Calculations for Energies, Lifetimes and Transition Parameters of E1 and E2 Transitions in Mg II

Betül Karaçoban Usta[*]

Physics Department, Sakarya University, 54140, Sakarya, Turkey

Abstract

The lifetimes for $2p^6ns$ (n = 4–15), $2p^6nd$ (n = 3–15), $2p^6ng$ (n = 5–15), $2p^6ni$ (n = 7–15), $2p^6np$ (n = 3–15), $2p^6nf$ (n = 4–15), $2p^6nh$ (n = 6–15), $2p^53s^2$, $2p^53snp$ (n = 3, 4), $2p^53p^2$, $2p^53sns$ (n = 4, 5), $2p^53snd$ (n = 3, 4), and $2p^53s4f$ configurations and the transition parameters for the electric dipole (E1) and electric quadrupole (E2) transitions between valence excitation levels have been calculated using the relativistic Hartree-Fock (HFR) method for singly ionized magnesium (Mg II, Z = 12). Comparisons are made with experimental and other available theoretical results to assess the reliability and accuracy of the present calculations. Moreover, some new wavelengths, oscillator strengths and transition probabilities of E1 and E2 transitions and lifetime values have been obtained using this method. These results are reported for the first time in this work.

Keywords: HFR method; Relativistic corrections; Wavelengths; Oscillator strengths; Transition probabilities

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[*] Corresponding author: Betül Karaçoban Usta (E-mail: bkaracoban@sakarya.edu.tr)
Tel.: +90 (264) 2956093; fax: +90 (264) 2955950

1. Introduction

Many research and technological areas such as astrophysics, plasma physics, thermonuclear fusion researches and isotope separation by laser are based mainly on the atomic data and therefore many research groups have worked to obtain such useful data using atomic spectroscopy. Accurate atomic data are essential in various fields of astrophysics [1].

The singly ionized magnesium (Mg II) has ground configuration $2p^63s\ ^1S_{1/2}$ and excited states of the type $2p^6nl$. The core-excited quartet levels of Mg II are metastable against autoionization. For this reason they are interest in atomic spectroscopy and also in the construction of XUV lasers. The core-excited configurations, $2p^5nln'l'$, are energetically located considerably above the $2p^6\ ^1S_0$ ionization limit forming doublet and metastable quartet states. The open 2p subshell produces strong spin-orbit interactions giving rise to subshell mixing of doublet and quartet states [2].

The energy levels and transition data for singly ionized magnesium can be found in the NIST website [3]. Lundin et al. investigated the beam-foil spectra of Mg I−Mg IV [4]. Lindgard and Nielsen presented numerical approach to transition probabilities in Mg II Rydberg series [5]. Liljeby et al. made lifetimes measurements using the beam-foil technique [6]. Biémont and Brault observed the spectrum of neutral and singly ionized magnesium produced by a hollow-cathode discharge by the Fourier transform spectroscopy technique [7]. Fischer reported muticonfiguration Hartree-Fock calculations for the metastable core-excited quartet states in Mg II [8]. Brage and Gaardsted studied experimentally by beam-foil spectroscopy and theoretically by multiconfiguration Hartree-Fock calculations for core-excited configurations of Mg II [2]. Energy levels, hyperfine constants, and transition rates for Mg II using relativistic many-body theory (MBPT) were calculated by Safronova et al. [9]. The weakest bound electron potential model theory

(WBEPMT) was used to calculate transition probabilities for Mg II by Zheng et al. [10]. Dzuba and Johnson presented the relativistic coupled-cluster single-double calculations of the relativistic energy shifts in Mg II [11]. Theodosiou and Federman reported the oscillator strengths of resonance lines for the lowest *np* configurations in Mg II [12]. Fischer et al. calculated energy levels, lifetimes and transition probabilities for Mg II [13]. Recently, Çelik et al. presented oscillator strengths, transition probabilities, and lifetimes using the WBEPMT for Mg II [1].

Electric quadrupole interactions are among the few important sources of hyperfine structure in atomic spectra. Transitions lines of alkali-like atomic ions are important in astronomical observations as well as in laser cooling [14]. There are studies relevant to electric quadrupole (E2) transitions for singly ionized magnesium in literature. Electric quadrupole transition probabilities for some transitions in sodium and potassium sequences using the frozen-core Hartree–Fock approximation were calculated by Ali [15]. Tull et al. presented theoretical multiplet strengths for E2 transitions between some levels of Mg II by using Hartree-Fock wavefunctions of frozen-core type [16]. Godefroid et al. reported forbidden transitions in Mg-like spectra [17]. Majumder et al. calculated studies of the E2 transition probabilities in Mg II using the relativistic coupled cluster (CC) theory [14]. The relativistic quantum defect orbital (RQDO) formalism to the study of E2 transitions in Mg II were applied by Charro and Martín [18]. Çelik et al. calculated electric quadrupole transition probabilities using the WBEPMT for Mg II [19].

The aim of this paper is to obtain atomic data for singly ionized magnesium (Mg II, Z = 12) using relativistic Hartree-Fock (HFR) code by developed Cowan [20]. We have reported relativistic energies, Landé *g*-factors and lifetimes for the levels of $2p^6ns$ (n = 3–15), $2p^6nd$ (n = 3–15), $2p^6ng$ (n = 5–15), $2p^6ni$ (n = 7–15), $2p^6np$ (n = 3–15), $2p^6nf$ (n = 4–15), $2p^6nh$ (n = 6–15), $2p^53s^2$, $2p^53snp$ (n = 3, 4), $2p^53p^2$, $2p^53sns$ (n = 4, 5), $2p^53snd$ (n =

3, 4) and $2p^53s4f$ configurations, and the transition parameters, such as the wavelengths, oscillator strengths, and transition probabilities, for electric dipole (E1) and electric quadrupole (E2) transitions between valence excitation levels in Mg II. Calculations have been carried out by the relativistic Hartree-Fock (HFR) method [21]. This method considers the correlation effects and relativistic corrections. These effects make important contribution to understanding physical and chemical properties of atoms or ions.

The ground-state level of Mg II is [Ne] 3s $^1S_{1/2}$. In this work, we have studied different configuration sets according to valence excitations and core-valence correlation for correlation effects in Mg II. In calculations, we have taken into account ns (n = 3−15), nd (n = 3−15), ng (n = 5−15), ni (n = 7−15), np (n = 3−15), nf (n = 4−15), and nh (n = 6−15) configurations outside the core [Ne] for the calculation A and $2p^6ns$, $2p^6nd$ (n = 3–10), $2p^6ng$ (n = 5–10), $2p^6ni$ (n = 7–10), $2p^6np$ (n = 3–10), $2p^6nf$ (n = 4–10), $2p^6nh$ (n = 6–10), $2p^53s^2$, $2p^53snp$ (n = 3, 4), $2p^53p^2$, $2p^53sns$ (n = 4, 5), $2p^53snd$ (n = 3, 4), and $2p^53s4f$ configurations outside the core [Be] for the calculation B. These configuration sets used in calculations have been denoted by A and B in tables. We reported some works related to these ion using the method mentioned above [22, 23]. In our previous works, we presented the wavelengths, oscillator strengths, and transition probabilities for 3s−3p, 3p−ns (n = 4−10), and 3p−nd (n = 3−10) E1 transitions [22], and for 3s−nd (n = 3−10), 3d−nd (n =4−10), 3p−np (n = 4−10), and 3p−nf (n = 4−10) E2 transitions [23] of calculation A. In this work, we have considered more transitions than in [22, 23] and added energy levels, Landé *g*-factors and lifetimes.

2. Method of calculation

In HFR method [21], for N electron atom of nuclear charge Z_0, the Hamiltonian is expanded as

$$H = -\sum_i \nabla_i^2 - \sum_i \frac{2Z_0}{r_i} + \sum_{i>j} \frac{2}{r_{ij}} + \sum_i \zeta_i(r_i)\mathbf{l}_i.\mathbf{s}_i \qquad (1)$$

in atomic units, with r_i the distance of the ith electron from the nucleus and $r_{ij} = |\mathbf{r}_i - \mathbf{r}_j|$. $\zeta_i(R) = \frac{\alpha^2}{2}\frac{1}{r}\left(\frac{\partial V}{\partial r}\right)$ is the spin-orbit term, with α being the fine structure constant and V the mean potential field due to the nucleus and other electrons.

In this method it is calculated single-configuration radial functions for a spherically symmetrized atom (center-of-gravity energy of the configuration) based on Hartree-Fock method. The radial wave functions are also used to obtain the total energy of the atom (E_{av}) including approximate relativistic and correlation energy corrections. Relativistic terms are included in the potential function of the differential equation to give approximate relativistic corrections to the radial functions, as well as improved relativistic energy corrections in heavy atoms. In addition, a correlation term is included in order to make the potential function more negative, and thereby help to bind negative ions. Also, Coulomb integrals F^k and G^k and spin-orbit integrals ζ_{nl} are computed with these radial functions. After radial functions have been obtained based on Hartree-Fock model, the wave function $|\gamma JM\rangle$ of the M sublevel of a level labeled γJ is expressed in terms of LS basis states $|\alpha LSJM\rangle$ by the formula

$$|\gamma JM\rangle = \sum_{\alpha LS} |\alpha LSJM\rangle\langle\alpha LSJ|\gamma J\rangle. \qquad (2)$$

If determinant wave functions are used for the atom, the total binding energy is given by

$$E = \sum_i (E_k^i + E_n^i + \sum_{j<i} E^{ij}) \tag{3}$$

where E_k^i is the kinetic energy, E_n^i is the electron-nuclear Coulomb energy, and E^{ij} is the Coulomb interaction energy between electrons *i* and *j* averaged over all possible magnetic quantum numbers.

In this method, relativistic corrections have been limited to calculations to the mass-velocity and the Darwin corrections by using the relativistic correction to total binding energy. The total binding energy can be given in by formulas (7.57), (7.58), and (7.59) in [21].

The Landé *g*-factor of an atomic level is related to the energy shift of the sublevels having magnetic number *M* by

$$\Delta E(\gamma JM) = \mu_B B g_{\gamma J} M \tag{4}$$

where B is the magnetic field intensity and μ_B is the Bohr magneton. The Landé *g*-factor of a level, denoted as *αJ*, belonging to a pure *LS*-coupling term is given by the formula

$$g_{\alpha LSJ} = 1 + (g_s - 1)\frac{J(J+1) - L(L+1) + S(S+1)}{2J(J+1)}. \tag{5}$$

This expression is derived from vector coupling formulas by assuming a *g* value of unity for a pure orbital angular momentum and writing the *g* value for a pure electron spin (S level) as g_s [24]. A value of 2 for g_s yields the Landé formula. The Landé *g*-factors for energy levels are a valuable aid in the analysis of a spectrum.

An electromagnetic transition between two states is characterized by the angular momentum and the parity of the corresponding photon. If the emitted or absorbed photon has angular momentum k and parity $\pi = (-1)^k$ then, the transition is an electric multipole transition (E*k*).

According to HFR method [21], the total E1 transition probability from a state $\gamma' J' M'$ to all states M levels of γJ is given by

$$A_{E1} = \frac{64\pi^4 e^2 a_0^2 \sigma^3}{3h(2J'+1)} \boldsymbol{S} \tag{6}$$

and absorption oscillator strength is given by

$$f_{ij} = \frac{2(E_j - E_i)}{3(2J+1)} \boldsymbol{S} . \tag{7}$$

Where $\boldsymbol{S}$ is the electric dipole line strength

$$\boldsymbol{S} = \left| \left\langle \gamma J \left\| \boldsymbol{P}^{(1)} \right\| \gamma' J' \right\rangle \right|^2 \tag{8}$$

in atomic units of $e^2 a^2{}_0$ and $\sigma = \left[\left(E_j - E_i \right) / hc \right]$ has units of kaysers (cm^{-1}).

The transition probability rate for pure electric quadrupole (E2) transitions is given by

$$A_{E2} = \frac{64\pi^6 e^2 a_0^4 \sigma^5}{15h\left(2J'+1\right)} \boldsymbol{S}_{E2} . \tag{9}$$

S_{E2} is the electric quadrupole (E2) transition line strength and is defined as

$$S_{E2} = \left|\left\langle \gamma J \left\| \boldsymbol{P}^{(2)} \right\| \gamma' J' \right\rangle\right|^2 \tag{10}$$

in atomic units of $e^2 a^2_0$.

Most experiments yield the lifetime of the upper level because of easy measuring. In this case the sum over multipole transitions to all lower lying levels must be taken. The lifetime τ for a level j is defined as follows

$$\tau_j = \frac{1}{\sum_j A_{ji}}. \tag{11}$$

3. Results and discussion

We have here calculated the relativistic energies, Landé *g*-factors and lifetimes for the levels of $2p^6ns$, $2p^6nd$ (n = 3–15), $2p^6ng$ (n = 5–15), $2p^6ni$ (n = 7–15), $2p^6np$ (n = 3–15), $2p^6nf$ (n = 4–15), $2p^6nh$ (n = 6–15), $2p^53s^2$, $2p^53snp$ (n = 3, 4), $2p^53p^2$, $2p^53sns$ (n = 4, 5), $2p^53snd$ (n = 3, 4), and $2p^53s4f$ configurations and the transition parameters (wavelengths, oscillator strengths, and transition probabilities) for electric dipole (E1) and electric quadrupole (E2) transitions between valence excitation levels in Mg II using HFR [20] code. The configuration sets selected for investigating correlation effects have given in Introduction section. Correlation effects in atoms can often be classified as valence-valence, core-valence and core-core contributions. Generally, these contributions can be evaluated by multiconfiguration techniques. Only the first two contributions are usually important, in particular valence-valence correlation although the core-valence correlation in many electron atoms is important. However, excitations from core to valence produce too many configurations. We have tried to perform the core-valence correlation other than valence excitations. Therefore, we have performed two types of calculations for obtaining configuration state functions (CSFs) according to valence excitations and core-valence correlation.

The results in this work are given in tables comparing with available data, and also compared as graphically. The results for energy levels, Landé *g*-factors and lifetimes of Mg II are reported in Tables 1 and 2. The fitted energy parameters in Table 3 and Table S1 display the scaling factors (Fitted/HFR) belonging to the calculation A. The electric dipole transitions data obtained using the HFR code [20] are given in the table provided in the supplemental material (Table S2) for this paper. An excerpt of that long table is presented here as Table 4. Table 4 and Table S2 show wavelengths λ (in Å), oscillator strengths, *f*, and transition probabilities, A_{ji} (in s^{-1}), for ns−n'p (n = 3−10, n' = 4−10), np−n'd (n = 4−10, n' = 3−10), nf−n'd (n = 4−10, n' = 3−10), nf−n'g (n = 4−10, n' = 5−10), nh−n'g (n = 6−10, n' = 5−10), 6h−ni (n = 7−9), 7i−nh (n = 8−10), 8i−nh (n = 9, 10), and 9i−nh (n = 8, 10), electric dipole (E1) transitions of the calculation A. We have also reported wavelengths, logarithmic weighted oscillator strengths, log(*gf*), and weighted transition probabilities, gA_{ji}, for atomic data in Table S3 (see Supplementary Material, Table S3). Table S3 consists np−n's (n = 3−15, n' = 11−15), ns−n'p (n = 3−15, n' = 10−15), np−n'd (n = 3−15, n' = 11−15), nf−n'd (n = 4−15, n' = 11−15), nf−n'g (n = 4−15, n' = 11−15), nh−n'g (n = 6−15, n' = 11−15), and nh−n'i (n=6−15, n' = 7−15) electric dipole transitions obtained from calculation A. Table 5 reports the wavelengths λ (in Å), logarithmic weighted oscillator strengths, log (g*f*), and transition probabilities, A_{ji} (in s^{-1}), for 4s−nd (n = 3−9), 4d−nd (n =5−7), 4p−np (n = 5−9), 4p−nf (n = 4−9), 4f−5f, 5s−nd (n = 3−5), and 5p−5f electric quadrupole transitions of the calculation A. We have also reported wavelengths λ (in Å), logarithmic weighted oscillator strengths, log (*gf*), and transition probabilities A_{ji} (in s^{-1}), for atomic data in Table S4 (see Supplementary Material, Table S4) for 3s−nd (n = 11−15), 3d−nd (n =11−15), 3d−ng (n= 5−15), 3p−np (n = 11−15), 3p−nf (n = 11−15), 4s−nd (n = 10−15), 4d−nd (n =8−15), 4d−ng (n= 5−15), 4p−np (n = 10−15), 4p−nf (n = 10−15), 4f−nf (n=6−15), 4f−nh (n= 6−15), 5s−nd (n = 6−15), 5d−nd (n =6−15), 5d−ng (n =6−15), 5p−np (n = 6−15), 5p−nf (n = 4, 6−15), 5f−nf (n = 6−15), and 5f−nh (n = 6−15) E2 transitions obtained from calculation A.

We have presented our calculations using the RCN, RCN2, RCG and RCE chain of programs developed by Cowan [21]. The HFR option of the RCN code was used to derive initial values of the parameters with appropriate scaling factors in the code RCN2. The RCE can be used to vary the various radial energy parameters E_{av}, F^k, G^k, ζ, and R^k to make a least-squares fit of experimental energy levels by an iterative procedure. The resulting least-squares-fit parameters can then be used to repeat the RCG calculation with the improved energy levels and wavefunctions [21]. Transition parameters were calculated by the RCG code after the fitting of energy parameters. In calculations, the Hamiltonian's calculated eigenvalues were optimized to the observed energy levels via a least-squares fitting procedure using experimentally determined energy levels, specifically all of the levels from the NIST compilation [3]. The scaling factors of the Slater parameters (F^k and G^k) and of configuration interaction integrals (R^k), not optimized in the least-squares fitting, were chosen equal to 0.95 for calculations A and B, while the spin-orbit parameters were left at their initial values. Additionally, we have presented Ab initio results (values not optimized in the least-squares fitting) calculated using the HFR [20] in this work. These Ab initio results are given in the supplemental material (Tables S5, S6 and S7). Table S5 reports energy levels and lifetimes of Mg II for calculations A and B. Tables S6 and S7 consist original outputs including all electric dipole and electric quadrupole transitions obtained from calculation A, respectively.

In this work, we have only given E1 transitions between valence excitation levels. Therefore, the fitted energy parameters in Table 3 and Table S1 were reported the scaling factors (Fitted/HFR) belonging to the calculation A. In this calculation, there is not the scaling factors $F^k(l_i, l_i)$ between equivalent electrons , $F^k(l_i, l_j)$ and $G^k(l_i, l_j)$ for non-equivalent electrons and configuration interaction (R^k) radial integrals. The ratio (Fitted/HFR) for energy parameters in calculation A is compared with 1.00 for total binding energy (E_{av}) and spin-orbit (ζ) in Table 3 and Table S1. It can be mentioned that the agreement for most of values is good (except $2p^6 6d$ level).

3.1. Energy levels and lifetimes

The relativistic energies, Landé *g*-factors, and lifetimes for the levels of $2p^6ns$, $2p^6nd$ (n = 3–15), $2p^6ng$ (n = 5–15), $2p^6ni$ (n = 7–15), $2p^6np$ (n = 3–15), $2p^6nf$ (n = 4–15) and $2p^6nh$ (n = 6–15) valence excited configurations and $2p^53s^2$, $2p^53snp$ (n = 3, 4), $2p^53p^2$, $2p^53sns$ (n = 4, 5), $2p^53snd$ (n = 3, 4), and $2p^53s4f$ core-excited quartet configurations in Mg II are presented in Tables 1 and 2, respectively. In tables, the results obtained have been given energies (cm^{-1}) relative to 3s $^2S_{1/2}$ ground-state level. Only odd-parity states in tables are indicated by the superscript "o". References for other comparison values are typed below the tables with a superscript lowercase letter. We have compared our results with previous works [1, 3, 13] in Tables 1 and 2. In Table 1, energy and lifetime results of the $2p^6ns$ (n = 3–10), $2p^6np$ (n = 3–10), $2p^6nd$ (n = 3–10), $2p^6nf$ (n = 4–10), $2p^6ng$ (n = 5–10), and $2p^6nh$ (n = 6–10) excited levels are compared with experimental [3] and theoretical [1, 13] results. Most of our energy results are in good agreement with others. Moreover, we have calculated $[|E_{\text{this work}} - E_{\text{other works}}|/E_{\text{other works}}] \times 100$, the differences in per cent, for interpreting accuracy of our results in Table 1. In calculations, difference (%) between our results and other experimental works [3] have been not found. When the differences (%) between our results and other theoretical results [1, 13] are investigated, the differences in energies are in range of 0.00−0.26% for calculations A and B. In addition, in Fig. 1, we have shown the comparison between our energies and those reported by NIST [3]. As seen from Fig. 1, the energy results obtained from our calculations are in good agreement with [3]. Linear correlation coefficient R^2 is 1.000 for calculation A.

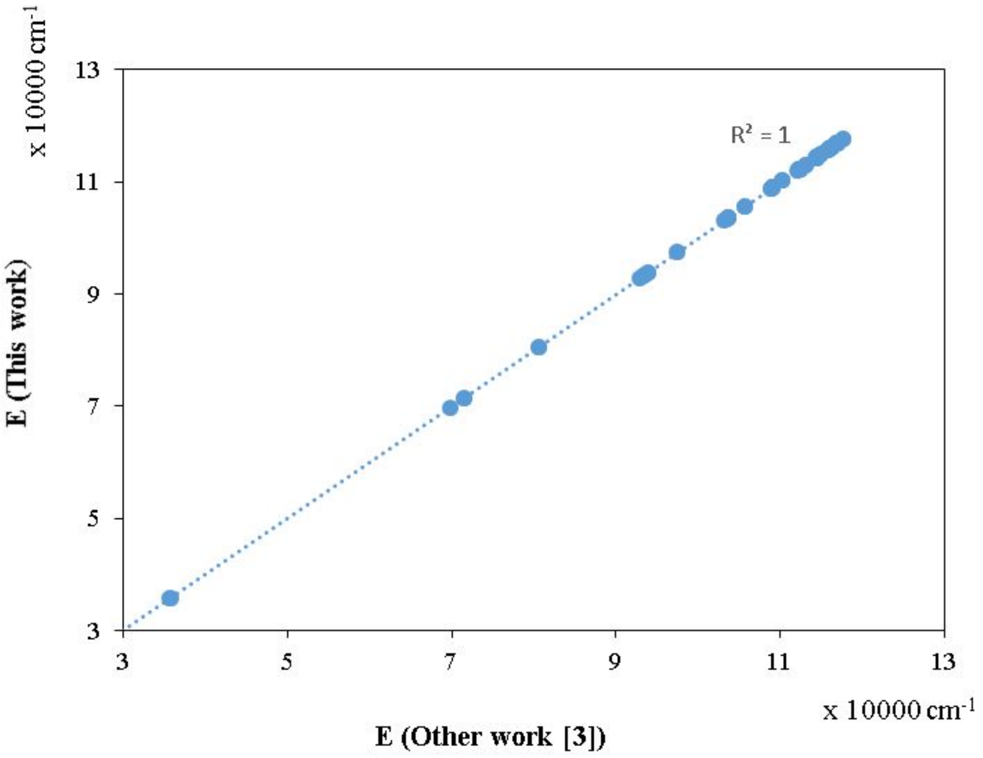

Figure 1. Comparison of the energies obtained from this work (calculation A) with those of NIST [3].

The radiative lifetimes give some information about atomic structure, since the electromagnetic interaction is well understood in atomic physics. So we have calculated the lifetimes of these levels. They have compared in Table 1 with other available theoretical results. As seen from this table, the lifetimes obtained from the calculation B are in agreement with other works. The agreement is somewhat poor for lifetimes of $2p^6 10s$, $2p^6 9d$ and $2p^6 np$ (n = 6–10) excited levels. Moreover, we have calculated $[|\tau_{\text{this work}} - \tau_{\text{other works}}|/ \tau_{\text{other works}}] \times 100$, the differences in per cent. For the differences (%) between our results and other theoretical results [13] are in range of 0.13−13.09% and 0.05−12.82% for calculations A and B, respectively, except the lifetimes of $2p^6 10s$ and $2p^6 9d$ levels. Except the lifetimes of $2p^6 np$ (n = 6–10) and $2p^6 9d$ levels, the differences (%) between our results and other theoretical results [1] are in range of 0.00−14.95%, and 0.09−14.47% for calculations A and B, respectively.

In Table 2, energy and lifetime results of the $2p^5 3s^2$, $2p^5 3s3p$, $2p^5 3p^2$, $2p^5 3s4s$ and $2p^5 3s3d$ excited levels are compared with experimental [3] and theoretical [8] results. Most of our energy results are in good agreement with [3, 8]. The differences (%) between our results and other works [3] are in range of 0.01−6.12% for calculation B. The lifetimes computed are compared in Table 2 with other available theoretical results for the 15 levels of core-excited quartet configurations. For $2p^5(^2P^o)3p^2(^3P)\ ^2D^o_{3/2}$, $2p^5(^2P^o)3s4s(^3S)\ ^4P^o_{1/2,\ 3/2}$ and $2p^5(^2P^o)3s3d(^3D)\ ^4P^o_{3/2,\ 5/2}$ levels, the agreement is poor. Figure 2 shows a comparison between our lifetime results in Table 1 and those reported by Çelik et al. [1]. When looking at this figure, we can observe that our lifetime results are in agreement with [1] except for $2p^6 10s$, $2p^6 9d$ and $2p^6 np$ (n = 6–10) levels. The coefficient of determination, R^2, is 0.996 for calculation A.

The Landé *g*-factor results are reported for the first time in Tables 1 and 2. Moreover it is well known that Landé *g*-factors are important in many scientific areas such as astrophysics. Therefore, new energies, Landé *g*-factors and lifetimes for $2p^6 ns$ (n = 11–15), $2p^6 np$ (n = 11–15), $2p^6 nd$ (n = 11–15), $2p^6 nf$ (n = 11–15), $2p^6 ng$ (n = 11–15), $2p^6 ni$ (n = 7–15), $2p^6 nh$ (n = 11–15), $2p^5 3s4p$, $2p^5 3s5s$, and $2p^5 3s4d$ configurations, not existing in the data bases for these configurations in Mg II, are presented in Tables 1 and 2.

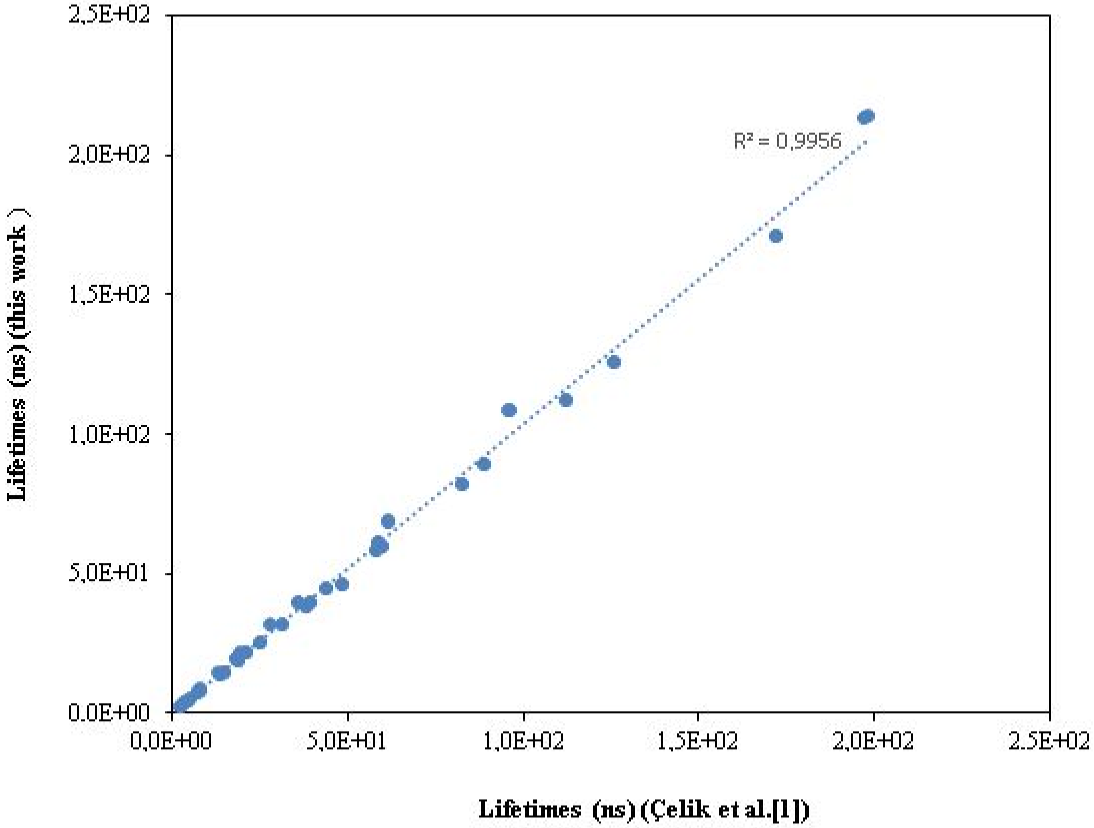

Figure 2. Comparison of the lifetimes obtained from this work (calculation A) with those of Çelik et al. [1].

3.2. Electric dipole (E1) transitions

We have obtained 2 171 and 6 798 possible electric dipole transitions between odd− and even−parity configurations in the HFR calculations A and B, respectively. In this work, the wavelengths λ (Å), oscillator strengths, *f*, and transition probabilities, A_{ji} (s^{-1}), for ns−n'p (n = 3−10, n' = 4−10), np−n'd (n = 4−10, n' = 3−10), nf−n'd (n = 4−10, n' = 3−10), nf−n'g (n = 4−10, n' = 5−10), nh−n'g (n = 6−10, n' = 5−10), and 6h−ni (n = 7−9), 7i−nh (n = 8−10), 8i−nh (n = 9, 10), and 9i−nh (n = 8, 10) electric dipole transitions of the calculation A are presented in Table 4 and Table S2. The comparing values for these transitions exist in literature. Therefore, it is also made a comparison with other works in Table 4 and Table S2. We have typed as transition probabilities (the division of the statistical weight g_j of the upper level and the weighted transition probabilities) and oscillator strengths (the division of the statistical weight g_i of the lower level and the weighted oscillator strengths) for comparing in tables.

The results obtained in Table 4 and Table S2 are presented with the theoretical results obtained using the WBEPMT [1] and the theoretical results obtained using the MCHF method [13] for comparison. We have seen a good agreement between our results with both the WBEPMT results and the MCHF results. The results are in excellent agreement with those of other works [1, 13] for wavelengths. We have calculated the mean ratio λ (this work) / λ (other works) for the accuracy of our results. In calculation A, the mean ratio between our results and other works [1, 13] have been found in the values 1.001. Also, the wavelengths comparison of the E1 transitions have been displayed in Fig. 3 (R^2=0.997). As seen from these tables, the oscillator strengths obtained from the calculations are in agreement with other works, except for some transitions. Except the transitions 5s−np (n = 6−10), 4d−6p, 5s−7p, 6s−8p, 6s−10p and 7s−10p, we have found the values 1.014 (in calculation A) for the mean ratio f (this work) / f [1]. The mean ratio between our results and other works [13] have been found in the values 0.992 (except 5s−9p transitions). In addition, we have given a comparison in Fig. 4 for oscillator strengths obtained from HFR calculations with those of other works [1, 13]. As seen from Fig. 4, f values obtained from our calculations are in good agreement with [1, 13]. R^2 is 0.999 for comparison with Ref. [1] and 0.997 for comparison with Ref. [13]. The agreement is poor for transition probability of some transitions. Also, we have found the values 1.020 and 0.990 for the mean ratio A_{ji} (this work) / A_{ji} [1, 13], except the transitions 3d−5p, 5s−np (n = 6−10), 4d−6p, 6s−np (n = 8−10), 7s−10p and 9f−10g, respectively. Fig. 5 shows a comparison between our transition probability results in Table 4 and Table S2 and those reported by Çelik et al. [1] and Fischer et al. [13]. It does not include the transition probability values of 3d−4f transitions for to show more data in figure.

We have also reported wavelengths, oscillator strengths, *gf*, and weighted transition probabilities, gA_{ji}, for atomic data in Table S3 (see Supplementary Material, Table S3). Table S3 consists np−n's (n = 3−15, n' = 11−15), ns−n'p (n = 3−15, n' = 10−15), np−n'd (n = 3−15, n' = 11−15), nf−n'd (n = 4−15, n' = 11−15), nf−n'g (n = 4−15, n' = 11−15), nh−n'g (n = 6−15, n' = 11−15), and nh−n'i (n = 6−15, n' = 7−15) E1 transitions obtained from calculation A. The data on E1 transitions between high levels for Mg II have been firstly presented in this work.

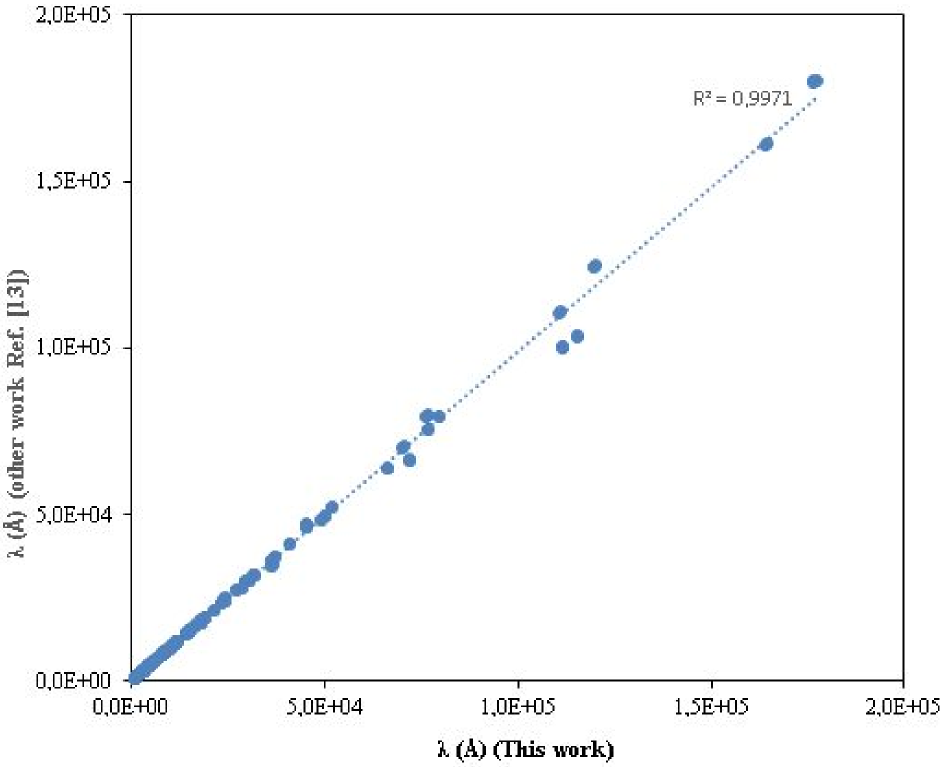

Figure 3. Comparison of the wavelengths obtained from E1 transitions with those of Fischer et al. [13].

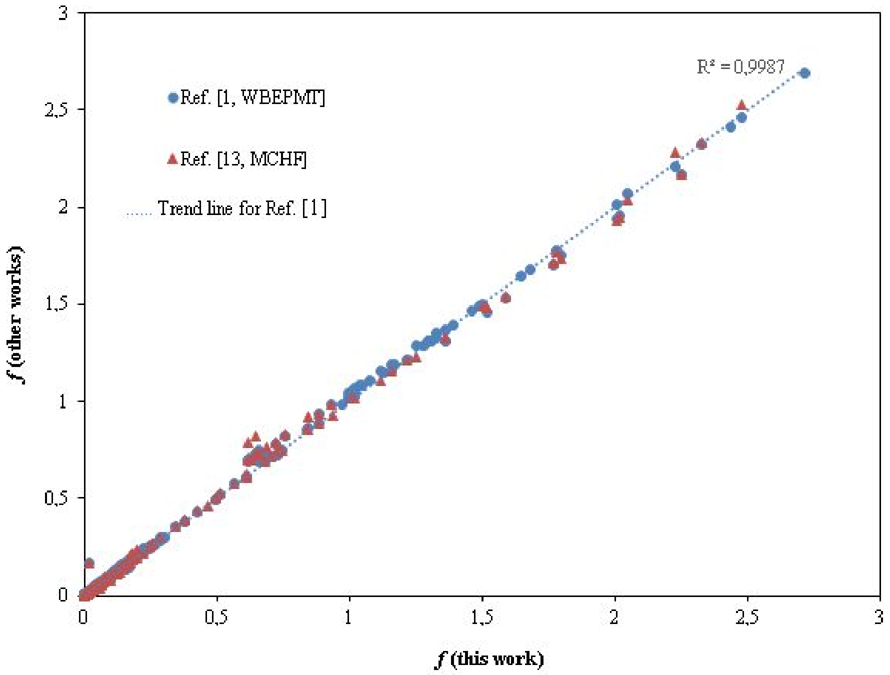

Figure 4. Comparison of the oscillator strengths obtained from E1 transitions with those of other works [1, 13].

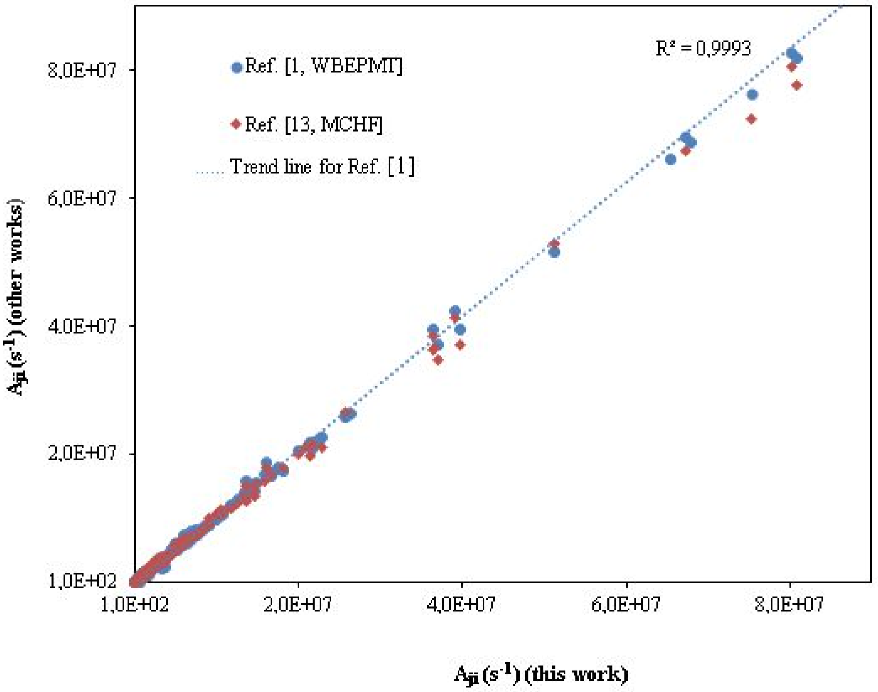

Figure 5. Comparison of the transition probabilities obtained from E1 transitions with those of other works [1, 13].

3.3. Electric quadrupole (E2) transitions

We have obtained 3 128 and 9 149 possible electric quadrupole transitions for the selected configurations in the HFR calculations A and B, respectively. In this work, we have presented results obtained according to valence excitations. The wavelengths λ (Å), logarithmic weighted oscillator strengths, log (*gf*), and transition probabilities, A_{ji} (s^{-1}), 4s−nd (n = 3−9), 4d−nd (n =5−7), 4p−np (n = 5−9), 4p−nf (n = 4−9), 4f−5f, 5s−nd (n = 3−5), and 5p−5f electric quadrupole transitions are reported in Table 5. In our previous work, we presented for 3s−nd (n = 3−10), 3d−nd (n =4−10), 3p−np (n = 4−10), and 3p−nf (n = 4−10) E2 transitions of calculation A [23]. We have made a comparison with other works in Table 5. We have typed as transition probabilities (the division of the statistical weight g_j of the upper level and the weighted transition probabilities) for comparing in table.

Comparisons are made with the relativistic coupled cluster (CC) theory results given by Majumder et al. [14] and theoretical results using the WBEPMT for Mg II given by Çelik et al. [19]. The wavelengths are in good agreement with other [14]. Moreover, we have calculated $[|\lambda_{\text{this work}} - \lambda_{\text{other works}}|/\lambda_{\text{other works}}] \times 100$, the differences in per cent. When the differences (%) between our results and other theoretical results [14] are investigated, the differences in wavelengths are in range of 0.00−0.29% for calculation A. The oscillator strength results are reported for the first time in Table 5. As seen from this table, the transition probabilities obtained from the calculation are in agreement with other works, except for some transitions. We have calculated the mean ratio A_{ji} (this work) / A_{ji} [14, 19]. In calculation A, the mean ratio between our results and other works [19] have been found in the values 1.010, except the transition 4f $^2F^o_{7/2}$ −5f $^2F^o_{7/2}$. Also, we have found the values 1.040 for the mean ratio A_{ji} (this work) / A_{ji} [14], except the transitions 3d−5s and 5p $^2P^o_{1/2}$ −5f $^2F^o_{5/2}$. Fig. 6 displays the transition probabilities comparison of the E2 transitions. The Fig. 6 (R^2= 0.991) does not include the transition probability values of 4s−4d, 4s−5d, 4f $^2F^o_{5/2}$ −5f $^2F^o_{5/2}$, and 4f $^2F^o_{7/2}$ −5f $^2F^o_{7/2}$ transitions in figure.

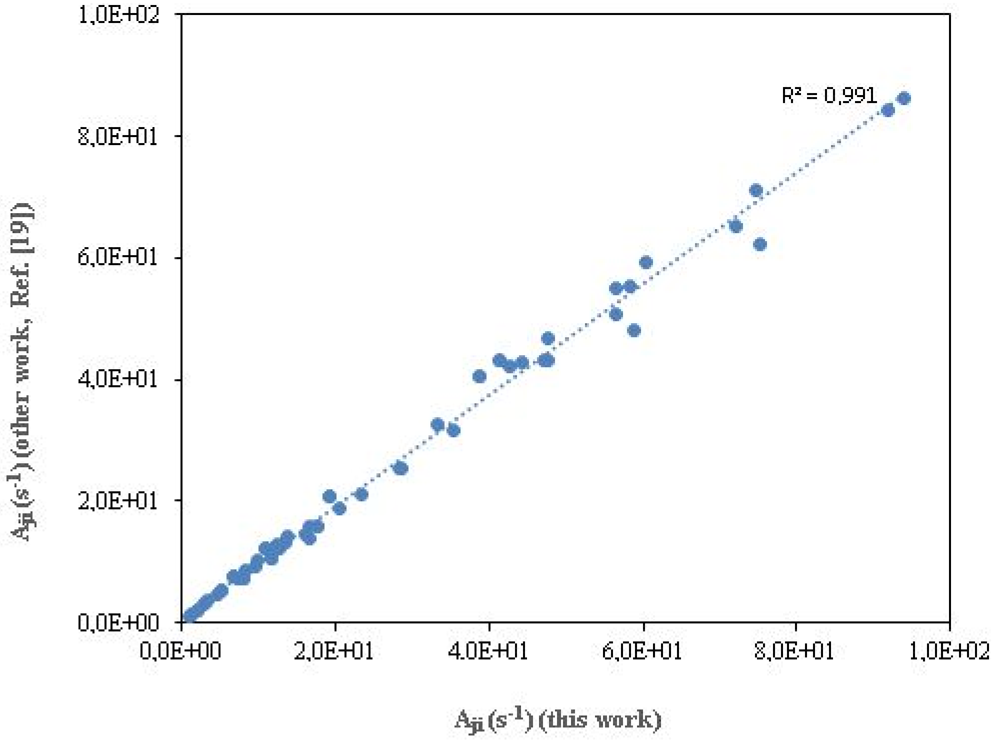

Figure 6. Comparison of the wavelengths obtained from E1 transitions with those of Çelik et al. [19].

We have also reported new wavelengths λ (in Å), logarithmic weighted oscillator strengths, log (*gf*), and transition probabilities A_{ji} (in s^{-1}), for atomic data in Table S4 (see Supplementary Material, Table S4) for 3s−nd (n = 11−15), 3d−nd (n =11−15), 3d−ng (n= 5−15), 3p−np (n = 11−15), 3p−nf (n = 11−15), 4s−nd (n = 10−15), 4d−nd (n =8−15), 4d−ng (n= 5−15), 4p−np (n = 10−15), 4p−nf (n = 10−15), 4f−nf (n=6−15), 4f−nh (n= 6−15), 5s−nd (n = 6−15), 5d−nd (n =6−15), 5d−ng (n =6−15), 5p−np (n = 6−15), 5p−nf (n = 4, 6−15), 5f−nf (n = 6−15), and 5f−nh (n = 6−15) E2 transitions obtained from calculation A.

4. Conclusion

The main purpose of this paper is to perform the HFR calculations for obtaining description of the Mg II spectrum. These energy data and Landé *g*-factors for Mg II can be useful in investigations of some radiative properties, and interpretation of many levels of Mg II. We have only given E1 and E2 transitions between the valence excitation levels. We have presented other our results obtained from this work as supplementary tables. E1 and E2 transitions of Mg II have been obtained for the first time for transitions between highly excited states. Therefore we hope that our results obtained using HFR method will be useful for research fields and technological applications and for interpreting the spectrum of Mg II.

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References

1. G. Çelik, Ş. Ateş, S. Özarslan, and M. Taşer, J. Quant. Spectrosc. Radiat. Transf.; **112**, 2330 (2011). doi:10.1016/j.jqsrt.2011.06.010.
2. T. Brage and J.O. Gaardsted, Phys. Scr. **44**, 336 (1991). doi: 10.1088/0031-8949/44/4/005.
3. A. Kramida, Yu. Ralchenko, J. Reader, and NIST ASD Team (2014). NIST Atomic Spectra Database (version 5.2), Available: http://physics.nist.gov/asd.
4. L. Lundin, B. Engman, J. Hilke, and I. Martinson, Phys. Scr. **8**, 274 (1973). doi: 10.1088/0031-8949/8/6/00.

5. A. Lindgard and S.E. Nielsen, J. Phys. B: Atom. Molec. Phys. **8**, 1183 (1975). doi: 10.1088/0022-3700/8/8/008.
6. L. Liljeby, A. Lindgard, S. Mannervik, E. Veje, and B. Jelenkovic, Phys. Scr. **21**, 805 (1980). doi: 10.1088/0031-8949/21/6/005.
7. E. Biémont and J.W. Brault, Phys. Scr. **34**, 751(1986). doi: 10.1088/0031-8949/34/6B/007.
8. C.F. Fischer. Phys. Rev. A, **34**, 1167(1986). doi: 10.1103/PhysRevA.34.1667.
9. M.S. Safronova, A. Derevianko, and W.R. Johnson, Phys. Rev. A, **58**, 1016 (1998). doi: 10.1103/PhysRevA.58.1016.
10. N. Wu Zheng, T. Wang, R.Y. Yang, T. Zhou, X.M. Dong, G.W. Yong, and T.W. Hai, At. Data and Nucl. Data Tables, **79**, 109 (2001). doi:10.1006/adnd.2001.0864.
11. V.A. Dzuba and W.R. Johnson, Phys. Rev. A, **76**, 062510 (2007). doi:10.1103/PhysRevA.76.062510.
12. C.E. Theodosiou and S.R. Federman, Astrophys. J. **527**, 470 (1999). doi: 10.1086/308088/meta.
13. C.F. Fischer, G. Tachiev, and A. Irimia, At. Data and Nucl. Data Tables, **92**, 607 (2006). doi:10.1016/j.adt.2006.03.001.
14. S. Majumder, G. Gopakumar, R.K. Chaudhuri, B.P. Das, H. Merlitz, U.S. Mahapatra, and D. Mukherjee, Eur. Phys. J. D, **28**, 3 (2004). doi: 10.1140/epjd/e2003-00282-6.
15. M.A. Ali, J. Quant. Spectrosc. Radiat. Transf. **11**, 1611 (1971). doi: 10.1016/0022-4073(71)90139-7.
16. C.E. Tull, M. Jackson, R.P. McEachran, and M. Cohen, Can. J. Phys. **50**, 1169 (1972). doi: 10.1139/p72-161.

17. M. Godefroid, C.E. Magnusson, P.O. Zetterberg, and I. Joelsson, Phys. Scr. **32**, 125 (1985).doi: 10.1088/0031-8949/32/2/006.

18. E. Charro and I. Martín, Astrophys. J. **585**, 1191 (2003). doi: 10.1086/323241.

19. G. Çelik, D. Doğan, Ş. Ateş, and M. Taşer, J. Quant. Spectrosc. Radiat. Transf. **113**, 1601 (2012). doi:10.1016/j.jqsrt.2012.03.033.

20. http://www.tcd.ie/Physics/People/Cormac.McGuinness/Cowan/

21. R.D. Cowan, *The Theory of Atomic Structure and Spectra* (Univ. of California Press, USA 1981)

22. B. Karaçoban Usta, E.G. Saka, E. Akgün, B. Alparslan, AIP Conference Proceedings, **1722**, 200002 (2016). doi: 10.1063/1.4944217.

23. B. Karaçoban Usta and S. Sever, AIP Conference Proceedings; **1815**, 100003 (2017). doi: 10.1063/1.4976466.

24. P. Jönsson and S. Gustafsson, Comput. Phys. Commun. 144, 188 (2002). doi: 10.1016/S0010-4655(01)00461-1.

Table 1. Energies, E (cm^{-1}), Landé *g*-factors, and lifetimes, τ (ns), for valence excitation states in Mg II.

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
$2p^63s$	$^2S_{1/2}$	A	0.00	2.002	
		B	-0.007	2.002	
		Other works	0.00		
$2p^63p$	$^2P^o_{1/2}$	A	35 669.31	0.666	3.802
		B	35 669.28	0.666	3.736
		Other works	35 669.31[a]		3.848[b]
			35 704.14[b]		3.64[c]
	$^2P^o_{3/2}$	A	35 760.88	1.334	3.773
		B	35 760.91	1.334	3.707
		Other works	35 760.88[a]		3.814[b]
			35 803.80[b]		3.61[c]
$2p^64s$	$^2S_{1/2}$	A	69 804.95	2.002	3.080
		B	69 804.95	2.002	3.081
		Other works	69 804.95[a]		2.900[b]
			69 730.16[b]		2.95[c]
$2p^63d$	$^2D_{5/2}$	A	71 490.19	1.200	2.088
		B	71 490.61	1.200	2.075
		Other works	71 490.19[a]		2.050[b]
			71 679.95[b]		1.97[c]
	$^2D_{3/2}$	A	71 491.06	0.800	2.074
		B	71 490.64	0.800	2.062
		Other works	71 491.06[a]		2.042[b]
			71 669.31[b]		1.96[c]
$2p^64p$	$^2P^o_{1/2}$	A	80 619.50	0.666	18.92
		B	80 619.50	0.666	18.92
		Other works	80 619.50[a]		18.78[b]
			80 564.26[b]		19.0[c]
	$^2P^o_{3/2}$	A	80 650.02	1.334	18.75
		B	80 650.02	1.334	18.76
		Other works	80 650.02[a]		18.69[b]
			80 598.44[b]		18.8[c]
$2p^65s$	$^2S_{1/2}$	A	92 790.51	2.002	5.163
		B	92 790.51	2.002	5.169
		Other works	92 790.51[a]		5.046[b]
			92 718.10[b]		5.05[c]
$2p^64d$	$^2D_{5/2}$	A	93 310.59	1.200	7.812
		B	93 310.84	1.200	7.783
		Other works	93 310.59[a]		7.469[b]
			93 376.95[b]		7.35[c]
	$^2D_{3/2}$	A	93 311.11	0.800	7.771
		B	93 310.86	0.800	7.742
		Other works	93 311.11[a]		7.432[b]
			93 377.46[b]		7.31[c]

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
$2p^64f$	$^2F^o_{5/2}$	A	93 799.63	0.857	4.529
		B	93 799.69	0.857	4.522
		Other works	93 799.63[a]		4.407[b]
			93 712.65[b]		4.28[c]
	$^2F^o_{7/2}$	A	93 799.75	1.143	4.529
		B	93 799.69	1.143	4.521
		Other works	93 799.75[a]		4.410[b]
			93 709.34[b]		4.28[c]
$2p^65p$	$^2P^o_{1/2}$	A	97 455.12	0.666	46.25
		B	97 455.12	0.666	46.03
		Other works	97 455.12[a]		45.55[b]
			97 390.79[b]		48.3[c]
	$^2P^o_{3/2}$	A	97 468.92	1.334	45.93
		B	97 468.92	1.334	45.71
		Other works	97 468.92[a]		45.57[b]
			97 405.89[b]		48.2[c]
$2p^66s$	$^2S_{1/2}$	A	103 196.75	2.002	8.857
		B	103 196.75	2.002	8.877
		Other works	103 196.75[a]		8.756[b]
			103 118.89[b]		8.18[c]
$2p^65d$	$^2D_{5/2}$	A	103 419.70	1.200	19.75
		B	103 419.85	1.200	19.71
		Other works	103 419.70[a]		18.42[b]
			103 428.61[b]		18.2[c]
	$^2D_{3/2}$	A	103 420.00	0.800	19.67
		B	103 419.85	0.800	19.62
		Other works	103 420.00[a]		18.32[b]
			103 425.46[b]		18.1[c]
$2p^65f$	$^2F^o_{5/2}$	A	103 689.86	0.857	8.351
		B	103 689.89	0.857	8.343
		Other works	103 689.86[a]		8.411[b]
			103 607.86[b]		8.14[c]
	$^2F^o_{7/2}$	A	103 689.92	1.143	8.351
		B	103 689.89	1.143	8.342
		Other works	103 689.92[a]		8.416[b]
			103 607.89[b]		8.14[c]
$2p^65g$	$^2G_{7/2}$	A	103 705.66	0.889	14.75
		B	103 705.66	0.889	14.74
		Other works	103 705.66[a]		14.6[c]
	$^2G_{9/2}$	A	103 705.66	1.111	14.75
		B	103 705.66	1.111	14.74
		Other works	103 705.66[a]		14.6[c]

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
2p^{6}6p	$^2P^o_{1/2}$	A	105 622.34	0.666	88.44
		B	105 622.34	0.666	87.54
		Other works	105 622.34[a]		87.50[b]
			105 549.07[b]		108[c]
	$^2P^o_{3/2}$	A	105 629.72	1.334	87.97
		B	105 629.72	1.334	87.07
		Other works	105 629.72[a]		87.86[b]
			105 557.15[b]		108[c]
2p^{6}7s	$^2S_{1/2}$	A	108 784.33	2.002	14.36
		B	108 784.33	2.002	14.39
		Other works	108 784.33[a]		14.26[b]
			108 703.70[b]		12.9[c]
2p^{6}6d	$^2D_{5/2}$	A	108 900.02	1.200	39.62
		B	108 900.11	1.200	39.57
		Other works	108 900.02[a]		36.41[b]
			108 872.86[b]		35.8[c]
	$^2D_{3/2}$	A	108 900.20	0.800	39.48
		B	108 900.11	0.800	39.43
		Other works	108 900.20[a]		36.19[b]
			108 871.05[b]		35.6[c]
2p^{6}6f	$^2F^o_{5/2}$	A	109 062.32	0.857	13.95
		B	109 062.34	0.857	13.94
		Other works	109 062.32[a]		14.32[b]
			108 979.98[b]		13.6[c]
	$^2F^o_{7/2}$	A	109 062.35	1.143	13.95
		B	109 062.34	1.143	13.94
		Other works	109 062.35[a]		14.33[b]
			108 979.73[b]		13.6[c]
2p^{6}6g	$^2G_{7/2}$	A	109 072.05	0.889	25.18
		B	109 072.05	0.889	25.18
		Other works	109 072.05[a]		25.0[c]
	$^2G_{9/2}$	A	109 072.05	1.111	25.18
		B	109 072.05	1.111	25.18
		Other works	109 072.05[a]		25.0[c]
2p^{6}6h	$^2H^o_{9/2}$	A	109 073.97	0.909	37.95
		B	109 073.97	0.909	37.94
		Other works	109 073.97[a]		37.9[c]
	$^2H^o_{11/2}$	A	109 073.97	1.091	37.95
		B	109 073.97	1.091	37.94
		Other works	109 073.97[a]		37.9[c]
2p^{6}7p	$^2P^o_{1/2}$	A	110 203.58	0.666	150.3
		B	110 203.58	0.666	147.4
		Other works	110 203.58[a]		148.5[b]
			110 125.83[b]		200.0[c]

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
	$^2P^o_{3/2}$	A	110 207.99	1.334	149.7
		B	110 207.99	1.334	146.8
		Other works	110 207.99[a]		149.4[b]
			110 130.65[b]		200.0[c]
2p^{6}8s	$^2S_{1/2}$	A	112 129.20	2.002	21.98
		B	112 129.20	2.002	22.03
		Other works	112 129.20[a]		21.88[b]
			112 047.10[b]		19.3[c]
2p^{6}7d	$^2D_{5/2}$	A	112 197.05	1.200	68.82
		B	112 197.11	1.200	68.79
		Other works	112 197.05[a]		62.66[b]
			112 148.69[b]		61.4[c]
	$^2D_{3/2}$	A	112 197.17	0.800	68.61
		B	112 197.11	0.800	68.58
		Other works	112 197.17[a]		62.28[b]
			112 148.69[b]		61.2[c]
2p^{6}7f	$^2F^o_{5/2}$	A	112 301.47	0.857	21.67
		B	112 301.47	0.857	21.64
		Other works	112 301.47[a]		22.49[b]
			112 218.43[b]		21.2[c]
	$^2F^o_{7/2}$	A	112 301.47	1.143	21.67
		B	112 301.47	1.143	21.64
		Other works	112 301.47[a]		22.52[b]
			112 218.29[b]		21.2[c]
2p^{6}7g	$^2G_{7/2}$	A	112 307.79	0.889	39.50
		B	112 307.79	0.889	39.49
		Other works	112 307.79[a]		39.4[c]
	$^2G_{9/2}$	A	112 307.79	1.111	39.50
		B	112 307.79	1.111	39.49
		Other works	112 307.79[a]		39.4[c]
2p^{6}7h	$^2H^o_{9/2}$	A	112 309.06	0.909	59.95
		B	112 309.06	0.909	59.95
		Other works	112 309.06[a]		59.9[c]
	$^2H^o_{11/2}$	A	112 309.06	1.091	59.95
		B	112 309.06	1.091	59.95
		Other works	112 309.06[a]		59.9[c]
2p^{6}7i	$^2I_{11/2}$	A	112 309.45	0.923	84.30
		B	112 309.45	0.923	84.30
	$^2I_{13/2}$	A	112 309.45	1.077	84.30
		B	112 309.45	1.077	84.30
2p^{6}8p	$^2P^o_{1/2}$	A	113 030.25	0.666	238.1
		B	113 030.25	0.666	229.6
		Other works	113 030.25[a]		232.6[b]
			112 950.15[b]		321.0[c]

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
	$^2P^o_{3/2}$	A	113 033.09	1.334	237.3
		B	113 033.09	1.334	228.9
		Other works	113 033.09[a]		234.4[b]
			112 953.25[b]		321.0[c]
$2p^69s$	$^2S_{1/2}$	A	114 289.36	2.002	32.07
		B	114 289.36	2.002	32.14
		Other works	114 289.36[a]		31.70[b]
			114 209.65[b]		27.9[c]
$2p^68d$	$^2D_{5/2}$	A	114 332.68	1.200	108.6
		B	114 332.71	1.200	108.7
		Other works	114 332.68[a]		97.74[b]
			114 276.17[b]		96.1[c]
	$^2D_{3/2}$	A	114 332.74	0.800	108.3
		B	114 332.71	0.800	108.4
		Other works	114 332.74[a]		97.08[b]
			114 275.45[b]		95.8[c]
$2p^68f$	$^2F^o_{5/2}$	A	114 403.55	0.857	31.84
		B	114 403.55	0.857	31.79
		Other works	114 403.55[a]		33.11[b]
			114 322.01[b]		31.2[c]
	$^2F^o_{7/2}$	A	114 403.55	1.143	31.84
		B	114 403.55	1.143	31.79
		Other works	114 403.55[a]		33.17[b]
			114 321.84[b]		31.2[c]
$2p^68g$	$^2G_{7/2}$	A	114 407.88	0.889	58.32
		B	114 407.88	0.889	58.31
		Other works	114 407.88[a]		58.3[c]
	$^2G_{9/2}$	A	114 407.88	1.111	58.32
		B	114 407.88	1.111	58.31
		Other works	114 407.88[a]		58.3[c]
$2p^68h$	$^2H^o_{9/2}$	A	114 408.74	0.909	88.89
		B	114 408.74	0.909	88.89
		Other works	114 408.74[a]		89.0[c]
	$^2H^o_{11/2}$	A	114 408.74	1.091	88.89
		B	114 408.74	1.091	88.89
		Other works	114 408.74[a]		89.0[c]
$2p^68i$	$^2I_{11/2}$	A	114 409.02	0.923	125.4
		B	114 409.02	0.923	125.4
	$^2I_{13/2}$	A	114 409.02	1.077	125.4
		B	114 409.02	1.077	125.4
$2p^69p$	$^2P^o_{1/2}$	A	114 896.79	0.666	363.3
		B	114 896.79	0.666	338.1
		Other works	114 896.79[a]		331.4[b]
			114 829.34[b]		477.0[c]

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
	$^2P^o_{3/2}$	A	114 898.72	1.334	362.3
		B	114 898.72	1.334	337.2
		Other works	114 898.72[a]		334.0[b]
			114 831.53[b]		478.0[c]
$2p^6 10s$	$^2S_{1/2}$	A	115 764.99	2.002	44.88
		B	115 764.99	2.002	45.08
		Other works	115 764.99[a]		36.18[b]
			115 796.93[b]		
$2p^6 9d$	$^2D_{5/2}$	A	115 794.39	1.200	160.0
		B	115 794.41	1.200	160.7
		Other works	115 794.39[a]		119.5[b]
			115 828.42[b]		70.6[c]
	$^2D_{3/2}$	A	115 794.44	0.800	159.7
		B	115 794.42	0.800	160.3
		Other works	115 794.44[a]		118.7[b]
			115 827.77[b]		70.4[c]
$2p^6 9f$	$^2F^o_{5/2}$	A	115 844.60	0.857	44.83
		B	115 844.60	0.857	44.72
		Other works	115 844.60[a]		39.64[b]
			115 845.05[b]		44.0[c]
	$^2F^o_{7/2}$	A	115 844.60	1.143	44.83
		B	115 844.60	1.143	44.72
		Other works	115 844.60[a]		39.69[b]
			115 844.95[b]		44.0[c]
$2p^6 9g$	$^2G_{7/2}$	A	115 847.67	0.889	82.27
		B	115 847.67	0.889	82.24
		Other works	115 847.67[a]		82.4[c]
	$^2G_{9/2}$	A	115 847.67	1.111	82.27
		B	115 847.67	1.111	82.24
		Other works	115 847.67[a]		82.4[c]
$2p^6 9h$	$^2H^o_{9/2}$	A	115 848.28	0.909	125.7
		B	115 848.28	0.909	125.7
		Other works	115 848.28[a]		126.0[c]
	$^2H^o_{11/2}$	A	115 848.28	1.091	125.7
		B	115 848.28	1.091	125.7
		Other works	115 848.28[a]		126.0[c]
$2p^6 9i$	$^2I_{11/2}$	A	115 848.51	0.923	177.8
		B	115 848.51	0.923	177.8
	$^2I_{13/2}$	A	115 848.51	1.077	177.8
		B	115 848.51	1.077	177.8
$2p^6 10p$	$^2P^o_{1/2}$	A	116 193.70	0.666	596.5
		B	116 193.70	0.666	476.6
		Other works	116 193.70[a]		649.0[c]

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
	$^2P^o_{3/2}$	A	116 195.00	1.334	595.0
		B	116 195.10	1.334	475.6
		Other works	116 195.00^a		650.0^c
2p^{6}10d	$^2D_{5/2}$	A	116 838.45	1.200	214.1
		B	116 838.46	1.200	226.0
		Other works	116 838.45^a		198.0^c
	$^2D_{3/2}$	A	116 838.48	0.800	213.6
		B	116 838.46	0.800	225.5
		Other works	116 838.48^a		197.0^c
2p^{6}10f	$^2F^o_{5/2}$	A	116 875.25	0.857	61.11
		B	116 875.25	0.857	60.78
		Other works	116 875.25^a		58.4^c
	$^2F^o_{7/2}$	A	116 875.25	1.143	61.11
		B	116 875.25	1.143	60.77
		Other works	116 875.25^a		58.4^c
2p^{6}10g	$^2G_{7/2}$	A	116 877.54	0.889	112.0
		B	116 877.54	0.889	111.9
		Other works	116 877.54^a		112.0^c
	$^2G_{9/2}$	A	116 877.54	1.111	112.0
		B	116 877.54	1.111	111.9
		Other works	116 877.54^a		112.0^c
2p^{6}10h	$^2H^o_{9/2}$	A	116 878.04	0.909	171.3
		B	116 878.04	0.909	171.3
		Other works	116 878.04^a		172.0^c
	$^2H^o_{11/2}$	A	116 878.04	1.091	171.3
		B	116 878.04	1.091	171.3
		Other works	116 878.04^a		172.0^c
2p^{6}10i	$^2I_{11/2}$	A	116 878.13	0.923	242.9
		B	116 878.13	0.923	242.9
	$^2I_{13/2}$	A	116 878.13	1.077	242.9
		B	116 878.13	1.077	242.9
2p^{6}11g	$^2G_{7/2}$	A	117 639.51	0.889	148.0
		Other works	117 639.51^a		
	$^2G_{9/2}$	A	117 639.51	1.111	148.0
		Other works	117 639.51^a		
2p^{6}11s	$^2S_{1/2}$	A	118 172.30	2.002	21.92
2p^{6}11p	$^2P^o_{1/2}$	A	118 483.40	0.666	40.68
	$^2P^o_{3/2}$	A	118 484.10	1.334	40.63
2p^{6}12s	$^2S_{1/2}$	A	118 948.80	2.002	54.49
2p^{6}11d	$^2D_{3/2}$	A	118 956.90	0.800	113.9
	$^2D_{5/2}$	A	118 956.90	1.200	114.0
2p^{6}11f	$^2F^o_{5/2}$	A	118 988.40	0.857	44.82
	$^2F^o_{7/2}$	A	118 988.40	1.143	44.82

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
$2p^6 11h$	$^2H^o_{9/2}$	A	118 994.50	0.909	53.79
	$^2H^o_{11/2}$	A	118 994.50	1.091	53.79
$2p^6 11i$	$^2I_{11/2}$	A	118 994.70	0.923	53.43
	$^2I_{13/2}$	A	118 994.70	1.077	53.43
$2p^6 12p$	$^2P^o_{1/2}$	A	119 183.50	0.666	538.4
	$^2P^o_{3/2}$	A	119 184.10	1.334	537.9
$2p^6 13s$	$^2S_{1/2}$	A	119 539.20	2.002	78.23
$2p^6 12d$	$^2D_{3/2}$	A	119 545.40	0.800	220.3
	$^2D_{5/2}$	A	119 545.40	1.200	220.6
$2p^6 12f$	$^2F^o_{5/2}$	A	119 569.60	0.857	70.06
	$^2F^o_{7/2}$	A	119 569.60	1.143	70.05
$2p^6 12g$	$^2G_{7/2}$	A	119 573.60	0.889	96.58
	$^2G_{9/2}$	A	119 573.60	1.111	96.58
$2p^6 12i$	$^2I_{11/2}$	A	119 573.90	0.923	132.4
	$^2I_{13/2}$	A	119 573.90	1.077	132.4
$2p^6 12h$	$^2H^o_{9/2}$	A	119 574.20	0.909	115.2
	$^2H^o_{11/2}$	A	119 574.20	1.091	115.2
$2p^6 13p$	$^2P^o_{1/2}$	A	119 719.80	0.666	895.0
	$^2P^o_{3/2}$	A	119 720.30	1.334	894.9
$2p^6 14s$	$^2S_{1/2}$	A	119 997.70	2.002	103.4
$2p^6 13d$	$^2D_{3/2}$	A	120 002.30	0.800	323.0
	$^2D_{5/2}$	A	120 002.30	1.200	323.3
$2p^6 13f$	$^2F^o_{5/2}$	A	120 021.30	0.857	94.42
	$^2F^o_{7/2}$	A	120 021.30	1.143	176.8
$2p^6 13g$	$^2G_{7/2}$	A	120 024.30	0.889	138.8
	$^2G_{9/2}$	A	120 024.30	1.111	138.8
$2p^6 13i$	$^2I_{11/2}$	A	120 024.50	0.923	219.0
	$^2I_{13/2}$	A	120 024.50	1.077	219.0
$2p^6 13h$	$^2H^o_{9/2}$	A	120 024.60	0.909	176.8
	$^2H^o_{11/2}$	A	120 024.60	1.091	176.8
$2p^6 14p$	$^2P^o_{1/2}$	A	120 139.90	0.666	1185.0
	$^2P^o_{3/2}$	A	120 140.30	1.334	1185.0
$2p^6 15s$	$^2S_{1/2}$	A	120 361.30	2.002	131.9
$2p^6 14d$	$^2D_{3/2}$	A	120 364.80	0.800	434.9
	$^2D_{5/2}$	A	120 364.80	1.200	435.4
$2p^6 14f$	$^2F^o_{5/2}$	A	120 380.00	0.857	121.4
	$^2F^o_{7/2}$	A	120 380.00	1.143	121.3
$2p^6 14g$	$^2G_{7/2}$	A	120 382.20	0.889	184.6
	$^2G_{9/2}$	A	120 382.20	1.111	184.6
$2p^6 14i$	$^2I_{11/2}$	A	120 382.30	0.923	316.3
	$^2I_{13/2}$	A	120 382.30	1.077	316.3
$2p^6 14h$	$^2H^o_{9/2}$	A	120 382.40	0.909	244.3
	$^2H^o_{11/2}$	A	120 382.40	1.091	244.3

Table 1. (continued)

Levels					
Conf.	**Term**	**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
$2p^6 15p$	$^2P^o_{1/2}$	A	120 475.90	0.666	1501.0
	$^2P^o_{3/2}$	A	120 476.20	1.334	1501.0
$2p^6 15d$	$^2D_{3/2}$	A	120 655.70	0.800	577.8
	$^2D_{5/2}$	A	120 655.70	1.200	578.3
$2p^6 15f$	$^2F^o_{5/2}$	A	120 668.10	0.857	151.9
	$^2F^o_{7/2}$	A	120 668.10	1.143	151.9
$2p^6 15g$	$^2G_{7/2}$	A	120 670.10	0.889	236.2
	$^2G_{9/2}$	A	120 670.10	1.111	236.2
$2p^6 15h$	$^2H^o_{9/2}$	A	120 670.70	0.909	320.1
	$^2H^o_{11/2}$	A	120 670.70	1.091	320.1
$2p^6 15i$	$^2I_{11/2}$	A	120 671.20	0.923	426.3
	$^2I_{13/2}$	A	120 671.20	1.077	426.3

[a] Nist [3]

[b] Fischer et al. [13]

[c] Çelik et al. [1]

Table 2. Energies, E (cm^{-1}), Landé g-factors, and lifetimes, τ (ns), for some core-excited quartet states in Mg II.

Levels		Source	E (cm^{-1})	g-factor	τ (ns)
Conf.	Term				
$2p^53s^2$	$^2P^o_{3/2}$	B	402 591.80	1.334	0.203
		Other works	402 590[a]		
	$^2P^o_{1/2}$	B	404 508.90	0.666	0.200
		Other works	404 510[a]		
$2p^5(^2P^o)3s3p(^3P^o)$	$^4S_{1/2}$	B	429 146.21	1.999	54.73
		Other works	428 957		
$2p^5(^2P^o)3s3p(^3P^o)$	$^4D_{7/2}$	B	433 921.82	1.430	
		Other works	434 090[a]		
	$^4D_{5/2}$	B	434 533.48	1.373	6.271
		Other works	434 633[a]		
	$^4D_{3/2}$	B	435 093.27	1.204	4.417
		Other works	435 190[a]		
	$^4D_{1/2}$	B	435 527.09	0.036	6.528
		Other works	435 640[a]		
$2p^5(^2P^o)3s3p(^3P^o)$	$^4P_{5/2}$	B	437 683.66	1.569	1.646
		Other works	437 570[a]		
	$^4P_{3/2}$	B	438 285.05	1.619	0.916
		Other works	438 167		
	$^4P_{1/2}$	B	438 660.53	2.610	6.968
$2p^5(^2P^o)3s3p(^1P^o)$	$^2D_{3/2}$	B	439 528.10	0.914	0.145
	$^2D_{5/2}$	B	440 236.71	1.233	0.139
$2p^5(^2P^o)3s3p(^1P^o)$	$^2P_{1/2}$	B	440 784.54	0.686	0.141
		Other works	459 800[a]		
	$^2P_{3/2}$	B	441 218.94	1.335	0.142
$2p^5(^2P^o)3s3p(^1P^o)$	$^2S_{1/2}$	B	449 965.51	2.003	0.078
		Other works	464 930[a]		
$2p^5(^2P^o)3s3p(^3P^o)$	$^2D_{5/2}$	B	465 298.64	1.200	0.212
		Other works	439 540[a]		
	$^2D_{3/2}$	B	466 581.47	0.938	0.202
$2p^5(^2P^o)3s3p(^3P^o)$	$^2P_{3/2}$	B	468 357.37	1.196	0.188
		Other works	441 330[a]		
	$^2P_{1/2}$	B	468 685.84	0.792	0.195
$2p^5(^2P^o)3s3p(^3P^o)$	$^2S_{1/2}$	B	471 530.82	1.877	0.492
$2p^5(^2P^o)3p^2(^1D)$	$^2P^o_{1/2}$	B	477 758.33	0.666	0.209
		Other works	477 490[a]		
	$^2P^o_{3/2}$	B	478 327.11	1.267	0.232
		Other works	478 260[a]		
$2p^5(^2P^o)3p^2(^1D)$	$^2F^o_{7/2}$	B	478 189.02	1.143	2.244
	$^2F^o_{5/2}$	B	479 248.34	0.994	2.328
$2p^5(^2P^o)3p^2(^1D)$	$^2D^o_{5/2}$	B	481 172.99	1.064	3.157
		Other works			0.612[b]

Table 2. (continued)

Levels		**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
Conf.	**Term**				
	$^2D^o_{3/2}$		481 494.92	0.868	1.159
$2p^5(^2P^o)3p^2(^3P)$	$^4P^o_{5/2}$	B	483 977.94	1.598	0.828
		Other works	483 373[a]		0.901[b]
	$^4P^o_{3/2}$	B	484 372.16	1.731	0.829
		Other works			0.846[b]
	$^4P^o_{1/2}$	B	484 619.76	2.656	0.839
		Other works			0.837[b]
$2p^5(^2P^o)3p^2(^3P)$	$^4D^o_{7/2}$	B	486 799.95	1.430	0.776
		Other works	486 856[a]		0.851[b]
	$^4D^o_{5/2}$	B	487 324.95	1.371	0.786
		Other works	488 343[a]		0.857[b]
	$^4D^o_{3/2}$	B	487 747.95	1.198	0.790
		Other works			0.822[b]
	$^4D^o_{1/2}$	B	488 031.50	0.007	0.790
		Other works			0.752[b]
$2p^5(^2P^o)3p^2(^3P)$	$^2D^o_{3/2}$	B	491 554.47	0.805	0.442
		Other works			0.945[b]
	$^2D^o_{5/2}$	B	492 003.76	1.224	0.721
		Other works			0.837[b]
$2p^5(^2P^o)3p^2(^3P)$	$^4S^o_{3/2}$	B	491 837.08	1.984	0.703
		Other works			0.742[b]
$2p^5(^2P^o)3p^2(^3P)$	$^2S^o_{1/2}$	B	491 868.53	2.007	0.828
		Other works			0.874[b]
$2p^5(^2P^o)3p^2(^3P)$	$^2P^o_{1/2}$	B	500 519.37	0.665	0.136
		Other works	501 730[a]		
	$^2P^o_{3/2}$	B	501 171.10	1.323	0.145
		Other works	505 780[a]		
$2p^5(^2P^o)3p^2(^1S)$	$^2P^o_{1/2}$	B	512 103.82	0.644	0.304
	$^2P^o_{3/2}$	B	511 333.04	1.110	0.264
$2p^5(^2P^o)3p^2(^1D)$	$^2P^o_{1/2}$	B	523 423.90	0.665	0.197
	$^2P^o_{3/2}$	B	525 019.41	1.240	0.184
$2p^5(^2P^o)3s4s(^3S)$	$^4P^o_{5/2}$	B	487 174.03	1.601	1.622
		Other works	487 205[a]		1.28[b]
	$^4P^o_{3/2}$	B	487 600.79	1.728	1.577
		Other works			0.157[b]
	$^4P^o_{1/2}$	B	487 844.48	2.636	1.511
		Other works			0.574[b]
$2p^5(^2P^o)3s4s(^3S)$	$^2P^o_{3/2}$	B	492 580.81	1.335	0.432
		Other works	491 330[a]		
	$^2P^o_{1/2}$	B	493 182.79	0.668	0.283
		Other works	491 590[a]		

Table 2. (continued)

Levels		**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
Conf.	**Term**				
$2p^5(^2P^o)3s4s(^1S)$	$^2P^o_{1/2}$	B	494 579.73	0.660	0.084
		Other works	495 050[a]		
	$^2P^o_{3/2}$	B	494 713.68	1.261	0.116
		Other works	494 390[a]		
$2p^5(^2P^o)3s3d(^3D)$	$^4P^o_{1/2}$	B	488 549.77	2.382	0.857
		Other works			0.170
	$^4P^o_{3/2}$	B	488 601.15	1.484	0.853
		Other works			0.126[b]
	$^4P^o_{5/2}$	B	491 708.29	1.303	0.439
		Other works	489 440[a]		0.859[b]
$2p^5(^2P^o)3s3d(^3D)$	$^4D^o_{5/2}$	B	488 747.94	1.354	0.881
	$^4D^o_{1/2}$	B	490 075.49	0.365	0.280
	$^4D^o_{7/2}$	B	490 518.30	1.322	0.544
	$^4D^o_{3/2}$	B	491 513.37	0.852	0.399
$2p^5(^2P^o)3s3d(^3D)$	$^4F^o_{7/2}$	B	488 955.32	1.325	0.872
	$^4F^o_{9/2}$	B	489 222.07	1.334	0.828
		Other works	489 383[a]		0.883[b]
	$^4F^o_{3/2}$	B	490 107.84	1.066	0.413
	$^4F^o_{5/2}$	B	490 224.70	1.232	0.522
$2p^5(^2P^o)3s3d(^1D)$	$^2P^o_{3/2}$	B	494 287.47	1.124	0.063
	$^2P^o_{1/2}$	B	495 096.19	0.626	0.063
$2p^5(^2P^o)3s3d(^1D)$	$^2F^o_{5/2}$	B	494 645.61	0.961	0.171
	$^2F^o_{7/2}$	B	496 087.75	1.164	0.167
$2p^5(^2P^o)3s3d(^1D)$	$^2D^o_{3/2}$	B	495 408.12	1.039	0.092
	$^2D^o_{5/2}$	B	495 896.60	1.190	0.155
$2p^5(^2P^o)3s4p(^3P^o)$	$^4S_{3/2}$	B	495 391.06	1.955	22.750
$2p^5(^2P^o)3s4p(^3P^o)$	$^4D_{7/2}$	B	495 777.36	1.430	53.130
	$^4D_{5/2}$	B	496 070.31	1.461	19.560
	$^4D_{3/2}$	B	496 654.42	1.362	2.925
	$^4D_{1/2}$	B	497 097.61	1.081	2.386
$2p^5(^2P^o)3s4p(^3P^o)$	$^4P_{5/2}$	B	496 885.06	1.480	2.519
	$^4P_{3/2}$	B	497 706.05	1.497	1.673
	$^4P_{1/2}$	B	497 814.59	1.636	2.749
$2p^5(^2P^o)3s4p(^3P^o)$	$^2D_{5/2}$	B	499 375.60	1.228	2.037
	$^2D_{3/2}$	B	499 493.24	0.881	0.486
$2p^5(^2P^o)3s4p(^3P^o)$	$^2P_{1/2}$	B	499 534.19	0.694	0.411
	$^2P_{3/2}$	B	499 636.30	1.368	0.690
$2p^5(^2P^o)3s4p(^1P^o)$	$^2S_{1/2}$	B	501 710.16	1.868	0.133
$2p^5(^2P^o)3s4p(^1P^o)$	$^2D_{5/2}$	B	502 711.01	1.206	0.125
	$^2D_{3/2}$	B	503 292.79	1.042	0.136
$2p^5(^2P^o)3s4p(^1P^o)$	$^2P_{3/2}$	B	504 339.90	1.100	0.166
	$^2P_{1/2}$	B	504 529.80	0.760	0.157

Table 2. (continued)

Levels		**Source**	**E (cm^{-1})**	**g-factor**	**τ (ns)**
Conf.	**Term**				
$2p^{5}(^{2}P^{o})3s4p(^{3}P^{o})$	$^{2}S_{1/2}$	B	508 615.11	1.966	0.198
$2p^{5}(^{2}P^{o})3s5s(^{3}S)$	$^{4}P^{o}_{5/2}$	B	511 287.82	1.595	1.788
	$^{4}P^{o}_{3/2}$	B	511 959.14	1.660	1.293
	$^{4}P^{o}_{1/2}$	B	512 607.86	2.477	1.162
$2p^{5}(^{2}P^{o})3s5s(^{3}S)$	$^{2}P^{o}_{3/2}$	B	513 323.36	1.364	2.406
	$^{2}P^{o}_{1/2}$	B	514 090.03	0.819	0.768
$2p^{5}(^{2}P^{o})3s5s(^{1}S)$	$^{2}P^{o}_{3/2}$	B	516 225.39	1.345	0.109
	$^{2}P^{o}_{1/2}$	B	516 450.46	0.681	0.122
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{2}F^{o}_{7/2}$	B	504 915.73	1.144	0.413
	$^{2}F^{o}_{5/2}$	B	507 810.19	0.948	0.528
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{2}D^{o}_{5/2}$	B	505 037.30	1.113	0.451
	$^{2}D^{o}_{3/2}$	B	505 821.94	0.972	0.266
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{2}P^{o}_{1/2}$	B	506 865.61	0.662	0.123
	$^{2}P^{o}_{3/2}$	B	508 263.69	1.176	0.167
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{4}P^{o}_{1/2}$	B	509 143.69	2.510	3.708
	$^{4}P^{o}_{3/2}$	B	509 259.68	1.589	3.782
	$^{4}P^{o}_{5/2}$	B	509 416.39	1.419	4.130
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{4}F^{o}_{9/2}$	B	509 282.51	1.334	4.188
	$^{4}F^{o}_{7/2}$	B	509 469.71	1.332	4.252
	$^{4}F^{o}_{5/2}$	B	510 722.11	1.250	1.463
	$^{4}F^{o}_{3/2}$	B	512 323.88	0.872	0.264
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{4}D^{o}_{3/2}$	B	510 771.74	1.140	0.439
	$^{4}D^{o}_{7/2}$	B	510 914.47	1.322	1.352
	$^{4}D^{o}_{1/2}$	B	511 053.35	0.231	0.730
	$^{4}D^{o}_{5/2}$	B	512 202.53	1.304	1.389
$2p^{5}(^{2}P^{o})3s4d(^{1}D)$	$^{2}F^{o}_{5/2}$	B	516 040.24	0.883	0.201
	$^{2}F^{o}_{7/2}$	B	520 680.27	1.146	0.141
$2p^{5}(^{2}P^{o})3s4d(^{1}D)$	$^{2}P^{o}_{3/2}$	B	517 861.08	1.289	0.058
	$^{2}P^{o}_{1/2}$	B	518 083.51	0.644	0.051
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{2}F^{o}_{7/2}$	B	520 680.27	1.146	0.141
	$^{2}F^{o}_{5/2}$	B	521 297.25	1.035	0.142
$2p^{5}(^{2}P^{o})3s4d(^{3}D)$	$^{2}D^{o}_{3/2}$	B	516 589.43	0.833	0.165
	$^{2}D^{o}_{5/2}$	B	516 748.22	1.204	0.242
$2p^{5}(^{2}P^{o})3s4d(^{1}D)$	$^{2}D^{o}_{3/2}$	B	522 196.45	0.893	0.157
	$^{2}D^{o}_{5/2}$	B	522 998.79	1.026	0.179
$2p^{5}(^{2}P^{o})3s4f(^{3}F^{o})$	$^{4}D_{1/2}$	B	513 647.10	-0.002	5.762
	$^{4}D_{3/2}$	B	513 669.39	1.097	5.716
	$^{4}D_{5/2}$	B	513 705.26	1.230	5.605
	$^{4}D_{7/2}$	B	514 953.73	1.169	1.704
$2p^{5}(^{2}P^{o})3s4f(^{3}F^{o})$	$^{4}G_{11/2}$	B	513 683.35	1.273	6.105

Table 2. (continued)

Levels		Source	E (cm^{-1})	g-factor	τ (ns)
Conf.	**Term**				
	$^4G_{9/2}$	B	513 734.01	1.234	5.530
	$^4G_{5/2}$	B	514 951.40	0.895	1.584
	$^4G_{7/2}$	B	515 006.01	1.040	1.422
$2p^5(^2P^o)3s4f(^3F^o)$	$^4F_{7/2}$	B	513 739.19	1.246	5.481
	$^4F_{9/2}$	B	514 990.09	1.216	1.674
	$^4F_{3/2}$	B	515 003.81	0.597	1.505
	$^4F_{5/2}$	B	515 974.07	0.873	5.916
$2p^5(^2P^o)3s4f(^3F^o)$	$^2D_{3/2}$	B	513 819.29	0.716	5.291
	$^2D_{5/2}$	B	513 864.48	0.997	5.264
$2p^5(^2P^o)3s4f(^3F^o)$	$^2G_{9/2}$	B	513 842.11	1.161	5.760
	$^2G_{7/2}$	B	515 974.01	1.128	6.743
$2p^5(^2P^o)3s4f(^3F^o)$	$^2F_{7/2}$	B	513 881.59	1.093	5.432
	$^2F_{5/2}$	B	515 021.43	1.039	1.379
$2p^5(^2P^o)3s4f(^1F^o)$	$^2D_{3/2}$	B	519 393.21	0.788	0.111
	$^2D_{5/2}$	B	519 421.84	1.172	0.112
$2p^5(^2P^o)3s4f(^1F^o)$	$^2G_{9/2}$	B	519 423.86	1.118	0.118
	$^2G_{7/2}$	B	519 462.09	0.930	0.119
$2p^5(^2P^o)3s4f(^1F^o)$	$^2F_{7/2}$	B	519 547.52	1.112	0.118
	$^2F_{5/2}$	B	519 557.48	0.880	0.117

[a] NIST [3]

[b] Fischer [8]

Table 3. Energy parameters obtained from the calculation A for low-lying levels in Mg II.

Conf.	**Parameter**	**HFR (Ab initio)**	**Fitted**	**SF (Fitted/HFR)**
$2p^63s$	E_{av}	0.00	0.00	
$2p^63p$	E_{av}	35 888.60	35 730.40	0.996
	ζ_{3p}	50.2492	61.000	1.214
$2p^64s$	E_{av}	71 091.40	69 805.00	0.982
$2p^63d$	E_{av}	72 294.70	71 490.50	0.989
	ζ_{3d}	0.2782	-0.300	-1.078
$2p^64p$	E_{av}	81 827.90	80 639.80	0.985
	ζ_{4p}	16.3582	20.300	1.241
$2p^65s$	E_{av}	94 131.90	92 790.50	0.986
$2p^64d$	E_{av}	94 473.30	93 310.80	0.988
	ζ_{4d}	0.1152	-0.200	-1.736
$2p^64f$	E_{av}	95 119.70	93 799.70	0.986
	ζ_{4f}	0.0582	0.000	0.000
$2p^65p$	E_{av}	98 762.50	97 464.30	0.987
	ζ_{5p}	7.3942	9.200	1.244
$2p^66s$	E_{av}	104 547.00	103 196.70	0.987
$2p^65d$	E_{av}	104 685.00	103 419.80	0.988
	ζ_{5d}	0.0602	-0.100	-1.661
$2p^65f$	E_{av}	105 017.30	103 689.90	0.987
	ζ_{5f}	0.0282	0.000	0.000
$2p^65g$	E_{av}	105 061.50	103 705.70	0.987
	ζ_{5g}	0.0172	0.000	0.000
$2p^66p$	E_{av}	106 955.70	105 627.30	0.988
	ζ_{6p}	3.9582	4.900	1.238
$2p^67s$	E_{av}	110 137.20	108 784.30	0.988
$2p^66d$	E_{av}	110 205.90	108 900.10	0.988
	ζ_{6d}	0.0352	-0.100	-2.841
$2p^66f$	E_{av}	110 398.90	109 062.30	0.988
	ζ_{6f}	0.0172	0.000	0.000
$2p^66g$	E_{av}	110 426.50	109 072.10	0.988
	ζ_{6g}	0.0112	0.000	0.000
$2p^66h$	E_{av}	110 428.90	109 074.00	0.988
	ζ_{6h}	0.0072	0.000	0.000
$2p^67p$	E_{av}	111 546.50	110 206.50	0.988
	ζ_{7p}	2.3592	2.900	1.229
$2p^68s$	E_{av}	113 482.90	112 129.20	0.988
$2p^67d$	E_{av}	113 521.90	112 197.10	0.988
	ζ_{7d}	0.0222	0.000	0.000
$2p^67f$	E_{av}	113 643.60	112 301.50	0.988
	ζ_{7f}	0.0102	0.000	0.000
$2p^67g$	E_{av}	113 661.80	112 307.80	0.988
	ζ_{7g}	0.0072	0.000	0.000

Table 4. Selection of electric dipole transitions for Mg II. Full table appears in supplemental material (Table S2).

Transitions				**λ (Å)**		***f***			**A_{ji} (s^{-1})**		
Lower Level	**Upper Level**	**g_i**	**g_j**	**This W.**	**Other W.**	**This W.**	**Other W.**		**This W.**	**Other W.**	
				HFR	**MCHF [13]**	**HFR**	**WBEPMT [1]**	**MCHF [13]**	**HFR**	**WBEPMT [1]**	**MCHF [13]**
4p $^2P^o$	5s ^2S	2	2	8216.25	8227.85	2.61E-01	2.63E-01	2.69E-01	2.58E+07	2.60E+07	2.65E+07
4p $^2P^o$	5s ^2S	4	2	8236.86	8251.06	2.60E-01	2.63E-01	2.70E-01	5.12E+07	5.16E+07	5.29E+07
3d ^2D	4p $^2P^o$	6	4	10917.33	11212.66	1.71E-01	1.82E-01	1.80E-01	1.44E+07	1.53E+07	1.43E+07
3d ^2D	4p $^2P^o$	4	2	10954.64	11242.33	1.42E-01	1.51E-01	1.49E-01	1.58E+07	1.68E+07	1.58E+07
3d ^2D	4p $^2P^o$	4	4	10918.22	11199.30	2.85E-02	3.03E-02	3.00E-02	1.60E+06	1.70E+06	1.59E+06
3d ^2D	4f $^2F^o$	6	6	4482.40	4538.71	4.44E-02	4.69E-02	4.67E-02	1.47E+07	1.56E+07	1.51E+07
3d ^2D	4f $^2F^o$	6	8	4482.40	4539.39	8.88E-01	9.38E-01	9.35E-01	2.21E+08	2.34E+08	2.27E+08
3d ^2D	4f $^2F^o$	4	6	4482.55	4536.52	9.33E-01	9.85E-01	9.82E-01	2.06E+08	2.18E+08	2.12E+08
4f $^2F^o$	5g ^2G	6	8	10094.89	–	1.33E+00	1.35E+00	–	6.54E+07	6.62E+07	–
4f $^2F^o$	5g ^2G	8	8	10094.89	–	3.70E-02	3.75E-02	–	2.42E+06	2.45E+06	–
4f $^2F^o$	5g ^2G	8	10	10094.89	–	1.30E+00	1.31E+00	–	6.78E+07	6.87E+07	–
5s ^2S	5p $^2P^o$	2	2	21438.07	21400.95	6.10E-01	6.06E-01	6.08E-01	8.85E+06	8.80E+06	8.85E+06
5s ^2S	5p $^2P^o$	2	4	21374.82	21332.02	1.22E+00	1.21E+00	1.21E+00	8.93E+06	8.87E+06	8.92E+06
5p $^2P^o$	5d ^2D	2	4	16764.88	16570.91	1.52E+00	1.46E+00	1.48E+00	1.80E+07	1.73E+07	1.80E+07
5p $^2P^o$	5d ^2D	4	6	16804.46	16603.78	1.36E+00	1.31E+00	1.33E+00	2.15E+07	2.07E+07	2.15E+07
5p $^2P^o$	5d ^2D	4	4	16803.76	16612.48	1.51E-01	1.46E-01	1.48E-01	3.58E+06	3.44E+06	3.58E+06
5d ^2D	5f $^2F^o$	6	6	370096.24	–	5.38E-03	5.38E-03	–	2.62E+02	2.62E+02	–
5d ^2D	5f $^2F^o$	6	8	370094.87	–	1.07E-01	1.08E-01	–	3.93E+03	3.93E+03	–
5d ^2D	5f $^2F^o$	4	6	370437.61	–	1.13E-01	1.13E-01	–	3.65E+03	3.65E+03	–
5f $^2F^o$	6g ^2G	6	8	18579.76	–	1.16E+00	1.19E+00	–	1.68E+07	1.72E+07	–
5f $^2F^o$	6g ^2G	8	10	18579.76	–	1.13E+00	1.15E+00	–	1.75E+07	1.79E+07	–
5f $^2F^o$	6g ^2G	8	8	18579.76	–	3.23E-02	3.30E-02	–	6.23E+05	6.37E+05	–
6s ^2S	6p $^2P^o$	2	2	41225.21	41149.19	7.49E-01	7.47E-01	7.47E-01	2.94E+06	2.97E+06	2.94E+06
6s ^2S	6p $^2P^o$	2	4	41100.66	41012.85	1.50E+00	1.50E+00	1.49E+00	2.97E+06	3.00E+06	2.97E+06
6p $^2P^o$	6d ^2D	2	4	30507.79	30102.49	1.77E+00	1.70E+00	1.71E+00	6.33E+06	6.09E+06	6.30E+06
6p $^2P^o$	6d ^2D	4	6	30578.69	30159.48	1.59E+00	1.53E+00	1.54E+00	7.54E+06	7.29E+06	7.54E+06
6p $^2P^o$	6d ^2D	4	4	30576.37	30175.87	1.76E-01	1.70E-01	1.71E-01	1.26E+06	1.22E+06	1.26E+06
3d ^2D	6f $^2F^o$	6	6	2661.55	2680.96	2.82E-03	2.81E-03	2.67E-03	2.65E+06	2.64E+06	2.48E+06
3d ^2D	6f $^2F^o$	6	8	2661.55	2680.98	5.63E-02	5.61E-02	5.35E-02	3.98E+07	3.96E+07	3.72E+07
3d ^2D	6f $^2F^o$	4	6	2661.60	2680.20	5.92E-02	5.89E-02	5.62E-02	3.71E+07	3.70E+07	3.48E+07

Table 4. (continued)

Transitions				λ (Å)		*f*			A_{ji} (s^{-1})		
Lower Level	Upper Level	g_i	g_j	This W.	Other W.	This W.	Other W.		This W.	Other W.	
				HFR	MCHF [13]	HFR	WBEPMT [1]	MCHF [13]	HFR	WBEPMT [1]	MCHF [13]
5g ^{2}G	6f ^{2}F^o	8	6	18668.56	–	7.88E-03	7.11E-03	–	2.01E+05	1.82E+05	–
5g ^{2}G	6f ^{2}F^o	8	8	18668.56	–	2.93E-04	2.63E-04	–	5.59E+03	5.04E+03	–
5g ^{2}G	6f ^{2}F^o	10	8	18668.56	–	8.18E-03	7.38E-03	–	1.96E+05	1.77E+05	–
5g ^{2}G	6h ^{2}H^o	8	10	18627.87	–	1.68E+00	1.68E+00	–	2.58E+07	2.58E+07	–
5g ^{2}G	6h ^{2}H^o	10	12	18627.87	–	1.65E+00	1.65E+00	–	2.64E+07	2.64E+07	–
5g ^{2}G	6h ^{2}H^o	10	10	18627.87	–	3.05E-02	3.05E-02	–	5.86E+05	5.86E+05	–
6h ^{2}H^o	7i ^{2}I	10	12	30908.07	–	2.01E+00	2.01E+00	–	1.17E+07	1.19E+07	–
6h ^{2}H^o	7i ^{2}I	12	12	30908.08	–	2.57E-02	–	–	1.80E+05	–	–
6h ^{2}H^o	7i ^{2}I	12	14	30908.07	–	1.98E+00	–	–	1.19E+07	–	–

Table 5. Some electric quadrupole transitions for Mg II.

Transitions				λ (Å)		log (*gf*)	A_{ji} (s^{-1})		
				This work	Other w.	This work	This work	Other w.	
Lower Level	Upper Level	g_i	g_j	HFR	CC [14]	HFR	HFR	WBEPMT [19]	CC[14]
4s ^{2}S	3d ^{2}D	2	6	59340.07	59338.7	-8.98	3.28E-04	–	3.42E-04
4s ^{2}S	3d ^{2}D	2	4	59313.71	59308.1	-9.16	3.29E-04	–	3.42E-04
4s ^{2}S	4d ^{2}D	2	6	4254.31	4254.3	-5.30	3.09E+02	3.00E+02	2.93E+02
4s ^{2}S	4d ^{2}D	2	4	4254.21	4254.2	-5.48	3.09E+02	3.00E+02	2.93E+02
4s ^{2}S	5d ^{2}D	2	6	2974.89	2974.9	-6.12	0.94E+02	1.02E+02	1.25E+02
4s ^{2}S	5d ^{2}D	2	4	2974.87	2974.8	-6.30	0.94E+02	1.02E+02	1.25E+02
4s ^{2}S	6d ^{2}D	2	6	2557.87	–	-6.64	3.87E+01	4.06E+01	–
4s ^{2}S	6d ^{2}D	2	4	2557.86	–	-6.82	3.87E+01	4.06E+01	–
4s ^{2}S	7d ^{2}D	2	6	2358.93	–	-7.02	1.92E+01	2.08E+01	–
4s ^{2}S	7d ^{2}D	2	4	2358.93	–	-7.19	1.92E+01	2.08E+01	–
4s ^{2}S	8d ^{2}D	2	6	2245.79	–	-7.31	1.09E+01	1.21E+01	–
4s ^{2}S	8d ^{2}D	2	4	2245.79	–	-7.48	1.09E+01	1.21E+01	–
4s ^{2}S	9d ^{2}D	2	6	2174.41	–	-7.54	6.78E+00	7.69E+00	–
4s ^{2}S	9d ^{2}D	2	4	2174.41	–	-7.72	6.78E+00	7.69E+00	–
4d ^{2}D	5d ^{2}D	6	6	9892.08	–	-5.91	1.39E+01	1.43E+01	–
4d ^{2}D	5d ^{2}D	6	4	9891.83	9891.77	-6.52	5.20E+00	5.36E+00	3.42E+00
4d ^{2}D	5d ^{2}D	4	6	9892.57	9892.6	-6.52	3.46E+00	3.57E+00	3.39E+00
4d ^{2}D	5d ^{2}D	4	4	9892.32	–	-6.15	1.21E+01	1.25E+01	–
4d ^{2}D	6d ^{2}D	6	6	6414.62	–	-6.51	8.28E+00	8.47E+00	–
4d ^{2}D	6d ^{2}D	6	4	6414.51	–	-7.12	3.11E+00	3.18E+00	–
4d ^{2}D	6d ^{2}D	4	6	6414.82	–	-7.12	2.07E+00	2.12E+00	–
4d ^{2}D	6d ^{2}D	4	4	6414.72	–	-6.75	7.24E+00	7.42E+00	–
4d ^{2}D	7d ^{2}D	6	4	5294.79	–	-7.49	1.94E+00	1.99E+00	–
4d ^{2}D	7d ^{2}D	6	6	5294.79	–	-6.88	5.19E+00	5.30E+00	–
4d ^{2}D	7d ^{2}D	4	4	5294.93	–	-7.12	4.54E+00	4.64E+00	–
4d ^{2}D	7d ^{2}D	4	6	5294.93	–	-7.49	1.30E+00	1.32E+00	–
4p ^{2}P^o	5p ^{2}P^o	2	4	5934.93	5934.9	-6.00	4.76E+01	4.31E+01	4.44E+01
4p ^{2}P^o	5p ^{2}P^o	4	2	5950.56	5950.6	-6.00	9.39E+01	8.63E+01	8.84E+01
4p ^{2}P^o	5p ^{2}P^o	4	4	5945.67	5945.7	-6.00	4.72E+01	4.31E+01	4.14E+01

Table 5. (continued)

Transitions				λ (Å)		log (*gf*)	A_{ji} (s^{-1})		
				This work	Other w.	This work	This work	Other w.	
Lower Level	Upper Level	g_i	g_j	HFR	CC [14]	HFR	HFR	WBEPMT [19]	CC[14]
4p $^2P^o$	6p $^2P^o$	2	4	3998.36	–	-6.56	2.85E+01	2.54E+01	–
4p $^2P^o$	6p $^2P^o$	4	2	4004.41	–	-6.57	5.66E+01	5.07E+01	–
4p $^2P^o$	6p $^2P^o$	4	4	4003.23	–	-6.57	2.84E+01	2.54E+01	–
4p $^2P^o$	7p $^2P^o$	2	4	3379.70	–	-6.92	1.78E+01	1.59E+01	–
4p $^2P^o$	7p $^2P^o$	4	2	3383.68	–	-6.92	3.53E+01	3.17E+01	–
4p $^2P^o$	7p $^2P^o$	4	4	3383.18	–	-6.92	1.77E+01	1.59E+01	–
4p $^2P^o$	8p $^2P^o$	2	4	3085.13	–	-7.18	1.17E+01	1.05E+01	–
4p $^2P^o$	8p $^2P^o$	4	2	3088.30	–	-7.18	2.33E+01	2.10E+01	–
4p $^2P^o$	8p $^2P^o$	4	4	3088.03	–	-7.18	1.16E+01	1.05E+01	–
4p $^2P^o$	9p $^2P^o$	2	4	2917.22	–	-7.39	8.07E+00	7.33E+00	–
4p $^2P^o$	9p $^2P^o$	4	2	2919.98	–	-7.39	1.61E+01	1.46E+01	–
4p $^2P^o$	9p $^2P^o$	4	4	2919.81	–	-7.39	8.04 E+00	7.31E+00	–
4p $^2P^o$	4f $^2F^o$	2	6	7587.14	7587.2	-5.61	4.76E+01	4.66E+01	4.73E+01
4p $^2P^o$	4f $^2F^o$	4	6	7604.71	7604.8	-6.16	1.34E+01	1.32E+01	1.34E+01
4p $^2P^o$	4f $^2F^o$	4	8	7604.71	7604.7	-5.38	6.05E+01	5.94E+01	6.02E+01
4p $^2P^o$	5f $^2F^o$	2	6	4334.56	4334.6	-6.00	5.89E+01	4.80E+01	4.80E+01
4p $^2P^o$	5f $^2F^o$	4	6	4340.29	4340.3	-6.55	1.67E+01	1.38E+01	1.37E+01
4p $^2P^o$	5f $^2F^o$	4	8	4340.29	4340.3	-5.77	7.52E+01	6.21E+01	6.18E+01
4p $^2P^o$	6f $^2F^o$	2	6	3515.83	–	-6.10	7.20E+01	6.52E+01	–
4p $^2P^o$	6f $^2F^o$	4	6	3519.60	–	-6.64	2.05E+01	1.87E+01	–
4p $^2P^o$	6f $^2F^o$	4	8	3519.60	–	-5.86	9.20E+01	8.41E+01	–
4p $^2P^o$	7f $^2F^o$	2	6	3156.37	–	-6.28	5.84E+01	5.52E+01	–
4p $^2P^o$	7f $^2F^o$	4	6	3159.40	–	-6.83	1.66E+01	1.58E+01	–
4p $^2P^o$	7f $^2F^o$	4	8	3159.40	–	-6.05	7.47E+01	7.11E+01	–
4p $^2P^o$	8f $^2F^o$	2	6	2959.98	–	-6.46	4.43E+01	4.28E+01	–
4p $^2P^o$	8f $^2F^o$	4	6	2962.65	–	-7.00	1.26E+01	1.23E+01	–
4p $^2P^o$	8f $^2F^o$	4	8	2962.65	–	-6.23	5.66E+01	5.51E+01	–
4p $^2P^o$	9f $^2F^o$	2	6	2838.88	–	-6.62	3.34E+01	3.27E+01	–
4p $^2P^o$	9f $^2F^o$	4	6	2841.34	–	-7.16	9.49E+00	9.36E+00	–
4p $^2P^o$	9f $^2F^o$	4	8	2841.34	–	-6.38	4.27E+01	4.21E+01	–

Table 5. (continued)

Transitions				**λ (Å)**		**log (*gf*)**	**A_{ji} (s^{-1})**		
				This work	**Other w.**	**This work**	**This work**	**Other w.**	
Lower Level	**Upper Level**	**g_i**	**g_j**	**HFR**	**CC [14]**	**HFR**	**HFR**	**WBEPMT [19]**	**CC [14]**
4f ^{2}F^{o}	5f ^{2}F^{o}	6	6	10111.02	–	-6.11	8.36E+00	8.42E+01	–
4f ^{2}F^{o}	5f ^{2}F^{o}	6	8	10111.02	–	-6.89	1.05E+00	1.05E+00	–
4f ^{2}F^{o}	5f ^{2}F^{o}	8	6	10111.02	–	-6.89	1.39E+00	1.40E+00	–
4f ^{2}F^{o}	5f ^{2}F^{o}	8	8	10111.02	–	-5.97	8.71E+00	1.47E+00	–
3d ^{2}D	5s ^{2}S	6	2	4694.77	4694.8	-6.58	3.94E+01	–	1.48E+01
3d ^{2}D	5s ^{2}S	4	2	4694.94	4694.9	-6.76	2.63E+01	–	1.47E+01
4d ^{2}D	5s ^{2}S	6	2	192269.98	192278.1	-9.34	1.36E-05	–	1.44E-05
4d ^{2}D	5s ^{2}S	4	2	192085.69	192086.1	-9.52	1.37E-05	–	1.45E-05
5s ^{2}S	5d ^{2}D	2	6	9408.04	9408.0	-5.48	4.15E+01	4.32E+01	4.22E+01
5s ^{2}S	5d ^{2}D	2	4	9407.82	9407.8	-5.66	4.15E+01	4.32E+01	4.22E+01
5p ^{2}P^{o}	5f ^{2}F^{o}	2	6	16039.00	16039.2	-5.64	0.98E+01	1.02E+01	1.16E+03
5p ^{2}P^{o}	5f ^{2}F^{o}	4	6	16074.58	16121.4	-6.19	2.78E+00	2.88E+00	2.86E+00
5p ^{2}P^{o}	5f ^{2}F^{o}	4	8	16074.58	16121.2	-5.41	1.25E+01	1.30E+01	1.29E+01