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Dipole allowed and intercombination transitions in K^{7+} and Ti^{10+} ions⋆

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Abstract. We have calculated 87 fine-structure energy levels of K^{7+} and Ti^{10+} belonging to the lowest 14 configurations within the $n = 3$ and $n = 4$ complexes using Program CIV3 of Hibbert. Relativistic effects are included through the Breit-Pauli approximation. New improved results of oscillator strengths, transition probabilities and line strengths for all allowed and intercombination transitions among these fine-structure levels are calculated using large-scale configuration interaction wavefunctions. Lifetimes of some relatively longer-lived levels are also computed. Our results are compared with a wide variety of other calculations and available experimental data. It is noted that most of our results compare more favourably with the measurements than the other available theoretical results.

Key words. atomic data

1. Introduction

Stellar coronal spectra are rich in emission lines from high ionization states of the cosmically abundant elements (Brickhouse 2000), such as C, O, Ne, Mg, Si, Fe and Ni, which radiate in the X-ray band. The X-ray Chandra and XMM-Newton observatories have been producing a wealth of spectroscopic information for a wide range of astrophysical X-ray sources, such as accretion driven binary systems and AGNs (Kaastra 2001; Paerels et al. 2000). Accurate and complete atomic data for all stages of ionization for elements at least up to Zn (Kurucz 2002) are required to infer reliably the properties of many cosmic plasmas and, hence for the understanding of the fundamental issues of astrophysics (Savin 2001). However, the field of high-Z atoms poses many open questions and still requires a substantial effort in the atomic physics (Behringer 2000) and some of the available atomic data are riddled with uncertainties or are incomplete. Hence, the present investigation.

Mg-like ions have been observed in rocket-borne measurements (Sofia et al. 1994). More recently, using time resolved X-ray spectroscopy, absorption and emission features from Fe XVI–Fe XIX, Na X, Na XI, F VIII and F IX have been observed in the laboratory (Foord et al. 2001). Reliable dipole allowed and intercombination transition rates and oscillator strengths among the various fine-structure levels of the Mg-like ions are also essential for plasma diagnostics and several diagnostic line ratios for the solar transitions have been determined using transitions in such ions as Fe XV and Si III.

Excitation energies and line strengths for some low-lying excited states of ions in the Mg-like sequence were studied using multiconfiguration Dirac Fock (MCDF) wavefunctions by Cheng & Johnson (1977) and lifetimes were evaluated using multiconfiguration Hartree-Fock wave functions by Fischer & Godefroid (1982). Shorer et al. (1977) calculated, using the relativistic random phase approximation (RRPA) within the frozen core prescription, the excitation energies and absorption oscillator strengths for the $3s^2\,{}^1S_0 \rightarrow 3s3p\,{}^1P_1$, $\rightarrow 3s4p\,{}^1P_1$, $\rightarrow 3s5p\,{}^1P_1$ transitions of the Mg isoelectronic sequence. Fawcett (1983) applied the Cowan-Zelot Hartree-XR computer package (1967, 1968, 1976) to study the weighted oscillator strengths, energy levels and wavelengths of a number of ions in this sequence. Huang & Johnson (1985) used an improved version of the RRPA by introducing a multiconfiguration wavefunction as the reference state to determine excitation energies and oscillator strengths of the resonance transitions in the Mg isoelectronic sequence. Later, Chou et al. (1993) used a large-scale multiconfiguration RRPA (MCRRPA) including excitation channels from core electrons for the calculation of energy levels and oscillator strengths for the intercombination transition $3s^2\,{}^1S_0 \rightarrow 3s3p\,{}^3P_1$ and the resonance transition $3s^2\,{}^1S_0 \rightarrow 3s3p\,{}^1P_1$ in Mg-like ions and thus provided an ab initio treatment of the core-polarization (CP) effects. They showed that the excitation energies for both the intercombination and resonance transitions increased linearly with increasing nuclear charge. Nevertheless, their intercombination

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⋆ Tables 6 and 7 are only available in electronic form at http://www.edpsciences.org

excitation energies with CP effects are not in good agreement with experiment and the percentage contributions due to CP effects are far too small compared to the corresponding effects in any CI calculation. They also found that the oscillator strengths for the intercombination transitions increased with increasing nuclear charge, whereas for the resonance transition the oscillator strengths decreased with increasing nuclear charge. Chou et al. (1993) made two important observations regarding oscillator strengths: (i) the differences between the length and the velocity results increased with increasing nuclear charge and (ii) the inclusion of CP effects brought the two forms into better agreement.

Butler et al. (1993) applied a modified R-matrix program to calculate energies and oscillator strengths for some $3l3l'$ transitions in a number of ions (Z = 12–14, 16, 18, 20 and 26). However, this calculation includes no relativistic correction which is expected to contribute to ions of moderately high Z, such as calcium and iron. Relativistic multiconfiguration Dirac-Fock (RMCDF) and configuration interaction Dirac-Fock (CIDF), with and without core-valence correlations, calculations were performed by Stanek et al. (1996) for Mg I through Cl VI. They concluded that intravalence electron correlation is of crucial importance for the ions towards the neutral end of the sequence. However, they (Stanek et al. 1996) have studied only two transitions, namely $3s^2(^1S_o) \rightarrow 3s3p(^1P_1)$ and $3s^2(^1S_o) \rightarrow 3s3p(^3P_1)$. Valence and core-valence multiconfiguration Dirac-Fock and relativistic configuration interaction calculations including the Breit interaction were performed by Jönsson & Fischer (1997). However, they have studied only the $3s^2(^1S) \rightarrow 3s3p(^{1,3}P)$ transitions in some low Z Mg-like ions. They found the Breit interaction to be of great importance both for the 3s3p ^{3}P fine-structure splitting and for the intercombination rates. Chen & Cheng (1997) applied B-spline basis techniques to study transition energies in this sequence, and showed that by including the interaction of the valence electrons with this core, along with Breit, QED, and mass-polarization effects, fairly accurate transition energies could be obtained. Correlations with the core are especially important for determining accurate transition rates for the $3s^2(^1S_0) \rightarrow 3s3p(^3P_1)$ intercombination transition.

In an attempt to resolve the controvertial energy position of the $3p^2(^1S_0)$ level, Deb & Msezane (1998) studied the fine-structure levels of Fe XV and confirmed the findings of Sugar & Corliss (1985) with or without the $3d^2$ configuration included in the calculation. Almaraz et al. (2000) have performed more extensive CIV3 calculations to study the configuration mixing among the levels involved in the $3s^2(^1S_0) \rightarrow 3snp(^{1,3}P_1)$ (n = 3–5) transitions in Mg-like ions such as Si III, S V and Fe XV. They also used relativistic quantum defect orbital (RQDO) formalism and MCDF procedures in their investigations. The fine- tuned results for the resonance transition showed a 7% disagreement between length and velocity forms. Interestingly, with a much smaller basis set, level energies for Fe XV from our group (Deb & Msezane 1998; Deb et al. 1999) showed far better agreement with the measurement. However, their (Almaraz et al. 2000) calculated oscillator strengths using MCDF agree closely with their length form of the CIV3 results as do the recent experimental values. Their RQDO method based on a simple model potential gave reasonably good oscillator strengths for the ions towards the neutral end of the sequence, but poor agreement with the measured data and both their CIV3 and MCDF for the $3s^2(^1S_0) \rightarrow 3s3p(^1P_1)$ transition in Fe XV. To obtain the excitation energies, transition probabilities, and lifetimes for the $3l–3l'$ electric dipole transitions in Mg-like ions (Z = 13–100), Safronova et al. (2000) used a relativistic many-body perturbation theory (MBPT). The Breit interaction was also included in their calculation. Their calculated values for allowed transitions agree with experiment within the experimental uncertainties for the 3s3p ($^1P_1$) level but for many of the other excited levels their agreement with the measured values is rather poor. To extend the data needed for astrophysical applications, Aggarwal et al. (1999, 2000, 2001, 2003) have investigated energy levels, radiative rates, collision strengths and effective collision strengths for Fe XV and compared their results with other available data as well as assessed the reliability of other theoretical calculations.

More recently Biémont et al. (2002) applied the relativistic Hartree-Fock (HFR) and Multiconfiguration Dirac-Fock (MCDF) methods, including both intravalence and corevalence correlations, extensively to calculate the radiative lifetimes and oscillator strengths in Mg-like K VIII. In order to assess the accuracy of theoretical methods for transition rates, it is essential to have reliable experimental values for comparison. A number of comparatively accurate experimental values are available (Curtis 1991) both for the allowed transition $3s^2(^1S_0)$–$3s3p(^1P_1)$ and for the intercombination transition $3s^2(^1S_0)$–$3s3p(^3P_1)$.

The purpose of this work is to study excitation energies, oscillator strengths, transition probabilities and lifetimes of allowed and intercombination transitions of two Mg-like ions, K^{7+} and Ti^{10+}, accounting for the electron correlations through an extensive set of configurations and relativistic effects through the Breit-Pauli Hamiltonian.

2. Method of calculation

We use the computer code CIV3 of Hibbert (1975) and of Glass & Hibbert (1978) to optimize various orbitals and to calculate energy levels, oscillator strengths, radiative decay rates and lifetimes for the lowest 87 fine-structure levels of Mg-like K VIII and Ti Xl. Relativistic effects are included through the Breit-Pauli approximation via spin-orbit, spin-other orbit, spin-spin, Darwin and mass correction terms. The basic 14 configurations $3s^2$, 3s3p, $3p^2$, 3s3d, 3p3d, $3d^2$, 3s4s, 3s4p, 3s4d, 3s4f, 3p4s, 3p4p, 3p4d and 3p4f result in the 47 LS states: $3s^2(^1S^e)$, $3s3p(^{1,3}P^o)$, $3p^2(^1S^e, ^1D^e, ^3P^e)$, $3s3d(^{1,3}D^e)$, $3p3d(^{1,3}P^o, ^{1,3}D^o, ^{1,3}F^o)$, $3d^2(^1S^e, ^1D^e, ^1G^e, ^3P^e, ^3F^e)$, $3s4s(^{1,3}S^e)$, $3s4p(^{1,3}P^o)$, $3s4d(^{1,3}D^e)$, $3s4f(^{1,3}F^o)$, $3p4s(^{1,3}P^o)$, $3p4p(^{1,3}S^e, ^{1,3}P^e, ^{1,3}D^e)$, $3p4d(^{1,3}P^o, ^{1,3}D^o, ^{1,3}F^o)$ and $3p4f(^{1,3}D^e, ^{1,3}F^e, ^{1,3}G^e)$. These LS states give rise to 87 fine-structure levels (47 even parity and 40 odd parity), corresponding to various J values.

We have taken the core configuration ($1s^2\ 2s^2\ 2p^6$) as frozen but the two valence electrons are distributed among all the

Table 1. Parameters for the optimized orbitals.

	K VIII			Ti XI		
Orbitals	p_j	ξ_j	C_j	p_j	ξ_j	C_j
3p	2	5.8986206	0.4001453	2	13.0854075	0.1046845
	2	11.2074413	0.0971636	2	6.9294436	0.4760082
	3	3.3184265	−1.1389354	3	4.3222458	−1.1986132
3d	3	6.7592894	0.0801860	3	8.5673148	0.0770588
	3	2.9913336	0.9522927	3	4.0341888	0.9507110
4s	1	15.2000205	0.0939256	1	15.2983070	0.1290024
	2	7.0118243	−0.1769061	2	11.2757064	−0.0989372
	2	1.8368330	−3.3274061	2	2.5035395	−4.4350670
	3	3.2678086	3.1927168	3	4.1167294	4.2864968
4p	2	7.7052228	0.1714105	2	8.8231176	0.2983943
	2	1.5705746	2.3866439	2	1.4850941	−0.0757807
	3	3.1453231	−2.1808499	3	3.0626329	−76.9581643
				3	3.0319666	77.3170529
4d	3	1.6722706	1.4733928	3	2.3154917	1.5549609
	3	3.0419079	−1.0736863	3	4.0354790	−1.1643178
4f	4	2.0370563	1.000	4	2.90000	1.000

possible combinations of the $n = 3$ and $n = 4$ orbitals. To be specific, we have included the $3s^2, 3p^2, 3d^2, 4s^2, 4p^2, 4d^2, 4f^2$, 3s3d, 3s4s, 3s4d, 3p4p, 3p4f, 3d4s, 3d4d, 4s4d, and 4p4f (16 in total) configurations in the generation of the even states and 3s3p, 3s4p, 3s4f, 3p3d, 3p4s, 3p4d, 3d4p, 3d4f, 4s4p, 4s4f, 4p4d, and 4d4f (12 in total) configurations in the generation of the odd states. This set of configurations gives rise to 205 individual configurations, and therefore opening the core configuration and the inclusion of $n = 5$ orbitals has been intentionally avoided to keep the computational requirements to a minimum. This will definitely affect the accuracy of our results (at least for some of the transitions) but leaves room for future improvement.

To construct the configuration-interaction (CI) wave functions we have used the Hartree-Fock radial orbitals for 1s, 2s, 2p and 3s given by Clementi & Roetti (1974) for K VIII and Ti XI. The CIV3 structure code of Hibbert (1975) has been used to optimize the 3p, 3d, 4s, 4p, 4d, and 4f orbitals on the $3s3p(^1P^o)$, $3s3d(^3D^e)$, $3s4s(^3S^e)$, $3s4p(^1P^o)$, $3s4d(^3D^e)$, $3s4f(^3F^o)$ levels, respectively. The explicit form of the wave function and the optimized orbitals are presented elsewhere (e.g. Deb et al. 1999). The parameters of the optimized orbitals for K VIII and Ti XI are given in Table 1.

In our calculation, apart from the inclusion of extensive CI (as described above), relativistic effects have also been accounted for through the Breit-Pauli approximation. For an ion like Mg, for which Z is not very high, this approach leads to satisfactory results. However, in order to improve the accuracy of our results further, we have adjusted the diagonal elements of the Hamiltonian matrix to reproduce the experimental energies as close as possible. This approach, justified further recently (McPeake & Hibbert 2000), leads to a better agreement with the experimental level energies as well as with the splitting between them. Oscillator strengths, transition probabilities and lifetimes are then calculated using these adjusted energies.

3. Result and discussions

New and improved calculations have been performed for the ions K^{7+} and Ti^{10+}. Although we have calculated all the 87 fine-structure energy levels (ab initio and fine-tuned) for both the ions, only the levels belonging to the lowest five excited configurations (up to $3d^2$) are tabulated in Tables 2 and 3. The remaining fine-structure levels for both the ions are available; they can be obtained from the authors on request. For comparison we include the NIST (`http://www.nist.gov`) recommended data , the measurement of Churilov et al. (1989) and calculations of Fawcett (1983) and Fischer (2002). It is interesting to note that among the lowest 34 excited levels only the $3s3p(^1P_1)$ level shows the same value in the NIST data and the measurement of Churilov et al. (1989). For all other levels the two sets of results differ by from a few cm^{-1} to a few hundred cm^{-1}.

During our fine tuning we have adjusted our ab initio energies mostly with the NIST data wherever they are available and with the data from Churilov et al. (1989) wherever the NIST data are not available. Our adjusted energies agree fairly well with both NIST data and the measurement of Churilov et al. (1989). For only a few levels does the calculation of Fawcett (1983) or of Fischer (2002) agree better with the measurement than does ours. For example, the result of Fawcett (1983) for the $3s3p(^1P_1)$ level merges exactly with both the NIST data and the measured value of Churilov et al. (1989) for both the ions. Similarly Fischer (2002) obtained the closest agreement with the measurement for the $3p^2(^1D_2)$ level. The last column in Tables 2 and 3 represents the leading percentage of the configuration mixing. The first number in this column represents the percentage composition of the level on the same row. The next set of numbers of the form $M(N)$ indicates that the next leading percentage is $M\%$ of the level number N under the "index" column. We note from the last column of these two tables that many of the levels are either pure or almost pure and some of them couple from weakly to strongly with other levels of the

Table 2. Comparisons of fine-structure energy levels (in cm^{-1}) for K VIII. CSS: measurement of Churilov et al. (1989); NIST: (http://www.nist.gov); CFF: calculation by Fischer (2002) and BF: calculation by Fawcett (1983). (a) and (b) in the present calculation represents fine-tuned and ab initio energies respectively.

Index	Conf.	Level	NIST	CSS	Present(a)	Present(b)	CFF	BF	Leading%
1	$3s^2$	$^1S_0$	0.0	0.0	0.0	0.0			
2	3s3p	$^3P_0$	128187	128097	128299.4	126868.1	127726.2	127948	100
3		$^3P_1$	129299	129209	129407.4	127888.8	128856.2	129121	100
4		$^3P_2$	131672	131582	131781.5	130046.4	131229.9	131607	100
5		$^1P_1$	192537	192537	192406.0	195479.7	192274.5	192537	96
6	$3p^2$	$^1D_2$	300387	300317	298309.8	299295.0	300376.2	300839	74, 24(14)
7		$^3P_0$	304890	304820	304991.1	305242.9	304648.4	304642	99
8		$^3P_1$	306249	306179	306358.7	306451.2	306059.5	306064	99
9		$^3P_2$	308826	308756	308905.6	308739.2	308656.5	308780	98
10		$^1S_0$	357660	357590	357711.7	361404.2	357870.3	357581	93, 3(1)
11	3s3d	$^3D_1$	368197	368127	368330.2	370132.8	369008.5	368385	100
12		$^3D_2$	368276	368206	368409.2	370246.4	369050.1	368546	100
13		$^3D_3$	368407	368337	368540.4	370426.2	369208.3	368790	100
14		$^1D_2$	419100	419030	421488.0	427516.5	420073.3	419545	74, 24(6)
15	3p3d	$^3F_2$	503877	503770	504000.4	504139.3	504412.9	503678	97
16		$^3F_3$	505277	505184	505404.0	505462.9	505939.8	505268	100
17		$^3F_4$	507077	506945	507207.5	507086.5	507788.3	507171	100
18		$^1D_2$	510990	510993	511122.8	511537.4	511447.5	510589	97
19		$^3P_2$	535417	535330	535515.8	538121.1	535985.9	534935	86, 13(23)
20		$^3P_1$		536211	536347.1	538937.6	536938.3	535781	82,17(22)
21		$^3P_0$		537294	537447.5	539782.1	538081.1	536830	99
22		$^3D_1$		538541	538688.4	541337.9	539239.4	538229	83, 17(20)
23		$^3D_2$	538637	539020	538835.7	541848.6	539706.7	538810	86, 13(19)
24		$^3D_3$	539257	539175	539390.3	542116.7	539850.4	539102	100
25		$^1F_3$		576421	576746.9	586240.2	577665.2	584295	98
26		$^1P_1$	553620	585520	586085.0	595776.1	586834.8	589192	95, 4(5)
27	$3d^2$	$^3F_2$		742660	742805.1	745600.1	744597.8		100
28		$^3F_3$		742797	742942.4	745783.3	744812.7		100
29		$^3F_4$		742952	743097.5	746017.3	744957.3		100
30		$^1G_4$		756866	757192.6	763964.1	759202.4		97
31	$3d^2$	$^1D_2$		757420	758019.9	761765.4	759299.4		83, 14(44)
32		$^3P_0$		762399	762561.3	766306.8	764444.7		99
33		$^3P_1$		762470	762633.7	766375.2	764562.6		99
34		$^3P_2$		762534	762701.1	766483.9	764565.9		99
35		$^1S_0$		803924	804779.4	813990.0	806682.8		92, 4(63)

same J values. As an example in K^{7+}, 74% of $3p^2(^1D_2)$ couples with 24% of $3s3d(^1D_2)$ and vice versa. Similarly, in Ti^{10+}, 62% of $3p3d(^3D_1)$ strongly couples with the $^3P_1$ level of the same configuration. It is to be noted here that in Table 2 level numbers 31 and 35 have some coupling with levels 44 and 63, respectively. In the list of 87 levels, level 44 represents $3s4d(^1D_2)$ and level 63 represents $3p4p(^1S_0)$. Similarly in Table 3 level 35 is coupled with level 36 which is $3s4s(^1S_0)$ in the list of 87 levels for this ion. We note that in the present calculation we have used the same set of configurations as used by Deb & Msezane (1999) for Fe XV and Das et al. (2003) for Ni XVII.

We present our oscillator strengths f_L (length form) and f_V (velocity form) in Table 4 and also compare them with the corresponding results from other theoretical groups. Unfortunately, most of the other calculations considered only one spin allowed transition $3s^2(^1S_o) \rightarrow 3s3p(^1P_1)$. There is generally satisfactory agreement between our results and those of others. Our results in the length and the velocity forms agree within 5% which is an indication of the high accuracy of our wave function generated for the calculation. For the ion K VIII we have compared our oscillator strengths mostly with two available sets of calculations due to Fawcett (1983) and Biémont et al. (2002). While the results of Fawcett (1983) agree very well with those of ours, the results of Biémont et al. (2002) are consistently lower by a few percent. This is interesting because Fawcett (1983) included a limited number of CI only among the $n = 3$ complex, whereas Biémont et al. (2002) included a large number of configurations, promoting one of the valence electrons up to the $n = 8$ complex, while restricting the other electron within the $n = 3$ complex. However, this calculation (Biémont et al. 2002) ignored configurations such as $4f^2$, 4s4p, 4s4d, 4s4f, 4p4d, 4p4f, 4d4f etc., which are found to be important in our calculation. In order to minimize the size of the table we have presented oscillator strengths for only a few optically allowed transitions. However, we have calculated oscillator strengths for all possible allowed and intercombination transitions among the lowest 87 fine structure levels of both the ions. Results for these transitions (over eleven hundred) are available from the authors on request.

Table 3. Comparisons of fine-structure energy levels (in cm^{-1}) for Ti XI. CSS; measurement of Churilov et al. (1989); NIST: (http://www.nist.gov); CFF: calculation by Fischer (2002) and BF: calculation by Fawcett (1983). (a) and (b) in the present calculation represents fine-tuned and ab initio energies respectively.

Index	Conf.	Level	NIST	CSS	Present(a)	Present(b)	CFF	BF	Leading%
1	$3s^2$	$^1S_0$	0.0	0.0	0.0	0.0			
2	3s3p	$^3P_0$	173200	173216	173306.4	171859.6	172733.1	173087	100
3		$^3P_1$	175753	175747	175849.4	174235.1	175298.4	175710	99
4		$^3P_2$	181400	181371	181500.6	179456.4	180924.8	181525	100
5		$^1P_1$	258973	258972	258877.8	262236.9	258412.5	258973	97
6	$3p^2$	$^1D_2$	408820	408880	406925.6	407887.1	408537.6	409487	73, 22(14), 4(9)
7		$^3P_0$	410640	410610	410712.4	411237.9	410334.0	410450	99
8		$^3P_1$	415150	414132	415245.8	414412.7	414010.1	414094	100
9		$^3P_2$	420700	420667	420675.0	420309.4	420578.9	420901	94, 6(6)
10		$^1S_0$	482840	482832	482957.8	486861.3	482835.1	482687	94, 4(6)
11	3s3d	$^3D_1$	499840	499808	499965.7	502305.4	500895.0	500264	100
12		$^3D_2$	500160	500163	500285.7	502682.6	501101.0	500745	100
13		$^3D_3$	500650	500633	500775.8	503272.7	501670.3	501474	100
14		$^1D_2$	564604	564513	566852.5	573423.4	565426.2	565226	76, 21(6)
15	3p3d	$^3F_2$	683920	683850	684021.2	684746.6	684576.2	683968	93, 6(18)
16		$^3F_3$	687580	687587	687689.1	688243.5	688557.1	687997	100
17		$^3F_4$	691980	691958	692102.0	692334.1	693155.3	692615	100
18		$^1D_2$	694610	694742	694734.2	695731.5	695077.0	694567	93, 6(15)
19		$^3P_2$		724697	724947.2	728183.6	725496.8	723438	73, 26(24)
20		$^3D_1$		725636	725949.1	729096.1	726470.8	728969	62, 38(22)
21		$^3P_0$		729721	729864.4	732538.5	730786.7	728288	100
22		$^3P_1$		730362	730298.5	733328.8	731329.1	724085	62, 38(20)
23		$^3D_3$	730564	730567	730684.8	734011.7	731421.3	729485	100
24		$^3D_2$		730835	730882.0	733994.6	731724.6	729586	74, 26(19)
25		$^1F_3$		781821	782018.4	791611.8	783298.1	785934	99
26		$^1P_1$	750220	791982	792428.8	802604.3	793450.7	792598	96
27	$3d^2$	$^3F_2$		1008527	1008656.0	1012362.7	1010796		100
28		$^3F_3$		1008991	1009113.1	1012962.2	1011513		100
29		$^3F_4$		1009602	1009726.8	1013719.0	1012096		100
30		$^1D_2$		1031369	1031635.7	1038041.0	1033485		95
31	$3d^2$	$^1G_4$		1032316	1032525.1	1040011.3	1035235		99
32		$^3P_0$		1034687	1034835.9	1039749.4	1037061		99
33		$^3P_1$		1034869	1035025.8	1039972.9	1037424		99
34		$^3P_2$		1035200	1035300.8	1040470.4	1037568		97
35		$^1S_0$		1098008	1098906.9	1107333.6	1099036		89, 7(36)

In Table 4 we compare our results for the electric dipole transition $3s^2(^1S_0) \rightarrow 3s3p(^1P_1)$ for both K VIII and Ti XI with five other calculations, where the results of Safronova et al. (2000) have the least agreement with those of ours. While the present calculation and that of Safronova et al. (2000) contain similar relativistic corrections through the Breit-Pauli Hamiltonian, our calculation involves a much larger set of interacting configurations. This could mean that the relatively large differences between the two sets of results are due to the use of a large number of interacting configurations in the present calculation.

In Table 5 we present lifetimes (in nanoseconds) of some relatively longer lived levels of K^{7+} and Ti^{10+}. Comparisons are made with other available calculations and the measurements of Curtis (1991) and Biémont et al. (2002). We note that our results give excellent agreement with the measurements. On the other hand the results of Safronova et al. (2000) slightly overestimate and those of Fischer (2002) slightly underestimate the measurement of Curtis (1991), for most of the transitions in Table 5. Finally in Tables 6 and 7 we present oscillator strengths, transition probabilities and line strengths for all allowed and intercombination transitions among the levels of K VIII and Ti XI within the $n = 3$ complex only.

4. Summary and conclusion

The lowest 87 fine-structure levels of the Mg-like ions K VIII and Ti XI have been calculated. We have included large scale interacting configurations and relativistic effects such as spin-orbit, spin-spin, spin-other-orbit, mass correction and Darwin terms. All possible allowed and intercombination transitions have also been incorporated in the calculation of oscillator strengths, transition probabilities and lifetimes of these levels, but only the results of the lowest 35 levels of K^{7+} and Ti^{10+} within the $n = 3$ complex have been presented in this paper. The rest of the 87 levels and associated data for all other allowed and intercombination transitions can be obtained from the authors on request. Present results for the fine-structure

Table 4. Oscillator strengths for some dipole-allowed transitions, f_L and f_V are the present length and velocity forms. OT represents other calculations.

		K VIII			Ti XI		
I	J	f_L	f_V	OT	f_L	f_V	OT
$3s^2(^1S_0)$	$3s3p(^1P_1)$	1.1439	1.1602	1.12[a], 1.07[b]	.96513	.96619	.95[a], .918[b]
				1.177[c], 1.16[d], 1.1066[e]			.9922[c], .98[d]
$3s3p(^1P_1)$	$3s3d(^1D_2)$	1.0660	1.0904	.986[d], .9724[e]	.82693	.85534	.78[d]
$3p^2(^1S_0)$	$3p3d(^1P_1)$	1.1538	1.2008	1.10[d], .9772[e]	.88631	.92450	.85[d]
$3p^2(^3P_1)$	$3p3d(^3P_2)$	.35693	.37601	.347[d], .3040[e]	.35851	.37832	.39[d]
$3p^2(^3P_2)$	$3p3d(^3D_3)$	.64512	.69546	.62[d], .612[e]	.46764	.50580	.434[d]
$3s3p(^3P_0)$	$3p^2(^3P_1)$	.39671	.39061	.40[d], .374[e]	.33946	.32305	.34[d]
$3s3p(^3P_0)$	$3s3d(^3D_1)$	.52420	.54699	.52[d], .5116[e]	.40552	.41691	.40[d]
$3s3p(^3P_1)$	$3s3d(^3D_2)$	.39137	.41159	.386[d], .3818[e]	.30177	.31421	.30[d]
$3s3p(^3P_2)$	$3p^2(^3P_2)$	.29094	.28970	.286[d], .2704[e]	.23696	.23084	.224[d]
$3s3p(^3P_2)$	$3s3d(^3D_3)$	.43486	.46486	.428[d], .4236[e]	.33333	.35720	.33[d]

[a] Stanek et al. (1996), [b] Safronova et al. (2000), [c] Huang & Johnson (1985), [d] Fawcett (1983), [e] Biémont et al. (2002).

Table 5. Lifetimes (10^{-9}s) for some long-lived levels of K VIII and Ti XI. Superscripts a-e represent the same authors as in Table 4.

		K VIII		Ti XI		
Level	Present	OT	Expt	Present	OT	Expt
$3s3p\ (^3P_1)$	.7154E+3	$.855E+3$[b]	$.705E+3$[g]	.1355E+3	$.154E+3$[b]	$.135E+3$[g]
		$.6281E+3$[f]			$.1203E+3$[f]	
$3s3p\ (^1P_1)$	.1062	.104[a], .106[a]	.106[g], .11 ± .02[e]	.0695	.0730[b], .0726[f]	.0677[g]
		.113[b], .103[d], .1011[f]				
$3p^2\ (^1D_2)$	1.627	1.52[b], 1.2049[f]		.6199	.571[b], .4736[f]	
$3p^2\ (^3P_0)$	.1245	.117[b], .1308[f]		.0827	.0836[b], .0867[f]	
$3p^2\ (^3P_1)$	.1228	.129[b], .1289[f]		.0795	.0845[b], .0842[f]	
$3p^2\ (^3P_2)$	.1219	.124[b], .1301[f]	.14 ± .02[e]	.0813	.0838[b], .0882[f]	
$3p^2\ (^1S_0)$	.1227	.131[b], .1288[f]		.07812	.0869[b], .0821[f]	
$3s3d\ (^3D_2)$	.08439	.0898[b], .0868[f]	.08 ± .02[e]	.0597	.0628[b], .0613[f]	
$3s3d\ (^3D_3)$	.0861	.0917[b], .0885[f]		.0618	.0654[b], .0634[f]	
$3p3d\ (^3F_2)$	.4933	.544[b], .5338[f]		.2754	.293[b], .2861[f]	
$3p3d\ (^3F_3)$	.5226	.584[b], .5730[f]		.3139	.338[b], .3331[f]	
$3p3d\ (^3F_4)$	.5064	.568[b], .5579[f]		.2991	.323[b], .3182[f]	

[f] Fischer (2002), [g] Curtis (1991).

levels, oscillator strengths and lifetimes show good agreement with recent measurements. It is concluded that the interactions among the various excited configurations within the $n = 3$ and $n = 4$ complexes are of crucial importance to obtain accurate results.

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Table 6. Oscillator strengths (f_L and f_V), transition probabilities (A_L) and line strengths (LST) for allowed and intercombination transitions of K^{7+} among levels of $n = 3$ complex. I and J are initial and final state of the transition as labeled in "Index" column in Table 2.

I	J	f_L	f_V	A_L	LST
1	3	.37544E-03	.93841E-03	.13979E+07	.95512E-03
1	5	.11439E+01	.11602E+01	.94155E+10	.19572E+01
1	20	.33848E-07	.90269E-07	.21649E+04	.20776E-07
1	22	.17842E-06	.20798E-06	.11512E+05	.10904E-06
1	26	.35271E-02	.27536E-02	.26938E+09	.19812E-02
2	8	.39671E+00	.39061E+00	.27966E+10	.73347E+00
2	11	.52420E+00	.54699E+00	.67151E+10	.71896E+00
2	33	.22825E-03	.72609E-04	.20420E+08	.11846E-03
3	6	.34577E-02	.31784E-02	.39478E+08	.20218E-01
3	7	.13010E+00	.13154E+00	.80263E+10	.73180E+00
3	8	.98492E-01	.98092E-01	.20571E+10	.54972E+00
3	9	.16310E+00	.15888E+00	.21031E+10	.89741E+00
3	10	.13985E-03	.10730E-03	.14586E+08	.60499E-03
3	11	.13044E+00	.13714E+00	.49667E+10	.53920E+00
3	12	.39137E+00	.41159E+00	.89472E+10	.16173E+01
3	14	.49456E-03	.35202E-03	.16886E+08	.16723E-02
3	27	.54466E-08	.52810E-09	.82016E+03	.87696E-08
3	31	.17308E-04	.17256E-04	.27371E+07	.27193E-04
3	32	.62668E-04	.18878E-04	.50272E+08	.97754E-04
3	33	.45773E-04	.12670E-04	.12242E+08	.71392E-04
3	34	.97424E-04	.31032E-04	.15638E+08	.15193E-03
3	35	.60671E-06	.12304E-06	.55377E+06	.88723E-06
4	6	.42881E-02	.48131E-02	.79321E+08	.42386E-01
4	8	.96905E-01	.99259E-01	.32833E+10	.91370E+00
4	9	.29094E+00	.28970E+00	.60884E+10	.27038E+01
4	11	.51749E-02	.55295E-02	.32191E+09	.36010E-01
4	12	.77680E-01	.83012E-01	.29012E+10	.54037E+00
4	13	.43486E+00	.46486E+00	.11614E+11	.30234E+01
4	14	.13782E-04	.54774E-05	.77154E+06	.78307E-04
4	27	.13980E-08	.52157E-12	.34814E+03	.37661E-08
4	28	.81194E-08	.41831E-09	.14449E+04	.21868E-07
4	31	.25719E-06	.18918E-06	.67277E+05	.67602E-06
4	33	.41694E-04	.12283E-04	.18447E+08	.10879E-03
4	34	.13351E-03	.37323E-04	.35449E+08	.34833E-03
5	6	.11047E+00	.86288E-01	.49586E+09	.10302E+01
5	7	.12520E-03	.18145E-03	.31755E+07	.10983E-02
5	8	.31592E-04	.82456E-04	.27363E+06	.27381E-03
5	9	.21859E-02	.14484E-02	.11873E+08	.18531E-01
5	10	.14877E+00	.14604E+00	.81348E+10	.88884E+00
5	11	.52336E-04	.99788E-04	.10804E+07	.29381E-03
5	12	.10986E-03	.18352E-03	.13619E+07	.61648E-03
5	14	.10660E+01	.10904E+01	.22388E+11	.45958E+01
5	27	.53021E-06	.74911E-06	.64284E+05	.95141E-06
5	31	.26786E-01	.19519E-01	.34296E+10	.46772E-01
5	32	.47118E-06	.21133E-06	.30650E+06	.81619E-06
5	33	.25880E-07	.20307E-07	.56132E+04	.44824E-07
5	34	.67883E-04	.48197E-04	.88359E+07	.11756E-03
5	35	.26064E-03	.17608E-04	.19558E+09	.42036E-03
6	15	.76304E-02	.80233E-02	.21534E+09	.61063E-01
6	16	.13895E-03	.20043E-03	.28393E+07	.11044E-02
6	18	.31577E+00	.31320E+00	.95390E+10	.24424E+01
6	19	.11596E-03	.14416E-03	.43520E+07	.80469E-03
6	20	.58003E-03	.53843E-03	.36537E+08	.40110E-02
6	22	.61736E-03	.62088E-03	.39657E+08	.42275E-02
6	23	.36324E-02	.35871E-02	.14017E+09	.24859E-01
6	24	.13467E-01	.13954E-01	.37290E+09	.91951E-01
6	25	.37657E+00	.39971E+00	.13909E+11	.22262E+01
6	26	.47709E-02	.39092E-02	.43924E+09	.27289E-01
7	20	.72150E+00	.74703E+00	.85866E+10	.10267E+01
7	22	.34964E+00	.37608E+00	.42457E+10	.49254E+00
7	26	.81706E-03	.57160E-03	.14354E+08	.95693E-03

Table 6. continued.

I	J	f_L	f_V	A_L	LST
8	15	.19455E-03	.26941E-03	.30414E+07	.97219E-03
8	18	.72450E-03	.90072E-03	.12157E+08	.34945E-02
8	19	.35693E+00	.37601E+00	.75015E+10	.15383E+01
8	20	.33859E-02	.28441E-02	.11946E+09	.14540E-01
8	21	.93528E-01	.94805E-01	.99946E+10	.39972E+00
8	22	.26433E+00	.27795E+00	.95171E+10	.11237E+01
8	23	.34809E+00	.37490E+00	.75291E+10	.14788E+01
8	26	.66277E-04	.58361E-04	.34592E+07	.23401E-03
9	15	.48057E-05	.15846E-05	.12201E+06	.40547E-04
9	16	.41046E-03	.56396E-03	.75510E+07	.34384E-02
9	18	.32739E-02	.33180E-02	.89298E+08	.26650E-01
9	19	.89734E-01	.91121E-01	.30737E+10	.65181E+00
9	20	.40786E-01	.41989E-01	.23456E+10	.29518E+00
9	22	.35330E-01	.37093E-01	.20738E+10	.25309E+00
9	23	.23305E+00	.24762E+00	.82182E+10	.16684E+01
9	24	.64512E+00	.69546E+00	.16328E+11	.46073E+01
9	25	.81269E-02	.89989E-02	.27778E+09	.49945E-01
9	26	.94745E-04	.63564E-04	.80923E+07	.56265E-03
10	20	.23136E-03	.42109E-03	.16415E+07	.42638E-03
10	22	.12390E-03	.25268E-03	.90228E+06	.22538E-03
10	26	.11538E+01	.12008E+01	.13379E+11	.16633E+01
11	15	.20171E+00	.22856E+00	.14859E+10	.14684E+01
11	18	.50937E-02	.51861E-02	.41566E+08	.35231E-01
11	19	.88180E-03	.12093E-02	.98642E+07	.52092E-02
11	20	.35448E-02	.12864E-02	.66748E+08	.20837E-01
11	21	.78235E-01	.59916E-01	.44776E+10	.45689E+00
11	22	.20870E+00	.18757E+00	.40401E+10	.12099E+01
11	23	.59675E-01	.54459E-01	.69433E+09	.34566E+00
11	26	.53292E-04	.38523E-04	.16855E+07	.24171E-03
12	15	.25283E-01	.29023E-01	.31006E+09	.30693E+00
12	16	.18519E+00	.20594E+00	.16559E+10	.22251E+01
12	18	.50558E-03	.58763E-03	.68686E+07	.58314E-02
12	19	.15010E-02	.39580E-03	.27958E+08	.14785E-01
12	20	.13439E+00	.10885E+00	.42135E+10	.13172E+01
12	22	.60190E-03	.13984E-02	.19402E+08	.58185E-02
12	23	.17300E+00	.15751E+00	.33517E+10	.16709E+01
12	24	.37015E-01	.34057E-01	.51556E+09	.35635E+00
12	25	.36009E-04	.20699E-04	.74466E+06	.28450E-03
12	26	.12133E-03	.66446E-04	.63911E+07	.91749E-03
13	15	.52671E-03	.61929E-03	.90254E+07	.89605E-02
13	16	.19758E-01	.22476E-01	.24686E+09	.33268E+00
13	17	.19794E+00	.21564E+00	.19746E+10	.32895E+01
13	18	.42900E-03	.44938E-03	.81443E+07	.69337E-02
13	19	.16085E+00	.12959E+00	.41880E+10	.22199E+01
13	23	.17296E-05	.23708E-03	.46841E+05	.23405E-04
13	24	.17834E+00	.16737E+00	.34724E+10	.24055E+01
13	25	.18657E-03	.11813E-03	.53948E+07	.20650E-02
14	15	.82285E-03	.33928E-03	.37368E+07	.16415E-01
14	16	.91093E-04	.35137E-03	.30563E+06	.17868E-02
14	18	.37787E-01	.13806E-01	.20251E+09	.69392E+00
14	19	.80404E-04	.61239E-05	.69733E+06	.11607E-02
14	20	.63213E-04	.53647E-04	.92710E+06	.90591E-03
14	22	.57081E-04	.65278E-04	.87164E+06	.80169E-03
14	23	.63633E-06	.70927E-05	.58449E+04	.89259E-05
14	24	.12829E-03	.23658E-03	.84969E+06	.17911E-02
14	25	.56670E+00	.73711E+00	.65085E+10	.60082E+01
14	26	.18116E+00	.12107E+00	.54563E+10	.18117E+01
15	27	.21315E+00	.20833E+00	.81081E+10	.14692E+01
15	28	.21381E-01	.21173E-01	.58159E+09	.14729E+00
15	31	.78289E-02	.72390E-02	.33696E+09	.50732E-01
15	33	.30590E-04	.18045E-04	.22748E+07	.19469E-03
15	34	.16270E-04	.86919E-05	.72632E+06	.10352E-03

Table 6. continued.

I	J	f_L	f_V	A_L	LST
16	27	.19097E-01	.18858E-01	.10051E+10	.18538E+00
16	28	.20493E+00	.20194E+00	.77130E+10	.19881E+01
16	29	.13978E-01	.14078E-01	.40972E+09	.13552E+00
16	30	.17068E-03	.11699E-03	.56136E+07	.15621E-02
16	31	.30251E-04	.17087E-04	.18027E+07	.27596E-03
16	34	.11869E-03	.75016E-04	.73376E+07	.10630E-02
17	28	.14759E-01	.14751E-01	.70337E+09	.18550E+00
17	29	.22161E+00	.22120E+00	.82252E+10	.27835E+01
17	30	.22259E-04	.20144E-04	.92785E+06	.26382E-03
18	27	.44251E-02	.44825E-02	.15843E+09	.31440E-01
18	28	.16615E-03	.18950E-03	.42542E+07	.11798E-02
18	31	.35498E+00	.34226E+00	.14434E+11	.23666E+01
18	33	.50142E-03	.37812E-03	.35262E+08	.32816E-02
18	34	.24223E-04	.93971E-05	.10226E+07	.15849E-03
19	27	.66215E-02	.71710E-02	.18978E+09	.52581E-01
19	28	.59761E-01	.65075E-01	.12251E+10	.47424E+00
19	31	.35601E-04	.59492E-04	.11757E+07	.26337E-03
19	33	.20681E+00	.18207E+00	.11859E+11	.14989E+01
19	34	.27702E+00	.26091E+00	.95371E+10	.20071E+01
20	27	.83958E-01	.92119E-01	.14323E+10	.40163E+00
20	31	.69008E-03	.52909E-03	.13571E+08	.30746E-02
20	32	.24518E+00	.21839E+00	.25106E+11	.10704E+01
20	33	.56990E-01	.56681E-01	.19465E+10	.24873E+00
20	34	.16475E+00	.15420E+00	.33782E+10	.71884E+00
20	35	.16468E-03	.92062E-04	.23745E+08	.60590E-03
21	33	.53529E+00	.49987E+00	.60352E+10	.78257E+00
22	27	.40496E+00	.45295E+00	.67525E+10	.19594E+01
22	31	.45573E-04	.73355E-04	.87741E+06	.20521E-03
22	32	.44549E-02	.19056E-02	.44679E+09	.19653E-01
22	33	.12917E+00	.10916E+00	.43209E+10	.56966E+00
22	34	.61831E-01	.55825E-01	.12418E+10	.27260E+00
22	35	.11710E-03	.72056E-04	.16591E+08	.43463E-03
23	27	.43071E-01	.47976E-01	.11953E+10	.34759E+00
23	28	.37974E+00	.42478E+00	.75374E+10	.30625E+01
23	31	.97629E-04	.84373E-04	.31285E+07	.73319E-03
23	33	.23107E-01	.14945E-01	.12866E+10	.16995E+00
23	34	.15752E+00	.13722E+00	.52657E+10	.11582E+01
24	27	.86648E-03	.96325E-03	.33481E+08	.98163E-02
24	28	.34068E-01	.38022E-01	.94155E+09	.38570E+00
24	29	.45244E+00	.50811E+00	.97402E+10	.51183E+01
24	30	.12536E-03	.10006E-03	.30851E+07	.13264E-02
24	31	.29373E-03	.22790E-03	.13111E+08	.30961E-02
24	34	.12541E+00	.97868E-01	.58403E+10	.12942E+01
25	27	.23980E-04	.27337E-04	.61749E+06	.33278E-03
25	28	.98476E-04	.16246E-03	.18143E+07	.13655E-02
25	29	.39178E-04	.66981E-04	.56246E+06	.54274E-03
25	30	.52736E+00	.64327E+00	.89084E+10	.67349E+01
25	31	.23108E-01	.21086E-01	.70909E+09	.29377E+00
25	34	.13580E-03	.15378E-03	.43853E+07	.16829E-02
26	27	.11617E-03	.24833E-03	.11419E+07	.73209E-03
26	31	.28770E+00	.27919E+00	.34037E+10	.16526E+01
26	32	.86093E-04	.11114E-03	.53654E+07	.48181E-03
26	33	.97306E-09	.48589E-06	.20231E+02	.54434E-08
26	34	.62425E-03	.62183E-03	.77931E+07	.34908E-02
26	35	.32331E+00	.23293E+00	.30943E+11	.14601E+01

Table 7. Oscillator strengths (f_L and f_V), transition probabilities (A_L) and line strengths (LST) for allowed and intercombination transitions in Ti^{10+} among its levels of $n = 3$ complex. I and J are initial and final states of the transition as labeled under the "Index" column in Table 3.

I	J	f_L	f_V	A_L	LST
1	3	.10731E-02	.24859E-02	.73783E+07	.20090E-02
1	5	.96513E+00	.96619E+00	.14381E+11	.12273E+01
1	20	.56995E-07	.61194E-06	.66783E+04	.25847E-07
1	22	.31428E-06	.81649E-07	.37268E+05	.14167E-06
1	26	.18525E-02	.12782E-02	.25864E+09	.76961E-03
2	8	.33946E+00	.32305E+00	.44180E+10	.46191E+00
2	11	.40552E+00	.41691E+00	.96211E+10	.40869E+00
2	33	.15207E-03	.52096E-04	.25107E+08	.58097E-04
3	6	.10755E-01	.96835E-02	.22984E+09	.45968E-01
3	7	.10937E+00	.10978E+00	.12072E+11	.45992E+00
3	8	.83801E-01	.81219E-01	.32035E+10	.34572E+00
3	9	.13216E+00	.12470E+00	.31704E+10	.53314E+00
3	10	.34678E-03	.27468E-03	.65448E+08	.11152E-02
3	11	.10047E+00	.10463E+00	.70398E+10	.30615E+00
3	12	.30177E+00	.31421E+00	.12712E+11	.91864E+00
3	14	.11975E-02	.86134E-03	.73270E+08	.30248E-02
3	27	.27264E-07	.97323E-09	.75678E+04	.32333E-07
3	30	.15859E-04	.76374E-05	.46482E+07	.18302E-04
3	32	.38925E-04	.13403E-04	.57473E+08	.44755E-04
3	33	.37569E-04	.13330E-04	.18498E+08	.43186E-04
3	34	.51667E-04	.16277E-04	.15274E+08	.59373E-04
3	35	.22711E-05	.73009E-05	.38721E+07	.24300E-05
4	6	.13258E-01	.14421E-01	.44940E+09	.96810E-01
4	8	.81545E-01	.82874E-01	.49531E+10	.57425E+00
4	9	.23696E+00	.23084E+00	.90416E+10	.16308E+01
4	11	.39602E-02	.42476E-02	.44651E+09	.20469E-01
4	12	.59546E-01	.63825E-01	.40364E+10	.30747E+00
4	13	.33333E+00	.35720E+00	.16189E+11	.17185E+01
4	14	.30581E-04	.11827E-04	.30291E+07	.13063E-03
4	27	.72032E-08	.93834E-09	.32873E+04	.14335E-07
4	28	.63790E-07	.72002E-08	.20817E+05	.12687E-06
4	30	.73169E-06	.28099E-06	.35273E+06	.14167E-05
4	33	.21373E-04	.65388E-05	.17310E+08	.41219E-04
4	34	.88546E-04	.29124E-04	.43055E+08	.17071E-03
5	6	.10644E+00	.91865E-01	.93372E+09	.71007E+00
5	7	.31567E-03	.40664E-03	.14562E+08	.20533E-02
5	8	.91726E-04	.21555E-03	.14960E+07	.57935E-03
5	9	.79182E-02	.58803E-02	.82959E+08	.48334E-01
5	10	.12674E+00	.11623E+00	.12735E+11	.55861E+00
5	11	.13362E-03	.24960E-03	.51804E+07	.54738E-03
5	12	.21820E-03	.37587E-03	.50893E+07	.89269E-03
5	14	.82693E+00	.85534E+00	.31390E+11	.26519E+01
5	27	.15677E-06	.44329E-06	.35270E+05	.20650E-06
5	30	.26481E-02	.16599E-02	.63286E+09	.33844E-02
5	32	.12227E-06	.37336E-06	.14732E+06	.15562E-06
5	33	.10476E-08	.78347E-10	.42095E+03	.13331E-08
5	34	.89072E-04	.52144E-04	.21490E+08	.11330E-03
5	35	.24951E-02	.41680E-02	.35233E+10	.29335E-02
6	15	.15772E-01	.16700E-01	.80779E+09	.93692E-01
6	16	.50569E-03	.73123E-03	.18992E+08	.29648E-02
6	18	.22975E+00	.22771E+00	.12694E+11	.13140E+01
6	19	.26288E-05	.11092E-04	.17734E+06	.13606E-04
6	20	.27753E-03	.22982E-03	.31402E+08	.14320E-02
6	22	.30455E-02	.29653E-02	.35404E+09	.15502E-01
6	23	.36159E-01	.37779E-01	.18058E+10	.18384E+00
6	24	.10540E-01	.10438E-01	.73784E+09	.53555E-01
6	25	.26507E+00	.29043E+00	.17769E+11	.11632E+01
6	26	.25938E-02	.23322E-02	.42854E+09	.11075E-01

Table 7. continued.

I	J	f_L	f_V	A_L	LST
7	20	.81500E+00	.83992E+00	.18007E+11	.85113E+00
7	22	.12577E-01	.15708E-01	.28561E+09	.12956E-01
7	26	.17757E-02	.12382E-02	.57527E+08	.15315E-02
8	15	.34560E-03	.48089E-03	.99920E+07	.12699E-02
8	18	.22775E-02	.28028E-02	.71200E+08	.80481E-02
8	19	.35851E+00	.37832E+00	.13762E+11	.11433E+01
8	20	.26355E-01	.30055E-01	.16971E+10	.83775E-01
8	21	.72492E-01	.72188E-01	.14359E+11	.22756E+00
8	22	.17966E+00	.18473E+00	.11895E+11	.56320E+00
8	24	.18115E+00	.19497E+00	.72228E+10	.56682E+00
8	26	.15048E-03	.13126E-03	.14280E+08	.39402E-03
9	15	.23694E-03	.21207E-03	.10960E+08	.14810E-02
9	16	.95589E-03	.12913E-02	.32470E+08	.58928E-02
9	18	.91422E-02	.93143E-02	.45802E+09	.54910E-01
9	19	.37817E-01	.37269E-01	.23354E+10	.20458E+00
9	20	.63546E-02	.63364E-02	.65836E+09	.34264E-01
9	22	.50020E-01	.51776E-01	.53309E+10	.26592E+00
9	23	.46764E+00	.50580E+00	.21413E+11	.24830E+01
9	24	.20426E+00	.21512E+00	.13111E+11	.10839E+01
9	25	.21199E-01	.24242E-01	.13188E+10	.96570E-01
9	26	.18221E-03	.13478E-03	.27995E+08	.80679E-03
10	20	.72611E-03	.13525E-02	.95325E+07	.98376E-03
10	22	.31224E-04	.76316E-04	.42472E+06	.41559E-04
10	26	.88631E+00	.92450E+00	.18873E+11	.94285E+00
11	15	.16639E+00	.18136E+00	.22558E+10	.89284E+00
11	18	.11662E-01	.11376E-01	.17706E+09	.59136E-01
11	19	.49618E-02	.52053E-02	.10051E+09	.21782E-01
11	20	.21256E-01	.23885E-01	.72407E+09	.92897E-01
11	21	.65226E-01	.53306E-01	.68985E+10	.28021E+00
11	22	.15692E+00	.13945E+00	.55532E+10	.67285E+00
11	24	.50244E-01	.45793E-01	.10722E+10	.21489E+00
11	26	.13567E-03	.10119E-03	.77407E+07	.45815E-03
12	15	.22871E-01	.25533E-01	.51501E+09	.20490E+00
12	16	.15987E+00	.16852E+00	.26752E+10	.14042E+01
12	18	.12350E-02	.13839E-02	.31148E+08	.10455E-01
12	19	.62865E-03	.13338E-02	.21164E+08	.46060E-02
12	20	.93667E-01	.84154E-01	.53027E+10	.68324E+00
12	22	.18226E-01	.13155E-01	.10720E+10	.13043E+00
12	23	.35421E-01	.32608E-01	.89584E+09	.25306E+00
12	24	.14459E+00	.13281E+00	.51285E+10	.10321E+01
12	25	.13109E-03	.81691E-04	.49576E+07	.76591E-03
12	26	.31455E-03	.18257E-03	.29845E+08	.17723E-02
13	15	.40061E-03	.46223E-03	.12562E+08	.50380E-02
13	16	.19633E-01	.21650E-01	.45753E+09	.24206E+00
13	17	.17606E+00	.17973E+00	.33436E+10	.21206E+01
13	18	.12879E-02	.13993E-02	.45245E+08	.15302E-01
13	19	.12862E+00	.11266E+00	.60357E+10	.13222E+01
13	23	.14709E+00	.14081E+00	.51861E+10	.14743E+01
13	24	.33095E-02	.18564E-02	.16364E+09	.33144E-01
13	25	.48687E-03	.31716E-03	.25687E+08	.39894E-02
14	15	.21490E-02	.14126E-02	.19679E+08	.30190E-01
14	16	.26429E-03	.84552E-03	.18386E+07	.36002E-02
14	18	.35804E-01	.20861E-01	.39056E+09	.46086E+00
14	19	.29262E-03	.78929E-04	.48785E+07	.30467E-02
14	20	.28364E-03	.30362E-03	.79815E+07	.29346E-02
14	22	.18827E-04	.32295E-04	.55915E+06	.18961E-03
14	23	.31983E-03	.51471E-03	.40901E+07	.32134E-02
14	24	.58901E-05	.24223E-05	.10571E+06	.59108E-04
14	25	.49154E+00	.58697E+00	.10842E+11	.37604E+01
14	26	.14349E+00	.10627E+00	.81172E+10	.10471E+01

Table 7. continued.

I	J	f_L	f_V	A_L	LST
15	27	.16004E+00	.15758E+00	.11250E+11	.81148E+00
15	28	.13266E-01	.13455E-01	.66796E+09	.67171E-01
15	30	.17706E-01	.16599E-01	.14271E+10	.83843E-01
15	33	.30235E-04	.18217E-04	.41412E+07	.14179E-03
15	34	.78374E-04	.97932E-04	.64509E+07	.36725E-03
16	27	.14555E-01	.14620E-01	.14002E+10	.10450E+00
16	28	.15853E+00	.15855E+00	.10925E+11	.11366E+01
16	29	.74258E-02	.78803E-02	.39953E+09	.53139E-01
16	30	.16204E-03	.90547E-04	.17901E+08	.10857E-02
16	31	.48714E-03	.32473E-03	.30052E+08	.32555E-02
16	34	.23341E-03	.16509E-03	.26338E+08	.15474E-02
17	28	.11111E-01	.11405E-01	.95760E+09	.10385E+00
17	29	.16694E+00	.17087E+00	.11234E+11	.15573E+01
17	31	.60068E-04	.55078E-04	.46433E+07	.52281E-03
18	27	.86631E-02	.88273E-02	.56946E+09	.45425E-01
18	28	.14522E-03	.19709E-03	.68381E+07	.76036E-03
18	30	.29765E+00	.29226E+00	.22535E+11	.14543E+01
18	33	.14364E-02	.11289E-02	.18492E+09	.69482E-02
18	34	.24108E-02	.26132E-02	.18651E+09	.11652E-01
19	27	.95783E-02	.10036E-01	.51425E+09	.55573E-01
19	28	.95774E-01	.10157E+00	.36847E+10	.55478E+00
19	30	.48455E-03	.34303E-03	.30400E+08	.26007E-02
19	33	.16825E+00	.15238E+00	.17985E+11	.89316E+00
19	34	.15890E+00	.15451E+00	.10209E+11	.84278E+00
20	27	.24933E+00	.26636E+00	.79753E+10	.87103E+00
20	30	.27952E-02	.22862E-02	.10453E+09	.90309E-02
20	32	.16590E+00	.14917E+00	.31674E+11	.53045E+00
20	33	.16656E-02	.24974E-02	.10613E+09	.53223E-02
20	34	.43136E-01	.42370E-01	.16521E+10	.13772E+00
20	35	.48869E-03	.29111E-03	.13602E+09	.12941E-02
21	33	.40581E+00	.39449E+00	.84024E+10	.43779E+00
22	27	.14981E+00	.16438E+00	.46456E+10	.53154E+00
22	30	.44051E-02	.43739E-02	.16009E+09	.14438E-01
22	32	.22445E-01	.24691E-01	.41655E+10	.72791E-01
23	27	.54912E-03	.58624E-03	.39622E+08	.45524E-02
23	28	.24720E-01	.26596E-01	.12782E+10	.20460E+00
23	29	.37083E+00	.40558E+00	.14980E+11	.30625E+01
23	30	.35025E-02	.28118E-02	.29623E+09	.26820E-01
23	31	.32728E-03	.24495E-03	.15469E+08	.24987E-02
23	34	.89281E-01	.75804E-01	.77363E+10	.67543E+00
24	27	.27987E-01	.30492E-01	.14404E+10	.16585E+00
24	28	.26373E+00	.28976E+00	.97273E+10	.15603E+01
24	30	.27447E-02	.25178E-02	.16560E+09	.15022E-01
24	33	.40576E-02	.23143E-02	.41727E+09	.21960E-01
24	34	.16805E+00	.15700E+00	.10388E+11	.90868E+00
25	27	.83635E-04	.84949E-04	.40117E+07	.85041E-03
25	28	.22846E-03	.37901E-03	.78589E+07	.23183E-02
25	29	.78132E-04	.13629E-03	.21018E+07	.79072E-03
25	30	.41032E-01	.24966E-01	.23875E+10	.37881E+00
25	31	.45993E+00	.52700E+00	.14974E+11	.42310E+01
25	34	.21221E-02	.15110E-02	.12713E+09	.19308E-01
26	27	.22284E-03	.47673E-03	.41697E+07	.10178E-02
26	30	.23795E+00	.24888E+00	.54492E+10	.98245E+00
26	32	.18525E-03	.25882E-03	.21782E+08	.75476E-03
26	33	.42205E-06	.22534E-05	.16568E+05	.17182E-05
26	34	.84364E-02	.89593E-02	.19916E+09	.34306E-01
26	35	.20919E+00	.16318E+00	.39319E+11	.67412E+00