03 | 1.135E-03 |
| 2−30 | 1.231E-03 | 1.471E-03 | 1.574E-03 | 1.299E-03 | 6.511E-04 |
| 2−31 | 1.091E-03 | 1.123E-03 | 1.147E-03 | 8.806E-04 | 4.621E-04 |
| 2−32 | 1.345E-01 | 1.506E-01 | 1.902E-01 | 2.633E-01 | 3.378E-01 |
| 2−33 | 4.206E-01 | 4.771E-01 | 5.641E-01 | 6.749E-01 | 6.908E-01 |
| 2−34 | 1.191E-01 | 1.345E-01 | 1.572E-01 | 1.841E-01 | 1.826E-01 |
| 2−35 | 2.974E-02 | 3.314E-02 | 3.808E-02 | 4.311E-02 | 4.026E-02 |
| 2−36 | 1.864E-01 | 2.122E-01 | 2.442E-01 | 2.730E-01 | 2.487E-01 |
| 2−37 | 1.819E-04 | 5.441E-05 | 8.462E-06 | 8.746E-07 | 1.732E-07 |
| 2−38 | 1.680E-03 | 1.878E-03 | 2.079E-03 | 2.128E-03 | 1.645E-03 |
| 2−39 | 1.115E-02 | 1.280E-02 | 1.424E-02 | 1.441E-02 | 1.087E-02 |
| 2−40 | 2.781E-02 | 3.189E-02 | 3.518E-02 | 3.499E-02 | 2.598E-02 |
| 2−41 | 6.652E-04 | 2.130E-04 | 4.276E-05 | 9.203E-06 | 2.536E-06 |
Table 7: continued

| $i - j$ | 10 Ry  | 20 Ry  | 40 Ry  | 80 Ry  | 160 Ry |
|---------|--------|--------|--------|--------|--------|
| 2 − 42 | 2.461E-02 | 2.961E-02 | 3.327E-02 | 4.031E-02 | 3.755E-02 |
| 2 − 43 | 6.854E-02 | 8.239E-02 | 9.270E-02 | 1.122E-01 | 1.038E-01 |
| 2 − 44 | 8.797E-02 | 1.051E-01 | 1.185E-01 | 1.422E-01 | 1.293E-01 |
| 2 − 45 | 2.313E-01 | 2.786E-01 | 3.162E-01 | 3.809E-01 | 3.424E-01 |
| 2 − 46 | 6.226E-02 | 7.289E-02 | 8.204E-02 | 9.890E-02 | 8.95E-02  |
| 2 − 47 | 4.168E-02 | 4.867E-02 | 5.480E-02 | 6.576E-02 | 5.890E-02 |
| 2 − 48 | 1.289E-01 | 1.543E-01 | 1.751E-01 | 2.099E-01 | 1.865E-01 |
| 2 − 49 | 8.933E-03 | 9.493E-03 | 1.048E-02 | 1.241E-02 | 1.095E-02 |
| 2 − 50 | 6.282E-02 | 7.504E-02 | 7.014E-02 | 5.022E-02 | 2.447E-02 |
| 2 − 51 | 4.714E-02 | 5.581E-02 | 5.195E-02 | 3.716E-02 | 1.831E-02 |
| 2 − 52 | 2.292E-01 | 2.902E-01 | 3.091E-01 | 2.522E-01 | 1.366E-01 |
| 2 − 53 | 3.350E-02 | 4.135E-02 | 4.385E-02 | 3.576E-02 | 1.953E-02 |
| 2 − 54 | 9.161E-02 | 1.084E-01 | 1.006E-01 | 7.204E-02 | 3.608E-02 |
| 2 − 55 | 5.542E-02 | 6.571E-02 | 6.121E-02 | 4.378E-02 | 2.138E-02 |
| 2 − 56 | 4.912E-02 | 5.782E-02 | 5.367E-02 | 3.829E-02 | 1.863E-02 |
| 2 − 57 | 1.480E-01 | 1.869E-01 | 1.984E-01 | 1.621E-01 | 8.858E-02 |
| 2 − 58 | 2.226E-03 | 2.614E-03 | 2.972E-03 | 3.486E-03 | 3.005E-03 |
| 2 − 59 | 7.032E-03 | 8.491E-03 | 9.756E-03 | 1.143E-02 | 9.775E-03 |
| 2 − 60 | 1.047E-02 | 1.254E-02 | 1.437E-02 | 1.664E-02 | 1.417E-02 |
| 2 − 61 | 1.247E-03 | 1.269E-03 | 1.399E-03 | 1.618E-03 | 1.366E-03 |
| 2 − 62 | 1.999E-03 | 2.208E-03 | 2.008E-03 | 1.673E-03 | 1.578E-03 |
| 2 − 63 | 1.624E-04 | 1.799E-04 | 1.662E-04 | 1.181E-04 | 5.769E-05 |
| 2 − 64 | 5.061E-04 | 5.778E-04 | 5.331E-04 | 4.019E-04 | 2.503E-04 |
| 2 − 65 | 4.184E-04 | 5.033E-04 | 5.151E-04 | 4.247E-04 | 2.320E-04 |
| 2 − 66 | 2.664E+00 | 3.113E+00 | 3.507E+00 | 4.169E+00 | 4.976E+00 |
| 2 − 67 | 1.782E-02 | 9.780E-03 | 4.092E-03 | 1.400E-03 | 4.139E-04 |
| 2 − 68 | 8.716E-05 | 1.097E-04 | 1.294E-04 | 1.295E-04 | 9.638E-05 |
| 2 − 69 | 2.095E-04 | 2.516E-04 | 2.912E-04 | 2.895E-04 | 2.148E-04 |
| 2 − 70 | 1.649E-03 | 2.185E-03 | 2.609E-03 | 2.921E-03 | 3.163E-03 |
| 2 − 71 | 3.839E-05 | 1.840E-05 | 6.894E-06 | 2.212E-06 | 6.807E-07 |
| 2 − 72 | 7.430E-04 | 9.753E-04 | 9.735E-04 | 1.197E-03 | 1.851E-03 |
| 2 − 73 | 1.818E-04 | 3.059E-04 | 3.543E-04 | 3.269E-04 | 2.526E-04 |
| 2 − 74 | 3.367E-03 | 4.024E-03 | 3.721E-03 | 5.262E-03 | 9.676E-03 |
| 2 − 75 | 1.639E-05 | 8.265E-06 | 3.291E-06 | 1.154E-06 | 4.135E-07 |
Table 8: Fine structure collision strengths from the Mg III level $1s^22s^22p^33p\,^1P_1$ (level 3 in Table 2) to all the other levels.

| $i - j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|---------|-------|-------|-------|-------|--------|
| 3 – 4   | 5.843E-02 | 2.442E-02 | 8.466E-03 | 2.544E-03 | 6.812E-04 |
| 3 – 5   | 8.958E-02 | 4.994E-02 | 3.075E-02 | 2.430E-02 | 2.291E-02 |
| 3 – 6   | 9.343E+00 | 1.116E+01 | 1.301E+01 | 1.482E+01 | 1.681E+01 |
| 3 – 7   | 8.263E-03 | 2.147E-03 | 6.073E-04 | 3.764E-04 | 2.470E-04 |
| 3 – 8   | 3.209E+01 | 5.843E-02 | 4.548E+01 | 5.225E+01 | 5.968E+01 |
| 3 – 9   | 3.209E+01 | 5.843E-02 | 4.548E+01 | 5.225E+01 | 5.968E+01 |
| 3 – 10  | 5.261E+00 | 6.322E+00 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 11  | 1.923E+01 | 1.522E+01 | 1.801E+01 | 2.078E+01 | 2.380E+01 |
| 3 – 12  | 9.222E+00 | 1.110E+01 | 1.315E+01 | 1.518E+01 | 1.739E+01 |
| 3 – 13  | 2.682E+00 | 3.221E+00 | 3.811E+00 | 4.396E+00 | 5.034E+00 |
| 3 – 14  | 3.008E-01 | 3.606E-01 | 4.416E-01 | 5.311E-01 | 6.332E-01 |
| 3 – 15  | 6.677E+01 | 3.860E+01 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 16  | 1.689E+01 | 2.031E+01 | 2.393E+01 | 2.751E+01 | 3.142E+01 |
| 3 – 17  | 5.261E+00 | 6.322E+00 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 18  | 1.923E+01 | 1.522E+01 | 1.801E+01 | 2.078E+01 | 2.380E+01 |
| 3 – 19  | 9.222E+00 | 1.110E+01 | 1.315E+01 | 1.518E+01 | 1.739E+01 |
| 3 – 20  | 2.682E+00 | 3.221E+00 | 3.811E+00 | 4.396E+00 | 5.034E+00 |
| 3 – 21  | 3.008E-01 | 3.606E-01 | 4.416E-01 | 5.311E-01 | 6.332E-01 |
| 3 – 22  | 6.677E+01 | 3.860E+01 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 23  | 1.689E+01 | 2.031E+01 | 2.393E+01 | 2.751E+01 | 3.142E+01 |
| 3 – 24  | 5.261E+00 | 6.322E+00 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 25  | 1.923E+01 | 1.522E+01 | 1.801E+01 | 2.078E+01 | 2.380E+01 |
| 3 – 26  | 9.222E+00 | 1.110E+01 | 1.315E+01 | 1.518E+01 | 1.739E+01 |
| 3 – 27  | 2.682E+00 | 3.221E+00 | 3.811E+00 | 4.396E+00 | 5.034E+00 |
| 3 – 28  | 3.008E-01 | 3.606E-01 | 4.416E-01 | 5.311E-01 | 6.332E-01 |
| 3 – 29  | 6.677E+01 | 3.860E+01 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 30  | 1.689E+01 | 2.031E+01 | 2.393E+01 | 2.751E+01 | 3.142E+01 |
| 3 – 31  | 5.261E+00 | 6.322E+00 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 32  | 1.923E+01 | 1.522E+01 | 1.801E+01 | 2.078E+01 | 2.380E+01 |
| 3 – 33  | 9.222E+00 | 1.110E+01 | 1.315E+01 | 1.518E+01 | 1.739E+01 |
| 3 – 34  | 2.682E+00 | 3.221E+00 | 3.811E+00 | 4.396E+00 | 5.034E+00 |
| 3 – 35  | 3.008E-01 | 3.606E-01 | 4.416E-01 | 5.311E-01 | 6.332E-01 |
| 3 – 36  | 6.677E+01 | 3.860E+01 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 37  | 1.689E+01 | 2.031E+01 | 2.393E+01 | 2.751E+01 | 3.142E+01 |
| 3 – 38  | 5.261E+00 | 6.322E+00 | 7.469E+00 | 8.609E+00 | 9.861E+00 |
| 3 – 39  | 1.923E+01 | 1.522E+01 | 1.801E+01 | 2.078E+01 | 2.380E+01 |
| 3 – 40  | 9.222E+00 | 1.110E+01 | 1.315E+01 | 1.518E+01 | 1.739E+01 |
| 3 – 41  | 2.682E+00 | 3.221E+00 | 3.811E+00 | 4.396E+00 | 5.034E+00 |
Table 8: continued.

| i − j | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|-------|-------|-------|-------|-------|--------|
| 3 − 42 | 1.512E-04 | 3.897E-05 | 6.479E-06 | 9.360E-07 | 1.360E-07 |
| 3 − 43 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 44 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 45 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 46 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 47 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 48 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 49 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 50 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 51 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 52 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 53 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 54 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 55 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 56 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 57 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 58 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 59 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 60 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 61 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 62 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 63 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 64 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 65 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 66 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 67 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 68 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 69 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 70 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 71 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 72 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |
| 3 − 73 | 8.665E-03 | 9.971E-03 | 1.106E-02 | 1.276E-02 | 1.177E-02 |
| 3 − 74 | 3.493E-02 | 4.184E-02 | 4.691E-02 | 5.708E-02 | 5.314E-02 |
| 3 − 75 | 1.445E-03 | 3.822E-04 | 7.190E-05 | 1.846E-05 | 8.076E-06 |

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### Table 9: Fine structure collision strengths from the Mg III level

$1s^22s^22p^53s^23p^5P_0^0$ (level 4 in Table 2) to all the other levels.

| $i \rightarrow j$ | 10 Ry  | 20 Ry  | 40 Ry  | 80 Ry  | 160 Ry |
|------------------|--------|--------|--------|--------|--------|
| 4 $\rightarrow$ 5 | 2.749E-02 | 1.186E-02 | 4.098E-03 | 1.207E-03 | 3.153E-04 |
| 4 $\rightarrow$ 6 | 2.757E+00 | 3.290E+00 | 4.235E+00 | 5.729E+00 | 1.259E+00 |
| 4 $\rightarrow$ 7 | 1.102E+01 | 1.324E+01 | 1.559E+01 | 1.789E+01 | 2.042E+01 |
| 4 $\rightarrow$ 8 | 7.658E-04 | 1.679E-04 | 1.873E-05 | 1.257E-06 | 1.633E-07 |
| 4 $\rightarrow$ 9 | 8.847E+00 | 1.064E+01 | 1.257E+01 | 1.448E+01 | 1.656E+01 |
| 4 $\rightarrow$ 10 | 4.503E-03 | 9.924E-04 | 1.101E-04 | 6.975E-06 | 1.259E-06 |
| 4 $\rightarrow$ 11 | 7.910E-04 | 1.742E-04 | 1.888E-05 | 1.257E-06 | 1.633E-07 |
| 4 $\rightarrow$ 12 | 3.371E-04 | 7.300E-05 | 8.892E-06 | 1.204E-06 | 2.971E-07 |
| 4 $\rightarrow$ 13 | 9.866E-01 | 1.132E+00 | 1.185E+00 | 1.073E+00 | 6.921E-01 |
| 4 $\rightarrow$ 14 | 4.135E-03 | 9.225E-04 | 1.471E-04 | 2.226E-05 | 3.132E-06 |
| 4 $\rightarrow$ 15 | 6.246E-01 | 7.220E-01 | 7.791E-01 | 6.821E-01 | 4.153E-01 |
| 4 $\rightarrow$ 16 | 9.865E-05 | 7.220E-05 | 7.791E-05 | 6.821E-05 | 4.153E-05 |
| 4 $\rightarrow$ 17 | 2.460E-04 | 6.141E-05 | 1.239E-05 | 2.491E-06 | 4.938E-07 |
| 4 $\rightarrow$ 18 | 3.623E-01 | 4.144E-01 | 4.336E-01 | 3.921E-01 | 2.526E-01 |
| 4 $\rightarrow$ 19 | 8.248E-04 | 1.831E-04 | 2.927E-05 | 4.443E-06 | 6.281E-07 |
| 4 $\rightarrow$ 20 | 7.910E-04 | 1.742E-04 | 1.888E-05 | 1.257E-06 | 1.633E-07 |
| 4 $\rightarrow$ 21 | 3.371E-04 | 7.300E-05 | 8.892E-06 | 1.204E-06 | 2.971E-07 |
| 4 $\rightarrow$ 22 | 9.866E-01 | 1.132E+00 | 1.185E+00 | 1.073E+00 | 6.921E-01 |
| 4 $\rightarrow$ 23 | 4.135E-03 | 9.225E-04 | 1.471E-04 | 2.226E-05 | 3.132E-06 |
| 4 $\rightarrow$ 24 | 6.246E-01 | 7.220E-01 | 7.791E-01 | 6.821E-01 | 4.153E-01 |
| 4 $\rightarrow$ 25 | 9.865E-05 | 7.220E-05 | 7.791E-05 | 6.821E-05 | 4.153E-05 |
| 4 $\rightarrow$ 26 | 2.460E-04 | 6.141E-05 | 1.239E-05 | 2.491E-06 | 4.938E-07 |
| 4 $\rightarrow$ 27 | 3.623E-01 | 4.144E-01 | 4.336E-01 | 3.921E-01 | 2.526E-01 |
| 4 $\rightarrow$ 28 | 8.248E-04 | 1.831E-04 | 2.927E-05 | 4.443E-06 | 6.281E-07 |
| 4 $\rightarrow$ 29 | 7.910E-04 | 1.742E-04 | 1.888E-05 | 1.257E-06 | 1.633E-07 |
| 4 $\rightarrow$ 30 | 3.371E-04 | 7.300E-05 | 8.892E-06 | 1.204E-06 | 2.971E-07 |
| 4 $\rightarrow$ 31 | 9.866E-01 | 1.132E+00 | 1.185E+00 | 1.073E+00 | 6.921E-01 |
| 4 $\rightarrow$ 32 | 4.135E-03 | 9.225E-04 | 1.471E-04 | 2.226E-05 | 3.132E-06 |
| 4 $\rightarrow$ 33 | 6.246E-01 | 7.220E-01 | 7.791E-01 | 6.821E-01 | 4.153E-01 |
| 4 $\rightarrow$ 34 | 9.865E-05 | 7.220E-05 | 7.791E-05 | 6.821E-05 | 4.153E-05 |
| 4 $\rightarrow$ 35 | 2.460E-04 | 6.141E-05 | 1.239E-05 | 2.491E-06 | 4.938E-07 |
| 4 $\rightarrow$ 36 | 3.623E-01 | 4.144E-01 | 4.336E-01 | 3.921E-01 | 2.526E-01 |
| 4 $\rightarrow$ 37 | 8.248E-04 | 1.831E-04 | 2.927E-05 | 4.443E-06 | 6.281E-07 |
| 4 $\rightarrow$ 38 | 7.910E-04 | 1.742E-04 | 1.888E-05 | 1.257E-06 | 1.633E-07 |
| 4 $\rightarrow$ 39 | 3.371E-04 | 7.300E-05 | 8.892E-06 | 1.204E-06 | 2.971E-07 |
| 4 $\rightarrow$ 40 | 9.866E-01 | 1.132E+00 | 1.185E+00 | 1.073E+00 | 6.921E-01 |
| 4 $\rightarrow$ 41 | 4.135E-03 | 9.225E-04 | 1.471E-04 | 2.226E-05 | 3.132E-06 |
| $i - j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|---------|-------|-------|-------|-------|--------|
| 4 – 42  | 8.822E-04 | 9.701E-04 | 9.609E-04 | 8.474E-04 | 6.138E-04 |
| 4 – 43  | 1.610E-05 | 4.440E-06 | 8.372E-07 | 1.424E-07 | 2.531E-08 |
| 4 – 44  | 3.127E-05 | 4.170E-03 | 4.725E-06 | 1.093E-06 | 5.090E-03 |
| 4 – 45  | 1.058E-05 | 8.789E-06 | 6.314E-06 | 5.068E-06 | 3.928E-06 |
| 4 – 46  | 2.492E-03 | 3.018E-03 | 3.367E-03 | 4.130E-03 | 3.950E-03 |
| 4 – 47  | 2.375E-05 | 6.046E-06 | 9.989E-07 | 1.433E-07 | 2.064E-08 |
| 4 – 48  | 3.873E-05 | 1.036E-05 | 1.792E-06 | 2.824E-07 | 4.776E-08 |
| 4 – 49  | 1.248E-05 | 1.458E-05 | 1.573E-05 | 1.122E-05 | 5.191E-06 |
| 4 – 50  | 9.369E-04 | 1.196E-03 | 1.297E-03 | 1.049E-03 | 5.701E-04 |
| 4 – 51  | 4.878E-04 | 6.226E-04 | 6.777E-04 | 5.472E-04 | 2.972E-04 |
| 4 – 52  | 4.382E-06 | 5.064E-07 | 1.297E-07 | 3.524E-08 | 4.491E-09 |
| 4 – 53  | 7.601E-02 | 9.196E-02 | 1.040E-01 | 1.254E-01 | 1.136E-01 |
| 4 – 54  | 6.061E-02 | 6.892E-02 | 8.285E-02 | 7.490E-02 | 5.099E-02 |
| 4 – 55  | 5.676E-04 | 1.457E-04 | 2.434E-05 | 3.539E-06 | 5.099E-07 |
| 4 – 56  | 7.801E-02 | 7.911E-02 | 6.473E-02 | 3.529E-02 | 5.099E-02 |
| 4 – 57  | 3.834E-02 | 1.057E-01 | 1.127E-01 | 9.223E-02 | 5.099E-02 |
| 4 – 58  | 2.663E-04 | 4.708E-05 | 6.932E-06 | 8.115E-07 | 7.682E-08 |
| 4 – 59  | 4.719E-04 | 8.520E-05 | 1.216E-05 | 1.291E-06 | 1.151E-07 |
| 4 – 60  | 5.371E-01 | 6.266E-01 | 7.059E-01 | 8.391E-01 | 9.998E-01 |
| 4 – 61  | 3.565E-03 | 1.955E-03 | 8.174E-04 | 2.795E-04 | 8.248E-05 |
| 4 – 62  | 2.965E-04 | 4.017E-04 | 4.826E-04 | 5.219E-04 | 4.719E-04 |
| 4 – 63  | 1.153E-05 | 5.119E-06 | 1.745E-06 | 4.813E-07 | 1.245E-07 |
| 4 – 64  | 8.868E-05 | 1.093E-04 | 1.290E-04 | 1.287E-04 | 9.430E-05 |
| 4 – 65  | 7.924E-06 | 3.792E-06 | 1.404E-06 | 4.292E-07 | 1.171E-07 |
| 4 – 66  | 3.803E-06 | 1.935E-06 | 7.692E-07 | 2.552E-07 | 7.554E-08 |
| 4 – 67  | 7.965E-04 | 9.402E-04 | 8.642E-04 | 1.233E-03 | 2.296E-03 |
| 4 – 68  | 8.095E-05 | 1.522E-04 | 2.049E-04 | 2.028E-04 | 1.168E-04 |
| 4 – 69  | 3.412E-06 | 1.714E-06 | 6.690E-07 | 2.191E-07 | 6.427E-08 |
Table 10: Fine structure collision strengths from the Mg III level
$1s^22s^22p^33s \, ^1P_o$ (level 5 in Table 2) to all the other levels.

| $i-j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|-------|-------|-------|-------|-------|-------|
| 5−6   | 2.010E-01 | 2.350E-01 | 2.709E-01 | 3.064E-01 | 3.460E-01 |
| 5−7   | 6.024E-03 | 1.322E-03 | 1.626E-04 | 2.918E-05 | 1.558E-05 |
| 5−8   | 9.277E-01 | 1.106E+00 | 1.293E+00 | 1.481E+00 | 1.690E+00 |
| 5−9   | 1.761E-01 | 2.062E-01 | 2.406E-01 | 2.758E-01 | 3.148E-01 |
| 5−10  | 2.891E+01 | 3.474E+01 | 4.083E+01 | 4.685E+01 | 5.350E+01 |
| 5−11  | 1.689E+01 | 2.028E+01 | 2.385E+01 | 2.738E+01 | 3.126E+01 |
| 5−12  | 2.296E+01 | 2.759E+01 | 3.248E+01 | 3.732E+01 | 4.264E+01 |
| 5−13  | 3.944E-01 | 4.711E-01 | 5.532E-01 | 6.340E-01 | 7.218E-01 |
| 5−14  | 1.361E+01 | 1.635E+01 | 1.925E+01 | 2.212E+01 | 2.528E+01 |
| 5−15  | 7.642E+00 | 9.216E+00 | 1.124E+01 | 1.342E+01 | 1.588E+01 |
| 5−16  | 5.654E-04 | 1.314E-04 | 2.335E-05 | 4.050E-06 | 6.862E-07 |
| 5−17  | 4.411E-03 | 1.071E-03 | 7.565E-04 | 6.678E-04 | 4.574E-04 |
| 5−18  | 5.024E-03 | 2.241E-03 | 1.510E-03 | 1.149E-03 | 6.830E-04 |
| 5−19  | 4.348E-03 | 9.651E-04 | 1.606E-03 | 3.075E-03 | 7.891E-03 |
| 5−20  | 5.120E-01 | 5.795E-01 | 5.998E-01 | 5.334E-01 | 3.408E-01 |
| 5−21  | 1.316E-01 | 1.467E-01 | 1.510E-01 | 1.340E-01 | 8.600E-02 |
| 5−22  | 1.585E+00 | 1.804E+00 | 1.873E+00 | 1.673E+00 | 1.070E+00 |
| 5−23  | 2.017E-01 | 2.288E-01 | 2.368E-01 | 2.096E-01 | 1.338E-01 |
| 5−24  | 1.090E+00 | 1.241E+00 | 1.290E+00 | 1.154E+00 | 7.425E+00 |
| 5−25  | 1.260E+00 | 1.434E+00 | 1.492E+00 | 1.337E+00 | 8.573E+01 |
| 5−26  | 1.067E+00 | 1.215E+00 | 1.263E+00 | 1.132E+00 | 7.284E+00 |
| 5−27  | 1.250E+00 | 1.429E+00 | 1.487E+00 | 1.329E+00 | 8.535E+00 |
| 5−28  | 1.390E-03 | 8.272E-04 | 6.248E-04 | 4.644E-04 | 2.602E-04 |
| 5−29  | 3.243E-01 | 3.421E-01 | 3.554E-01 | 3.780E-01 | 4.045E-01 |
| 5−30  | 4.429E-04 | 1.433E-04 | 3.680E-05 | 6.963E-06 | 1.535E-06 |
| 5−31  | 1.693E+00 | 1.791E+00 | 1.863E+00 | 1.981E+00 | 2.140E+00 |
| 5−32  | 1.873E-03 | 1.880E-03 | 1.934E-03 | 1.791E-03 | 1.258E-03 |
| 5−33  | 6.907E-04 | 2.062E-04 | 3.282E-05 | 3.495E-06 | 9.512E-07 |
| 5−34  | 5.607E-02 | 6.360E-02 | 8.102E-02 | 1.080E-01 | 1.279E-01 |
| 5−35  | 5.545E-02 | 6.324E-02 | 8.126E-02 | 1.086E-01 | 1.289E-01 |
| 5−36  | 8.911E-02 | 1.011E-01 | 1.281E-01 | 1.705E-01 | 2.024E-01 |
| 5−37  | 3.064E-03 | 3.309E-03 | 4.444E-03 | 6.541E-03 | 9.270E-03 |
| 5−38  | 7.286E-02 | 8.254E-02 | 1.031E-01 | 1.337E-01 | 1.535E-01 |
| 5−39  | 2.263E-01 | 2.569E-01 | 3.163E-01 | 4.029E-01 | 4.512E-01 |
| 5−40  | 9.009E-02 | 1.023E-01 | 1.271E-01 | 1.632E-01 | 1.845E-01 |
| 5−41  | 4.596E-01 | 5.286E-01 | 6.038E-01 | 6.398E-01 | 5.966E-01 |
| $i - j$ | 10 Ry | 20 Ry | 40 Ry | 80 Ry | 160 Ry |
|--------|-------|-------|-------|-------|-------|
| 5 - 42 | 1.230E-04 | 3.196E-05 | 5.519E-06 | 8.425E-07 | 1.314E-07 |
| 5 - 43 | 8.574E-04 | 6.493E-04 | 6.411E-04 | 6.545E-04 | 5.269E-04 |
| 5 - 44 | 5.765E-03 | 6.284E-03 | 6.909E-03 | 8.413E-03 | 7.388E-03 |
| 5 - 45 | 1.063E-03 | 2.716E-04 | 4.481E-05 | 6.906E-06 | 1.342E-06 |
| 5 - 46 | 3.994E-02 | 4.757E-02 | 5.312E-02 | 6.529E-02 | 5.913E-02 |
| 5 - 47 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 48 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 49 | 8.574E-04 | 6.284E-03 | 6.909E-03 | 8.413E-03 | 7.388E-03 |
| 5 - 50 | 8.574E-04 | 6.284E-03 | 6.909E-03 | 8.413E-03 | 7.388E-03 |
| 5 - 51 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 52 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 53 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 54 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 55 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 56 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 57 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 58 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 59 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 60 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 61 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 62 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 63 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 64 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 65 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 66 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 67 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 68 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 69 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 70 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 71 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 72 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 73 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 74 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
| 5 - 75 | 2.785E-02 | 3.300E-02 | 3.689E-02 | 4.522E-02 | 4.060E-02 |
Table 11: Fine structure collision strengths from the Al IV ground level $1s^22s^22p^6 \ ^3S_0$ (level 1 in Table 4) to all the other levels.

| $i-j$ | 15 Ry | 30 Ry | 60 Ry | 8120 Ry | 240 Ry |
|-------|-------|-------|-------|----------|--------|
| 1−2   | 2.480E-03 | 1.217E-03 | 4.371E-04 | 1.254E-04 | 3.629E-05 |
| 1−3   | 2.146E-02 | 2.696E-02 | 2.890E-02 | 3.420E-02 | 4.390E-02 |
| 1−4   | 4.946E-04 | 2.428E-04 | 8.716E-05 | 2.497E-05 | 7.211E-06 |
| 1−5   | 2.574E-01 | 3.390E-01 | 3.694E-01 | 4.391E-01 | 5.646E-01 |
| 1−6   | 7.575E-03 | 3.519E-03 | 1.336E-03 | 4.322E-04 | 1.362E-04 |
| 1−7   | 5.152E-03 | 9.342E-04 | 3.254E-04 | 9.359E-05 | 2.481E-05 |
| 1−8   | 6.647E-03 | 6.950E-03 | 7.754E-03 | 8.619E-03 | 7.504E-03 |
| 1−9   | 2.113E-03 | 9.342E-04 | 3.254E-04 | 9.359E-05 | 2.481E-05 |
| 1−10  | 1.982E-02 | 3.095E-02 | 4.042E-02 | 4.723E-02 | 4.172E-02 |
| 1−11  | 1.558E-03 | 6.188E-04 | 1.860E-04 | 4.348E-05 | 8.564E-06 |
| 1−12  | 1.242E-02 | 1.805E-02 | 2.312E-02 | 2.690E-02 | 2.379E-02 |
| 1−13  | 9.670E-04 | 6.579E-04 | 1.336E-03 | 4.322E-04 | 1.362E-04 |
| 1−14  | 6.647E-03 | 6.950E-03 | 7.754E-03 | 8.619E-03 | 7.504E-03 |
| 1−15  | 2.754E-01 | 2.711E-01 | 2.760E-01 | 2.838E-01 | 3.008E-01 |
| 1−16  | 8.808E-04 | 2.828E-04 | 7.175E-05 | 1.676E-05 | 3.060E-06 |
| 1−17  | 4.945E-03 | 4.307E-03 | 4.113E-03 | 4.491E-03 | 5.647E-03 |
| 1−18  | 4.195E-03 | 3.863E-03 | 3.655E-04 | 7.916E-05 | 1.435E-05 |
| 1−19  | 2.577E-03 | 7.682E-04 | 2.013E-04 | 4.525E-05 | 8.969E-06 |
| 1−20  | 3.913E-03 | 3.804E-03 | 4.953E-03 | 6.006E-03 | 6.258E-03 |
| 1−21  | 1.256E-03 | 3.687E-04 | 9.486E-05 | 2.141E-05 | 4.292E-06 |
| 1−22  | 6.345E-03 | 9.129E-03 | 1.306E-03 | 1.614E-03 | 1.691E-02 |
| 1−23  | 8.561E-04 | 2.120E-04 | 4.990E-05 | 1.124E-05 | 2.366E-06 |
| 1−24  | 3.913E-03 | 3.312E-03 | 4.526E-03 | 5.562E-03 | 5.835E-03 |
| 1−25  | 8.166E-04 | 2.233E-04 | 5.115E-05 | 1.152E-05 | 2.328E-06 |
| 1−26  | 6.924E-01 | 1.039E+00 | 1.671E+00 | 1.332E+00 | 1.692E+00 |
| 1−27  | 6.044E-04 | 3.030E-04 | 1.125E-04 | 3.226E-05 | 9.192E-06 |
| 1−28  | 1.057E-02 | 1.513E-02 | 1.648E-02 | 2.137E-02 | 3.142E-02 |
| 1−29  | 1.212E-04 | 6.056E-05 | 2.242E-05 | 6.397E-06 | 1.816E-06 |
| 1−30  | 1.862E-02 | 2.712E-02 | 2.971E-02 | 3.824E-02 | 5.583E-02 |
| 1−31  | 1.735E-03 | 8.034E-04 | 3.651E-04 | 9.754E-05 | 3.083E-05 |
| 1−32  | 1.447E-03 | 6.475E-04 | 2.923E-04 | 6.600E-05 | 1.809E-05 |
| 1−33  | 8.561E-02 | 1.275E-01 | 1.429E-01 | 1.632E-01 | 2.072E-01 |
| 1−34  | 8.166E-04 | 2.120E-04 | 4.890E-05 | 1.124E-05 | 2.366E-06 |
| 1−35  | 3.913E-03 | 3.312E-03 | 4.526E-03 | 5.562E-03 | 5.835E-03 |
| 1−36  | 8.166E-04 | 2.233E-04 | 5.115E-05 | 1.152E-05 | 2.328E-06 |
| 1−37  | 6.924E-01 | 1.039E+00 | 1.671E+00 | 1.332E+00 | 1.692E+00 |
Table 11, continued.

| i − j | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|-------|-------|-------|-------|--------|--------|
| 1 − 42 | 3.703E-04 | 1.203E-04 | 3.388E-05 | 7.775E-06 | 1.513E-06 |
| 1 − 43 | 2.953E-03 | 3.276E-03 | 3.376E-03 | 4.010E-03 | 5.679E-03 |
| 1 − 44 | 1.533E-03 | 4.927E-04 | 1.373E-04 | 3.147E-05 | 6.126E-06 |
| 1 − 45 | 1.189E-03 | 3.954E-04 | 9.594E-05 | 2.211E-05 | 4.505E-06 |
| 1 − 46 | 1.814E-03 | 1.840E-03 | 2.396E-03 | 2.884E-03 | 3.230E-03 |
| 1 − 47 | 4.810E-04 | 1.337E-04 | 3.268E-05 | 7.556E-06 | 1.593E-06 |
| 1 − 48 | 1.657E-03 | 1.914E-03 | 2.617E-03 | 3.190E-03 | 3.584E-03 |
| 1 − 49 | 6.809E-02 | 1.057E-01 | 1.183E-01 | 1.435E-01 | 2.038E-01 |
| 1 − 50 | 5.205E-04 | 1.484E-04 | 3.736E-05 | 8.671E-06 | 1.827E-06 |
| 1 − 51 | 4.293E-05 | 9.901E-06 | 2.145E-06 | 3.985E-07 | 6.545E-08 |
| 1 − 52 | 1.239E-03 | 2.181E-03 | 3.097E-03 | 4.000E-03 | 3.551E-03 |
| 1 − 53 | 6.574E-04 | 1.909E-04 | 4.852E-05 | 1.112E-05 | 2.238E-06 |
| 1 − 54 | 1.732E-03 | 1.901E-03 | 2.561E-03 | 3.118E-03 | 3.512E-03 |
| 1 − 55 | 4.619E-05 | 1.076E-05 | 2.543E-06 | 5.097E-07 | 8.496E-08 |
| 1 − 56 | 2.287E-04 | 3.004E-04 | 4.099E-04 | 4.638E-04 | 3.938E-04 |
| 1 − 57 | 6.313E-05 | 1.424E-05 | 3.060E-06 | 5.652E-07 | 9.120E-08 |
| 1 − 58 | 1.415E-03 | 2.551E-03 | 3.634E-03 | 4.697E-03 | 4.172E-03 |
| 1 − 59 | 1.895E-05 | 3.902E-06 | 8.600E-07 | 1.665E-07 | 2.605E-08 |
| 1 − 60 | 7.672E-05 | 8.506E-05 | 1.131E-04 | 1.276E-04 | 1.083E-04 |
| 1 − 61 | 2.850E-01 | 4.455E-01 | 4.998E-01 | 6.045E-01 | 8.553E-01 |
| 1 − 62 | 5.092E-05 | 1.133E-05 | 2.423E-06 | 4.456E-07 | 7.096E-08 |
| 1 − 63 | 2.435E-05 | 5.433E-06 | 1.257E-06 | 2.502E-07 | 4.122E-08 |
| 1 − 64 | 9.397E-04 | 1.688E-03 | 2.406E-03 | 3.105E-03 | 2.769E-03 |
| 1 − 65 | 1.334E-04 | 1.634E-04 | 2.218E-04 | 2.516E-04 | 2.148E-04 |
| 1 − 66 | 1.393E-03 | 5.814E-04 | 2.148E-04 | 6.729E-05 | 2.020E-05 |
| 1 − 67 | 1.005E-01 | 1.022E-01 | 1.065E-01 | 1.121E-01 | 1.221E-01 |
| 1 − 68 | 2.665E-04 | 1.401E-04 | 5.617E-05 | 1.803E-05 | 5.474E-06 |
| 1 − 69 | 8.299E-04 | 4.869E-04 | 2.447E-04 | 1.334E-04 | 1.245E-04 |
| 1 − 70 | 1.348E-03 | 7.098E-04 | 2.850E-04 | 9.171E-05 | 2.795E-05 |
| 1 − 71 | 2.583E-02 | 5.796E-02 | 6.648E-02 | 6.926E-02 | 9.505E-02 |
| 1 − 72 | 1.134E-03 | 4.005E-04 | 1.251E-04 | 3.304E-05 | 7.716E-06 |
| 1 − 73 | 6.795E-04 | 2.397E-04 | 7.456E-05 | 1.927E-05 | 4.015E-06 |
| 1 − 74 | 1.586E-03 | 5.595E-04 | 1.738E-04 | 4.479E-05 | 9.240E-06 |
| 1 − 75 | 2.340E-02 | 3.725E-02 | 5.591E-02 | 6.983E-02 | 7.777E-02 |
Table 12: Fine structure collision strengths from the Al IV level
1s22s22p53s 3P3 (level 2 in Table 4) to all the other levels.

| i – j | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|-------|-------|-------|-------|--------|--------|
| 2 – 3 | 1.471E-01 | 1.123E-01 | 1.021E-01 | 1.023E-01 | 1.050E-01 |
| 2 – 4 | 4.920E-02 | 4.552E-02 | 4.616E-02 | 4.808E-02 | 4.991E-02 |
| 2 – 5 | 9.792E-02 | 4.682E-02 | 2.118E-02 | 1.169E-02 | 8.896E-03 |
| 2 – 6 | 1.446E+01 | 1.728E+01 | 2.007E+01 | 2.278E+01 | 2.577E+01 |
| 2 – 7 | 4.938E+01 | 6.007E+01 | 7.049E+01 | 8.064E+01 | 9.182E+01 |
| 2 – 8 | 1.295E+01 | 1.559E+01 | 1.828E+01 | 2.091E+01 | 2.379E+01 |
| 2 – 9 | 1.728E+00 | 2.079E+00 | 2.441E+00 | 2.794E+00 | 3.182E+00 |
| 2 – 10 | 8.268E+00 | 9.981E+00 | 1.177E+01 | 1.353E+01 | 1.544E+01 |
| 2 – 11 | 1.715E+00 | 2.067E+00 | 2.436E+00 | 2.798E+00 | 3.193E+00 |
| 2 – 12 | 8.268E+00 | 9.981E+00 | 1.177E+01 | 1.353E+01 | 1.544E+01 |
| 2 – 13 | 7.026E-04 | 1.528E-04 | 1.559E-05 | 1.010E-06 | 1.590E-07 |
| 2 – 14 | 4.003E+00 | 4.833E+00 | 5.705E+00 | 6.560E+00 | 7.495E+00 |
| 2 – 15 | 9.914E-04 | 2.161E-04 | 2.739E-05 | 4.424E-06 | 1.139E-06 |
| 2 – 16 | 3.479E-01 | 3.924E-01 | 4.092E-01 | 3.758E-01 | 2.531E-01 |
| 2 – 17 | 8.703E-01 | 9.819E-01 | 1.024E+00 | 9.397E-01 | 6.313E-01 |
| 2 – 18 | 8.711E-01 | 9.829E-01 | 1.025E+00 | 9.390E-01 | 6.283E-01 |
| 2 – 19 | 2.960E+00 | 3.364E+00 | 3.509E+00 | 3.204E+00 | 2.117E+00 |
| 2 – 20 | 8.617E-01 | 9.712E-01 | 1.012E+00 | 9.243E-01 | 6.122E-01 |
| 2 – 21 | 3.304E-01 | 3.716E-01 | 3.872E-01 | 3.539E-01 | 2.352E-01 |
| 2 – 22 | 9.219E-01 | 1.043E+00 | 1.088E+00 | 9.932E-01 | 6.576E-01 |
| 2 – 23 | 1.434E-01 | 1.608E-01 | 1.675E-01 | 1.531E-01 | 1.019E-01 |
| 2 – 24 | 1.483E-01 | 1.674E-01 | 1.745E-01 | 1.594E-01 | 1.059E-01 |
| 2 – 25 | 4.546E-01 | 5.174E-01 | 5.404E-01 | 4.931E-01 | 3.263E-01 |
| 2 – 26 | 2.880E-01 | 3.273E-01 | 3.417E-01 | 3.120E-01 | 2.067E-01 |
| 2 – 27 | 7.572E-03 | 7.288E-03 | 7.308E-03 | 6.616E-03 | 4.367E-03 |
| 2 – 28 | 1.945E+00 | 2.062E+00 | 2.150E+00 | 2.288E+00 | 2.500E+00 |
| 2 – 29 | 1.515E+00 | 9.738E-04 | 7.920E-04 | 5.561E-04 | 2.717E-04 |
| 2 – 30 | 3.599E-04 | 4.329E-04 | 4.676E-04 | 3.485E-04 | 1.694E-04 |
| 2 – 31 | 3.910E-04 | 3.802E-04 | 3.820E-04 | 2.789E-04 | 1.345E-04 |
| 2 – 32 | 1.408E-01 | 1.571E-01 | 2.088E-01 | 3.085E-01 | 4.342E-01 |
| 2 – 33 | 3.347E-01 | 3.751E-01 | 4.772E-01 | 6.568E-01 | 8.306E-01 |
| 2 – 34 | 9.439E-02 | 1.054E-01 | 1.329E-01 | 1.805E-01 | 2.254E-01 |
| 2 – 35 | 2.114E-02 | 2.332E-02 | 2.899E-02 | 3.857E-02 | 4.663E-02 |
| 2 – 36 | 1.282E-01 | 1.441E-01 | 1.794E-01 | 2.368E-01 | 2.829E-01 |
| 2 – 37 | 1.335E-04 | 3.530E-05 | 5.656E-06 | 7.313E-07 | 1.674E-07 |
| 2 – 38 | 7.511E-04 | 8.263E-04 | 9.882E-04 | 1.214E-03 | 1.294E-03 |
| 2 – 39 | 5.426E-03 | 6.175E-03 | 7.364E-03 | 8.794E-03 | 8.939E-03 |
| 2 – 40 | 1.527E-02 | 1.741E-02 | 2.001E-02 | 2.204E-02 | 1.977E-02 |
| 2 – 41 | 4.079E-04 | 1.420E-04 | 3.278E-05 | 8.034E-06 | 2.190E-06 |
| $i - j$ | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|---------|--------|--------|--------|--------|--------|
| 2 - 42  | 1.075E-02 | 1.297E-02 | 1.364E-02 | 1.539E-02 | 1.726E-02 |
| 2 - 43  | 2.972E-02 | 3.580E-02 | 3.770E-02 | 4.299E-02 | 4.792E-02 |
| 2 - 44  | 3.669E-02 | 4.379E-02 | 4.628E-02 | 5.350E-02 | 5.863E-02 |
| 2 - 45  | 9.894E-02 | 1.191E-01 | 1.266E-01 | 1.473E-01 | 1.596E-01 |
| 2 - 46  | 3.107E-02 | 3.626E-02 | 3.820E-02 | 4.481E-02 | 4.867E-02 |
| 2 - 47  | 1.757E-02 | 2.021E-02 | 2.134E-02 | 2.524E-02 | 2.725E-02 |
| 2 - 48  | 4.974E-02 | 5.899E-02 | 6.300E-02 | 7.503E-02 | 8.019E-02 |
| 2 - 49  | 4.073E-03 | 4.227E-03 | 4.406E-03 | 5.275E-02 | 5.542E-02 |
| 2 - 50  | 1.174E-03 | 1.352E-03 | 1.465E-03 | 1.775E-03 | 1.823E-03 |
| 2 - 51  | 5.659E-02 | 6.849E-02 | 6.510E-02 | 4.740E-02 | 2.389E-02 |
| 2 - 52  | 4.558E-02 | 5.472E-02 | 5.186E-02 | 3.778E-02 | 1.933E-02 |
| 2 - 53  | 4.830E-03 | 5.736E-03 | 6.285E-03 | 7.588E-03 | 7.693E-03 |
| 2 - 54  | 3.406E-03 | 4.076E-03 | 4.475E-03 | 5.445E-03 | 5.537E-03 |
| 2 - 55  | 2.066E-01 | 2.641E-01 | 2.846E-01 | 2.370E-01 | 1.324E-01 |
| 2 - 56  | 3.106E-02 | 3.868E-02 | 4.150E-02 | 3.452E-02 | 1.946E-02 |
| 2 - 57  | 8.248E-02 | 9.903E-02 | 9.366E-02 | 6.849E-02 | 3.590E-02 |
| 2 - 58  | 4.682E-02 | 5.623E-02 | 5.325E-02 | 3.871E-02 | 1.956E-02 |
| 2 - 59  | 4.444E-02 | 5.304E-02 | 5.004E-02 | 3.625E-02 | 1.822E-02 |
| 2 - 60  | 1.331E-01 | 1.697E-01 | 1.824E-01 | 1.519E-01 | 8.560E-02 |
| 2 - 61  | 5.333E-04 | 3.423E-04 | 3.000E-04 | 3.505E-04 | 3.435E-04 |
| 2 - 62  | 1.954E-03 | 2.233E-03 | 2.233E-03 | 2.083E-03 | 2.051E-03 |
| 2 - 63  | 2.210E-04 | 2.548E-04 | 2.395E-04 | 1.740E-04 | 8.757E-05 |
| 2 - 64  | 6.821E-04 | 8.061E-04 | 7.691E-04 | 5.935E-04 | 3.691E-04 |
| 2 - 65  | 5.920E-04 | 7.386E-04 | 7.782E-04 | 6.491E-04 | 3.649E-04 |
| 2 - 66  | 2.310E+00 | 2.619E+00 | 3.021E+00 | 3.634E+00 | 4.293E+00 |
| 2 - 67  | 1.206E-02 | 6.167E-03 | 2.450E-03 | 8.096E-04 | 2.266E-04 |
| 2 - 68  | 5.971E-05 | 6.777E-05 | 7.534E-05 | 7.082E-05 | 5.681E-05 |
| 2 - 69  | 1.456E-04 | 1.547E-04 | 1.704E-04 | 1.590E-04 | 1.272E-04 |
| 2 - 70  | 1.428E-03 | 1.746E-03 | 1.999E-03 | 2.205E-03 | 2.431E-03 |
| 2 - 71  | 3.035E-05 | 1.391E-05 | 5.046E-06 | 1.624E-06 | 5.327E-07 |
| 2 - 72  | 5.721E-04 | 6.753E-04 | 7.131E-04 | 9.182E-04 | 1.350E-03 |
| 2 - 73  | 1.403E-04 | 2.080E-04 | 2.397E-04 | 2.298E-04 | 1.886E-04 |
| 2 - 74  | 2.610E-03 | 2.829E-03 | 2.863E-03 | 4.178E-03 | 7.051E-03 |
| 2 - 75  | 1.340E-05 | 6.205E-06 | 2.315E-06 | 8.059E-07 | 3.092E-07 |
Table 13: Fine structure collision strengths from the Al IV level $1s^22s^22p^3\text{3}P^0_1$ (level 3 in Table 4) to all the other levels.

| $i-j$ | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|-------|-------|-------|-------|--------|--------|
| 3−4   | 3.685E-02 | 1.502E-02 | 5.086E-03 | 1.496E-03 | 3.916E-04 |
| 3−5   | 6.059E-02 | 3.646E-02 | 2.580E-02 | 2.268E-02 | 2.228E-02 |
| 3−6   | 6.336E+00 | 7.556E+00 | 8.754E+00 | 9.914E+00 | 1.120E+01 |
| 3−7   | 5.507E-03 | 1.423E-03 | 3.950E-04 | 2.524E-04 | 1.709E-04 |
| 3−8   | 2.54E+01 | 3.713E+01 | 3.04E+01 | 2.84E+01 | 2.78E+01 |
| 3−9   | 1.238E+01 | 1.490E+01 | 1.747E+01 | 1.996E+01 | 2.270E+01 |
| 3−10  | 5.194E+00 | 6.258E+00 | 7.356E+00 | 8.431E+00 | 9.611E+00 |
| 3−11  | 1.441E+00 | 1.735E+00 | 2.041E+00 | 2.341E+00 | 2.670E+00 |
| 3−12  | 7.852E+00 | 9.470E+00 | 1.115E+01 | 1.279E+01 | 1.458E+01 |
| 3−13  | 6.508E+00 | 7.855E+00 | 9.254E+00 | 1.062E+01 | 1.211E+01 |
| 3−14  | 1.628E+00 | 1.961E+00 | 2.310E+00 | 2.650E+00 | 3.020E+00 |
| 3−15  | 3.006E+00 | 3.644E-01 | 1.423E-03 | 4.442E-04 | 1.227E-01 |
| 3−16  | 6.537E-01 | 7.500E-01 | 7.818E-01 | 7.171E-01 | 4.798E-01 |
| 3−17  | 1.703E-01 | 1.909E-01 | 1.988E-01 | 1.826E-01 | 1.227E-01 |
| 3−18  | 6.653E-01 | 7.500E-01 | 7.818E-01 | 7.171E-01 | 4.798E-01 |
| 3−19  | 4.680E-03 | 1.311E-03 | 2.487E-04 | 9.777E-05 | 5.137E-05 |
| 3−20  | 1.281E+00 | 1.449E+00 | 1.511E+00 | 1.381E+00 | 9.135E-01 |
| 3−21  | 9.454E-01 | 1.071E+00 | 1.117E+00 | 1.022E+00 | 6.779E-01 |
| 3−22  | 1.551E-01 | 1.729E-01 | 1.792E-01 | 1.627E-01 | 1.072E-01 |
| 3−23  | 7.962E-01 | 9.050E-01 | 9.450E-01 | 8.647E-01 | 5.750E-01 |
| 3−24  | 4.488E-03 | 2.338E-03 | 1.773E-03 | 1.450E-03 | 9.293E-04 |
| 3−25  | 8.430E-01 | 9.568E-01 | 9.997E-01 | 9.160E-01 | 6.069E-01 |
| 3−26  | 6.749E-02 | 7.422E-02 | 7.724E-02 | 7.126E-02 | 4.772E-02 |
| 3−27  | 4.221E-03 | 3.131E-03 | 2.952E-03 | 2.858E-03 | 2.091E-03 |
| 3−28  | 1.629E-03 | 1.362E-03 | 1.283E-03 | 9.491E-04 | 4.727E-04 |
| 3−29  | 1.082E+00 | 1.089E+00 | 1.136E+00 | 1.207E+00 | 1.319E+00 |
| 3−30  | 1.678E-04 | 5.264E-05 | 1.177E-05 | 1.837E-06 | 3.833E-07 |
| 3−31  | 1.529E-01 | 1.618E-01 | 1.685E-01 | 1.782E-01 | 1.958E-01 |
| 3−32  | 5.296E-02 | 5.918E-02 | 7.879E-02 | 1.163E-01 | 1.662E-01 |
| 3−33  | 5.841E-04 | 1.864E-04 | 3.840E-05 | 9.711E-06 | 6.470E-06 |
| 3−34  | 1.242E-01 | 1.392E-01 | 1.787E-01 | 2.492E-01 | 3.223E-01 |
| 3−35  | 8.938E-02 | 1.005E-01 | 1.285E-01 | 1.770E-01 | 2.245E-01 |
| 3−36  | 5.192E-02 | 5.836E-02 | 7.378E-02 | 9.940E-02 | 1.215E-01 |
| 3−37  | 4.279E-02 | 4.838E-02 | 5.950E-02 | 7.707E-02 | 8.956E-02 |
| 3−38  | 6.662E-03 | 7.173E-03 | 8.799E-03 | 1.197E-02 | 1.549E-02 |
| 3−39  | 6.532E-02 | 7.315E-02 | 9.074E-02 | 1.204E-01 | 1.460E-01 |
| 3−40  | 1.740E-02 | 1.927E-02 | 2.438E-02 | 3.376E-02 | 4.362E-02 |
| 3−41  | 1.275E-02 | 1.457E-02 | 1.665E-02 | 1.771E-02 | 1.653E-02 |
Table 13: continued.

| $i - j$ | 15 Ry  | 30 Ry  | 60 Ry  | 120 Ry | 240 Ry |
|--------|--------|--------|--------|--------|--------|
| 3 - 42 | 9.618E-05 | 2.584E-05 | 4.255E-06 | 5.883E-07 | 8.559E-08 |
| 3 - 43 | 3.608E-03 | 4.123E-03 | 4.299E-03 | 4.578E-03 | 5.022E-03 |
| 3 - 44 | 1.657E-02 | 1.990E-02 | 2.070E-02 | 2.318E-02 | 2.603E-02 |
| 3 - 45 | 9.090E-04 | 2.480E-04 | 4.489E-05 | 9.713E-06 | 4.161E-06 |
| 3 - 46 | 3.619E-02 | 4.377E-02 | 4.594E-02 | 5.273E-02 | 5.793E-02 |
| 3 - 47 | 2.989E-02 | 3.612E-02 | 3.806E-02 | 4.427E-02 | 4.836E-02 |
| 3 - 48 | 1.491E-02 | 1.750E-02 | 1.851E-02 | 2.194E-02 | 2.326E-02 |
| 3 - 49 | 3.240E-02 | 3.932E-02 | 4.225E-02 | 5.016E-02 | 5.406E-02 |
| 3 - 50 | 3.475E-03 | 3.637E-03 | 3.758E-03 | 4.257E-03 | 4.861E-03 |
| 3 - 51 | 6.042E-04 | 5.337E-04 | 5.436E-04 | 6.031E-04 | 7.597E-04 |
| 3 - 52 | 3.210E-02 | 3.862E-02 | 3.665E-02 | 2.690E-02 | 1.413E-02 |
| 3 - 53 | 6.623E-03 | 7.511E-03 | 7.963E-03 | 9.220E-03 | 1.031E-02 |
| 3 - 54 | 2.946E-02 | 3.524E-02 | 3.791E-02 | 4.474E-02 | 4.858E-02 |
| 3 - 55 | 5.116E-04 | 1.085E-04 | 2.999E-05 | 1.436E-05 | 6.697E-06 |
| 3 - 56 | 8.581E-02 | 1.095E-01 | 1.177E-01 | 9.769E-02 | 5.465E-02 |
| 3 - 57 | 3.672E-02 | 4.671E-02 | 5.024E-02 | 4.173E-02 | 2.347E-02 |
| 3 - 58 | 1.943E-02 | 2.318E-02 | 2.190E-02 | 1.607E-02 | 8.468E-03 |
| 3 - 59 | 5.594E-02 | 7.130E-02 | 7.655E-02 | 6.356E-02 | 3.572E-02 |
| 3 - 60 | 1.269E-02 | 1.577E-02 | 1.677E-02 | 1.391E-02 | 7.769E-03 |
| 3 - 61 | 1.353E-03 | 1.168E-03 | 1.132E-03 | 1.190E-03 | 1.318E-03 |
| 3 - 62 | 2.367E-02 | 3.003E-02 | 3.255E-02 | 2.727E-02 | 1.542E-02 |
| 3 - 63 | 1.725E-02 | 2.177E-02 | 2.360E-02 | 1.976E-02 | 1.117E-02 |
| 3 - 64 | 4.088E-02 | 4.948E-02 | 4.717E-02 | 3.460E-02 | 1.779E-02 |
| 3 - 65 | 6.912E-02 | 8.835E-02 | 9.552E-02 | 7.992E-02 | 4.494E-02 |
| 3 - 66 | 1.299E+00 | 1.471E+00 | 1.696E+00 | 2.040E+00 | 2.406E+00 |
| 3 - 67 | 8.579E-02 | 9.363E-02 | 1.054E-01 | 1.256E-01 | 1.480E-01 |
| 3 - 68 | 8.033E-06 | 2.383E-06 | 1.024E-06 | 2.652E-07 | 6.983E-08 |
| 3 - 69 | 7.842E-04 | 9.693E-04 | 1.114E-03 | 1.231E-03 | 1.365E-03 |
| 3 - 70 | 1.421E-04 | 1.464E-04 | 1.585E-04 | 1.465E-04 | 1.164E-04 |
| 3 - 71 | 3.180E-05 | 2.757E-05 | 2.669E-05 | 2.886E-05 | 2.645E-05 |
| 3 - 72 | 1.349E-03 | 1.477E-03 | 1.503E-03 | 2.150E-03 | 3.564E-03 |
| 3 - 73 | 4.274E-04 | 4.556E-04 | 4.591E-04 | 6.763E-04 | 1.154E-03 |
| 3 - 74 | 1.169E-04 | 1.905E-04 | 2.449E-04 | 2.475E-04 | 1.618E-04 |
| 3 - 75 | 5.170E-05 | 5.829E-05 | 6.691E-05 | 7.088E-05 | 6.504E-05 |
Table 14: Fine structure collision strengths from the Al IV level
$1s^22s^22p^53s\ ^3P_0$ (level 4 in Table 4).

| $i-j$ | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|-------|-------|-------|-------|--------|--------|
| 4−5   | 1.733E-02 | 7.144E-03 | 2.359E-03 | 6.720E-04 | 1.699E-04 |
| 4−6   | 1.864E+00 | 2.219E+00 | 2.566E+00 | 2.902E+00 | 3.275E+00 |
| 4−7   | 1.176E-04 | 1.330E-04 | 1.410E-04 | 1.307E-04 | 9.220E-05 |
| 4−8   | 7.840E-04 | 1.847E-04 | 2.633E-05 | 4.108E-06 | 9.574E-07 |
| 4−9   | 1.176E-04 | 1.330E-04 | 1.410E-04 | 1.307E-04 | 9.220E-05 |
| 4−10  | 3.378E-04 | 7.343E-05 | 7.813E-06 | 5.988E-07 | 1.022E-07 |
| 4−11  | 6.675E+00 | 8.045E+00 | 9.453E+00 | 1.082E+01 | 1.232E+01 |
| 4−12  | 3.012E-03 | 6.583E-04 | 6.932E-05 | 4.988E-06 | 8.227E-07 |
| 4−13  | 4.918E-04 | 1.070E-04 | 1.081E-05 | 6.170E-07 | 2.399E-07 |
| 4−14  | 6.675E+00 | 8.045E+00 | 9.453E+00 | 1.082E+01 | 1.232E+01 |
| 4−15  | 3.012E-03 | 6.583E-04 | 6.932E-05 | 4.988E-06 | 8.227E-07 |
| 4−16  | 5.821E-05 | 5.771E-05 | 5.623E-05 | 4.803E-05 | 4.803E-05 |
| 4−17  | 1.627E-04 | 3.834E-05 | 6.539E-06 | 1.085E-06 | 1.741E-07 |
| 4−18  | 1.958E-05 | 2.204E-05 | 2.297E-05 | 2.111E-05 | 1.415E-05 |
| 4−19  | 3.442E-05 | 4.218E-05 | 4.587E-05 | 4.218E-05 | 2.798E-05 |
| 4−20  | 3.080E-04 | 7.460E-05 | 1.355E-05 | 2.389E-06 | 4.156E-07 |
| 4−21  | 3.226E-04 | 3.648E-04 | 3.806E-04 | 3.488E-04 | 2.315E-04 |
| 4−22  | 6.206E-04 | 1.412E-04 | 2.249E-05 | 3.396E-06 | 4.775E-07 |
| 4−23  | 4.088E-04 | 9.422E-05 | 1.511E-05 | 2.334E-06 | 3.405E-07 |
| 4−24  | 6.521E-05 | 5.763E-05 | 5.771E-05 | 5.623E-05 | 4.803E-05 |
| 4−25  | 2.981E-03 | 6.818E-04 | 1.087E-04 | 1.641E-05 | 2.301E-06 |
| 4−26  | 4.652E-01 | 5.275E-01 | 5.507E-01 | 5.047E-01 | 3.354E-01 |
| 4−27  | 1.075E-03 | 2.488E-04 | 4.087E-05 | 6.357E-06 | 9.300E-07 |
| 4−28  | 4.981E-04 | 5.940E-04 | 6.378E-04 | 4.909E-04 | 2.479E-04 |
| 4−29  | 4.467E-05 | 1.482E-05 | 3.901E-06 | 8.292E-07 | 1.975E-07 |
| 4−30  | 3.887E-01 | 4.122E-01 | 4.290E-01 | 4.315E-01 | 3.850E-01 |
| 4−31  | 3.822E-04 | 1.197E-04 | 2.610E-05 | 3.863E-06 | 7.827E-07 |
| 4−32  | 1.325E-02 | 1.487E-02 | 1.959E-02 | 2.842E-02 | 4.060E-02 |
| 4−33  | 5.183E-06 | 5.938E-06 | 6.673E-06 | 3.917E-06 | 3.269E-06 |
| 4−34  | 1.221E-05 | 3.711E-06 | 5.530E-07 | 5.095E-08 | 9.744E-09 |
| 4−35  | 5.449E-03 | 6.083E-03 | 7.823E-03 | 1.109E-02 | 1.497E-02 |
| 4−36  | 1.974E-06 | 5.883E-07 | 8.382E-08 | 7.351E-09 | 1.311E-09 |
| 4−37  | 5.177E-05 | 1.577E-05 | 2.314E-06 | 1.969E-07 | 3.558E-08 |
| 4−38  | 8.437E-02 | 9.476E-02 | 1.197E-01 | 1.629E-01 | 2.046E-01 |
| 4−39  | 4.624E-04 | 1.414E-04 | 2.121E-05 | 2.110E-06 | 4.246E-07 |
| 4−40  | 4.568E-02 | 5.129E-02 | 6.503E-02 | 8.884E-02 | 1.116E-01 |
| 4−41  | 9.976E-05 | 3.418E-05 | 7.549E-06 | 1.769E-06 | 4.764E-07 |
| $i - j$ | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|---------|-------|-------|-------|--------|--------|
| 4 − 42  | 2.354E-04 | 2.602E-04 | 2.611E-04 | 2.310E-04 | 1.677E-04 |
| 4 − 43  | 1.125E-05 | 3.122E-06 | 5.488E-07 | 8.427E-08 | 1.420E-08 |
| 4 − 44  | 1.829E-03 | 2.230E-03 | 2.298E-03 | 2.352E-03 | 2.749E-03 |
| 4 − 45  | 3.389E-06 | 3.305E-06 | 2.948E-06 | 2.479E-06 | 1.987E-06 |
| 4 − 46  | 1.405E-05 | 3.994E-06 | 7.728E-07 | 1.322E-07 | 2.453E-08 |
| 4 − 47  | 1.513E-03 | 1.852E-03 | 1.920E-03 | 2.053E-03 | 2.370E-03 |
| 4 − 48  | 1.343E-05 | 3.537E-06 | 5.779E-07 | 7.899E-08 | 1.138E-08 |
| 4 − 49  | 5.731E-05 | 1.568E-05 | 2.618E-06 | 3.747E-07 | 5.781E-08 |
| 4 − 50  | 2.659E-07 | 4.065E-08 | 5.123E-09 | 6.700E-10 | 8.400E-11 |
| 4 − 51  | 7.999E-04 | 2.094E-04 | 3.445E-05 | 4.742E-06 | 6.777E-07 |
| 4 − 52  | 6.904E-04 | 7.593E-04 | 8.096E-04 | 9.060E-04 | 1.141E-03 |
| 4 − 53  | 2.659E-07 | 4.065E-08 | 5.123E-09 | 6.700E-10 | 8.400E-11 |
| 4 − 54  | 7.999E-04 | 2.094E-04 | 3.445E-05 | 4.742E-06 | 6.777E-07 |
| 4 − 55  | 7.409E-06 | 8.909E-06 | 1.004E-05 | 7.913E-06 | 4.015E-06 |
| 4 − 56  | 6.634E-07 | 4.571E-08 | 2.504E-08 | 9.512E-09 | 1.274E-09 |
| 4 − 57  | 1.149E-03 | 1.471E-03 | 1.605E-03 | 1.336E-03 | 7.524E-04 |
| 4 − 58  | 4.615E-06 | 8.355E-07 | 1.235E-07 | 1.421E-08 | 1.344E-09 |
| 4 − 59  | 5.746E-04 | 7.360E-04 | 8.058E-04 | 6.700E-04 | 3.760E-04 |
| 4 − 60  | 4.967E-06 | 6.567E-07 | 1.555E-07 | 3.888E-08 | 4.836E-09 |
| 4 − 61  | 3.170E-04 | 8.488E-05 | 1.416E-05 | 1.997E-06 | 2.889E-07 |
| 4 − 62  | 5.257E-02 | 6.709E-02 | 7.238E-02 | 6.040E-02 | 3.398E-02 |
| 4 − 63  | 7.535E-02 | 9.637E-02 | 1.040E-01 | 8.681E-02 | 4.838E-02 |
| 4 − 64  | 2.521E-04 | 4.639E-05 | 6.699E-06 | 8.171E-07 | 7.690E-08 |
| 4 − 65  | 4.478E-04 | 8.413E-05 | 1.224E-05 | 1.294E-06 | 1.145E-07 |
| 4 − 66  | 4.656E-01 | 5.278E-01 | 6.089E-01 | 7.323E-01 | 8.636E-01 |
| 4 − 67  | 2.411E-03 | 1.232E-03 | 4.891E-04 | 1.615E-04 | 4.508E-05 |
| 4 − 68  | 2.655E-04 | 3.315E-04 | 3.814E-04 | 4.038E-04 | 3.639E-04 |
| 4 − 69  | 9.104E-06 | 3.862E-06 | 1.253E-06 | 3.348E-07 | 8.664E-08 |
| 4 − 70  | 5.870E-05 | 6.555E-05 | 7.387E-05 | 6.908E-05 | 5.500E-05 |
| 4 − 71  | 6.360E-06 | 2.908E-06 | 1.032E-06 | 3.071E-07 | 8.184E-08 |
| 4 − 72  | 2.719E-06 | 1.260E-06 | 4.617E-07 | 1.439E-07 | 3.960E-08 |
| 4 − 73  | 6.196E-04 | 6.647E-04 | 6.708E-04 | 9.851E-04 | 1.677E-03 |
| 4 − 74  | 6.287E-05 | 1.032E-04 | 1.329E-04 | 1.345E-04 | 8.777E-05 |
| 4 − 75  | 2.792E-06 | 1.281E-06 | 4.615E-07 | 1.431E-07 | 3.977E-08 |
Table 15: Fine structure collision strengths from the Al IV level
$1s^22s^22p^33s^1P^0_1$ (level 5 in Table 4).

| $i-j$ | 15 Ry | 30 Ry   | 60 Ry   | 120 Ry  | 240 Ry  |
|-------|-------|---------|---------|---------|---------|
| 5 – 6 | 1.993E-01 | 2.338E-01 | 2.684E-01 | 3.020E-01 | 3.396E-01 |
| 5 – 7 | 3.479E-03 | 7.600E-04 | 9.430E-05 | 2.344E-05 | 1.419E-05 |
| 5 – 8 | 5.053E-01 | 6.018E-01 | 6.999E-01 | 7.969E-01 | 9.050E-01 |
| 5 – 9 | 9.052E-02 | 1.055E-01 | 1.223E-01 | 1.394E-01 | 1.585E-01 |
| 5 – 10 | 1.741E-01 | 2.092E-01 | 2.445E-01 | 2.790E-01 | 3.171E-01 |
| 5 – 11 | 1.163E+01 | 1.397E+01 | 1.635E+01 | 1.866E+01 | 2.120E+01 |
| 5 – 12 | 1.939E+01 | 2.332E+01 | 2.732E+01 | 3.121E+01 | 3.550E+01 |
| 5 – 13 | 3.750E-01 | 4.493E-01 | 5.253E-01 | 5.991E-01 | 6.794E-01 |
| 5 – 14 | 9.910E+00 | 1.192E+01 | 1.396E+01 | 1.596E+01 | 1.814E+01 |
| 5 – 15 | 5.583E+00 | 6.792E+00 | 8.244E+00 | 9.761E+00 | 1.146E+01 |
| 5 – 16 | 3.911E-04 | 9.237E-05 | 1.609E-05 | 2.693E-06 | 4.403E-07 |
| 5 – 17 | 4.486E-03 | 3.834E-03 | 3.731E-03 | 3.440E-03 | 2.354E-03 |
| 5 – 18 | 3.672E-03 | 1.535E-03 | 1.032E-03 | 9.269E-05 | 6.535E-05 |
| 5 – 19 | 3.015E-03 | 6.885E-04 | 1.155E-04 | 2.284E-05 | 6.411E-06 |
| 5 – 20 | 1.889E-01 | 2.104E-01 | 2.172E-01 | 1.958E-01 | 1.285E-01 |
| 5 – 21 | 4.460E-02 | 4.775E-02 | 4.874E-02 | 4.371E-02 | 2.878E-02 |
| 5 – 22 | 1.248E+00 | 1.407E+00 | 1.460E+00 | 1.324E+00 | 8.715E-01 |
| 5 – 23 | 1.217E-02 | 1.242E-02 | 1.248E-02 | 1.092E-02 | 7.025E-03 |
| 5 – 24 | 8.104E-01 | 9.135E-01 | 9.484E-01 | 8.612E-01 | 5.697E-01 |
| 5 – 25 | 9.495E-01 | 1.070E+00 | 1.112E+00 | 1.011E+00 | 6.669E-01 |
| 5 – 26 | 7.800E-01 | 8.795E-01 | 9.135E-01 | 8.302E-01 | 5.496E-01 |
| 5 – 27 | 1.026E+00 | 1.164E+00 | 1.211E+00 | 1.096E+00 | 7.216E-01 |
| 5 – 28 | 6.465E-04 | 3.010E-04 | 1.735E-04 | 1.086E-04 | 5.392E-05 |
| 5 – 29 | 2.093E-01 | 2.215E-01 | 2.306E-01 | 2.460E-01 | 2.653E-01 |
| 5 – 30 | 2.913E-04 | 9.526E-05 | 2.363E-05 | 4.594E-06 | 1.060E-06 |
| 5 – 31 | 1.133E+00 | 1.201E+00 | 1.251E+00 | 1.333E+00 | 1.449E+00 |
| 5 – 32 | 1.199E-03 | 1.217E-03 | 1.256E-03 | 1.182E-03 | 9.245E-04 |
| 5 – 33 | 3.856E-04 | 1.185E-04 | 1.871E-05 | 2.378E-06 | 8.466E-07 |
| 5 – 34 | 4.015E-02 | 4.524E-02 | 6.045E-02 | 8.732E-02 | 1.157E-01 |
| 5 – 35 | 4.272E-02 | 4.832E-02 | 6.540E-02 | 9.531E-02 | 1.274E-01 |
| 5 – 36 | 6.933E-02 | 7.812E-02 | 1.038E-01 | 1.496E-01 | 1.988E-01 |
| 5 – 37 | 3.479E-03 | 3.834E-03 | 5.164E-03 | 7.596E-03 | 1.084E-02 |
| 5 – 38 | 6.296E-02 | 7.069E-02 | 9.352E-02 | 1.340E-01 | 1.769E-01 |
| 5 – 39 | 1.922E-01 | 2.161E-01 | 2.820E-01 | 3.981E-01 | 5.170E-01 |
| 5 – 40 | 7.506E-02 | 8.438E-02 | 1.115E-01 | 1.593E-01 | 2.096E-01 |
| 5 – 41 | 1.952E-01 | 2.271E-01 | 2.564E-01 | 2.619E-01 | 2.192E-01 |
| $i-j$ | 15 Ry | 30 Ry | 60 Ry | 120 Ry | 240 Ry |
|-------|-------|-------|-------|--------|--------|
| 5 - 42 | 6.740E-05 | 1.816E-05 | 3.060E-06 | 4.349E-07 | 6.580E-08 |
| 5 - 43 | 3.529E-04 | 2.163E-04 | 1.906E-04 | 1.766E-04 | 1.364E-04 |
| 5 - 44 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 45 | 1.453E-02 | 1.720E-02 | 1.719E-02 | 1.939E-02 | 2.060E-02 |
| 5 - 46 | 1.151E-02 | 1.353E-02 | 1.345E-02 | 1.534E-02 | 1.612E-02 |
| 5 - 47 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 48 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 49 | 1.151E-02 | 1.353E-02 | 1.345E-02 | 1.534E-02 | 1.612E-02 |
| 5 - 50 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 51 | 1.151E-02 | 1.353E-02 | 1.345E-02 | 1.534E-02 | 1.612E-02 |
| 5 - 52 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 53 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 54 | 2.091E-03 | 2.133E-03 | 2.045E-03 | 2.380E-03 | 2.403E-03 |
| 5 - 55 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 56 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 57 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 58 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 59 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 60 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 61 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 62 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 63 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 64 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 65 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 66 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 67 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 68 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 69 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 70 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 71 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 72 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 73 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 74 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |
| 5 - 75 | 3.316E-03 | 3.734E-03 | 4.030E-03 | 4.853E-03 | 4.753E-03 |