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Oscillator Strengths and Transition Probabilities
for the Intercombination Transitions in Fe XXII

by

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Abstract: Oscillator strengths and transition probabilities are evaluated for the intercombination transitions between the $2s^2 2p$, $2s 2p^2$ and $2p^3$ states of Fe XXII using configuration interaction wavefunctions. We have also calculated the fine-structure splittings. Some significant differences with previous calculations are obtained.

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1. Introduction

In the analysis of the solar flame spectrum 171-630 Å, observed from Skylab mission 1973, new solar identifications and wavelengths in the lithium, beryllium and boron sequences were proposed by Sandlin et al 1976. In the boron sequence they found that the $2s^2 2p^2 P_J^0 \rightarrow 2s 2p^2 4P_J$ transitions of N III and O IV were strong in the solar spectrum. They also noted from the trend of the sequence that the $2s^2 2p^2 P_J^0 \rightarrow 2s 2p^2 4P_J$ transitions of Fe XXII should lie between 240 and 400 Å. They have listed as tentative the five lines associated with the transition.

Dankwort and Trefftz (1978), using the multiconfigurational Hartree-Fock method, have calculated the weighted oscillator strengths and transition probabilities for the intercombination transitions $2s^2 2p^2 P_J^0 \rightarrow 2s 2p^2 4P$ for S XII up to Fe XXII. They used, where possible, the observed values for the energy differences of the two states in a transition.

The present investigation extends these studies for Fe XXII by considering intercombination transitions between the $2s^2 2p$, $2s 2p^2$ and $2p^3$ states. We have also looked at the fine-structure splittings of the $2s^2 2p^2 P_J^0$, $2s 2p^2 2P_J$, $2p^3 2P_J^0$ ($J = 1/2, 3/2$), $2s 2p^2 4P_J$ ($J = 1/2, 3/2, 5/2$), $2s 2p^2 2D_J$ and $2p^3 2D_J^0$ ($J = 3/2, 5/2$) levels. Unfortunately at present there are still no experimental results for comparison.

2. Method of Calculation

2.1. *Radial functions*

The radial functions used in the final calculation were determined in an LS coupled representation of the atomic states. We chose the $1s$, $2s$, $2p$ functions as the Hartree-Fock functions of the $1s^2 2s^2 2p^2 P^0$ state (Clementi and Roetti 1974). We saw in our consideration of allowed

transitions (Glass 1979a) that a reasonably accurate transition probability could be obtained by using a 3d correlation orbital and by including all possible configurations keeping the $1s^2$ core fixed. As a starting point we adopt the same procedure here. The 3d function was optimized on the $2s^2 2p^2 P^0$ state.

2.2. Transition probabilities

In evaluating the transition probabilities of intercombination lines it is necessary to include the J-dependent spin-orbit, spin-other-orbit and spin-spin interactions in the final Hamiltonian. Hence we have to use a J-dependent configuration interaction expansion which takes the form

$$\Psi(J, M_J) = \sum_j a_j \phi_j(\alpha_j L_j S_j J M_J) \quad (1)$$

where $\{\phi_j\}$ denotes a set of single-configuration wavefunctions, $\{\alpha_j\}$ defines the coupling of the angular momenta of the electrons,

$$\underline{J} = \underline{L} + \underline{S} \quad (2)$$

for each j , and $\{a_j\}$ are determined as the components of the appropriate eigenvector of the Hamiltonian matrix with basis $\{\phi_j\}$. The Hamiltonian consists of the normal non-relativistic terms plus the one-electron operators for the mass correction, Darwin contact term, nuclear spin-orbit interaction and the two electron operators for the spin-other-orbit and spin-spin interactions.

We have evaluated the coefficients $\{a_j\}$ using the computer code CIV3 (Glass and Hibbert 1979) where the code was adapted to include these relativistic effects: each is expressed as a product of irreducible terms whose matrix elements are calculated using Racah algebra techniques (Fano et al 1963).

Using these configuration interaction wavefunctions we evaluated the emission electric dipole transition probabilities.

3. Results and Discussion

In table 1 a list of configurations used in each state is given. The first eight wavefunctions are LS coupled and are used in the expansions for the last fifteen intermediate-coupled wavefunctions. The eigenvector for each eigenstate are given together with the corresponding eigenvalues in tables 2 and 3. The ordering is given by table 1. In obtaining the eigenvectors in table 2 the one-electron operators for the mass-correction, Darwin contact term and the nuclear spin-orbit interaction plus the non-relativistic terms are included in the Hamiltonian, while in table 3 the two-body-operators for the spin-other-orbit and spin-spin interactions are also included. We have also used the definition of spherical harmonics given by Fano and Racah (1959) which includes a factor of i^l to give time reversal invariance.

From table 3 we see that when the two-body J-dependent operators are included in the Hamiltonian the lower J-levels of the state are raised and the upper J-levels are lowered. For example, for the $2s\ 2p^2\ ^4P$ state the $J = 1/2$ and $3/2$ levels are raised by 0.056 au and 0.022 au respectively, the $J = 5/2$ level is lowered by 0.012 au when the two-body J-dependent terms are included in the Hamiltonian. Also from table 2 and 3 we see that when the two body relativistic terms are omitted there is usually not always a stronger mixing between the different states of a particular J-level.

Fine-structure splittings of the $2s\ 2p\ ^2P_J^0$, $2s\ 2p^2\ ^2P_J$, $2p^3\ ^2P_J^0$ ($J = 1/2, 3/2$), $2s\ 2p^2\ ^4P_J$ ($J = 1/2, 3/2, 5/2$), $2s\ 2p^2\ ^2D_J$ and $2p^3\ ^2D_J^0$ ($J = 3/2, 5/2$) levels are given in table 4. Dankwort and Trefftz (1978)

have calculated the fine-structure splittings for the $2s^2 2p^2 P^0$, $2s 2p^2 D$, $2s^2 2p^2 P^0$ and $2s 2p^2 P$ states of the boron sequence up to Fe XXII. They found that the simpler calculation (including the one-electron relativistic operators plus the non-relativistic term in the Hamiltonian) described the fine-structure splitting about as well as the full Breit-Pauli calculation. However, from our calculations of the fine-structure splitting for the $n = 2$ states of Fe XXII, table 4, we see that they can change by as much as 25% when the two body J-dependent operators are included in the Hamiltonian. Unfortunately they (Dankwort and Treffitz) do not provide any results for us to compare our calculations with.

In tables 5-8 we present our results for the corresponding oscillator strengths, theoretical values of $\{AE\}$, the energy difference of the two states in a transition, wavelength $\{A\}$ and transition probabilities $\{A\}$ calculated using the length form for intercombination transitions between the $n = 2$ levels. The energy differences $E(2P_J^0 \rightarrow 4P_J)$, calculation a: table 5, determined by including the one-electron relativistic operators in the Hamiltonian are in fairly good agreement with the observed values of Facwett (1975) and the tentative observations of Sandbin et al (1976). The agreement is within 5% of the observed values. The agreement with the observed values is enhanced by also including the spin-other orbit and spin-spin interactions in the Hamiltonian, the accuracy is within 1 1/2% of the observed values.

For the intercombination transition $2s 2p^3 P_1^0 \rightarrow 2s^2 1S_0$ in the beryllium sequence we found (Glass 1979b) that it was necessary to include the two-electron operators, spin-other-orbit and spin-spin interactions as well as the one-electron relativistic operators in the Hamiltonian.

This was because the intercombination transition probability was highly sensitive to the values of very small coefficients in the configuration interaction expression of the wavefunctions. From tables 5-8 we see that this is also the case for Fe XXII.

For the intercombination transitions $2s^2 2p^2 P_J^0 \rightarrow 2s 2p^2 4P_J$, it is seen that the transition $J = 3/2 \rightarrow J' = 3/2$ is the weakest in the multiplet. The agreement with the theoretical calculation of Dankwort and Treffitz (1978) calculation e: table 5, is very good. Where there is disagreement between our results and those of Dankwort and it is worth noting that in their calculations of oscillator strengths and transition probabilities they have used, where possible, the observed values for the energy differences of the two states in a transition.

From table 6 it is seen that the wavelengths of the intercombination transitions $2s 2p^2 2L_J \rightarrow 2p^3 4S_J^0$, ($L = 0, 1, 2$) lies within the spectral range $195 \text{ \AA}$ to $390 \text{ \AA}$. The transitions $2s 2p^2 2P_{1/2} \rightarrow 2p^3 4S_{3/2}^0$ and $2s 2p^2 2D_{3/2} \rightarrow 2p^3 4S_{3/2}^0$ are the strongest. The transition probabilities are $1.14 \times 10^8 \text{ Sec}^{-1}$ and $1.28 \times 10^8 \text{ Sec}^{-1}$ respectively. For the intercombination transitions $2s 2p^2 4P_J \rightarrow 2p^3 2D_J^0$, (table 7) the $J = 3/2 \rightarrow J' = 3/2$ and $J = 5/2 \rightarrow J' = 5/2$ transitions are the strongest. The transition probabilities are $21.10 \times 10^8 \text{ Sec}^{-1}$ and $17.94 \times 10^8 \text{ Sec}^{-1}$ respectively. The wavelength range for the transitions lies within the spectral range $100 \text{ \AA}$ to $115 \text{ \AA}$. It is also interesting that the energy differences $E(4P_J \rightarrow 2D_J^0)$ determined either by method a: or b: are in very good agreement. However, as is the case for the other intercombination transitions it is seen that the oscillator strengths and transition probabilities are strongly dependent on the mixing coefficients in the configuration interaction expansion of the wavefunctions.

Finally in table 8 we present our results for the intercombination transitions $2s\ 2p^2\ ^4P_J \rightarrow 2p^3\ ^2P_J^0$. Here we see that the energy difference between the two states in a transition is large; hence the wavelengths associated with the transitions will be short, they lie within the spectral range $80\ \text{\AA}$ to $90\ \text{\AA}$.

We have presented in this paper some fairly detailed configuration interaction calculations of fine-structure splittings, energy splittings, oscillator strengths and transition probabilities for Fe XXII between the $2s^2\ 2p$, $2s\ 2p^2$ and $2p^3$ states. We see from these calculations that for calculation of fine-structure splittings and intercombinations transitions that it is also necessary to include the two-electron operators, spin-other-orbit and spin-spin interactions, as well as the one-electron relativistic operators in the Hamiltonian. We also noticed that in calculating the fine-structure splitting the results were the same whether or not the one-electron mass-correction and Darwin contact term were included.

Unfortunately there are no theoretical or experimental results for us to compare our results for transitions between the $2s\ 2p^2$ and $2p^3$ states with.

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Table 1: Configurations used for each state.

State	Configurations
$\Psi(2s^2 2p^2 P^0)$	$[1s^2] 2s^2 2p, 2p^3, 2s 2p (^1P) 3d, 2s 2p (^3P) 3d,$ $2p 3d^2 (^1S), 2p 3d^2 (^3P), 2p 3d^2 (^1D)$
$\Psi(2p^3 2D^0)$	$[1s^2] 2p^3, 2s 2p (^3P) 3d, 2s 2p (^1P) 3d, 2p 3d^2 (^1D),$ $2p 3d^2 (^3P), 2p 3d^2 (^3F)$
$\Psi(2p^3 2P^0)$	$[1s^2] 2s^2 2p, 2p^3, 2s 2p (^1P) 3d, 2s 2p (^3P) 3d,$ $2p 3d^2 (^1S), 2p 3d^2 (^3P), 2p 3d^2 (^1D)$
$\Psi(2p^3 4S^0)$	$[1s^2] 2p^3, 2p 3d^2 (^3P)$
$\Psi(2s 2p^2 2S)$	$[1s^2] 2s 2p^2 (^1S) 2s 3d^2 (^1S), 2p^2 (^1D) 3d$
$\Psi(2s 2p^2 2P)$	$[1s^2] 2s 2p^2 (^3P), 2p^2 (^1D) 3d, 2p^2 (^3P) 3d,$ $2s 3d^2 (^3P), 3d^3$
$\Psi(2s 2p^2 4P)$	$[1s^2] 2s 2p^2 (^3P), 2p^2 (^3P) 3d, 2s 3d^2 (^3P), 3d^3 (^4P)$
$\Psi(2s 2p^2 2D)$	$[1s^2] 2s 2p^2 (^1D), 2p^2 (^3P) 3d, 2s^2 3d, 2s 3d^2 (^1D),$ $2p^2 (^1D) 3d, 2p^2 (^1S) 3d, 3d_1^3, 3d_3^3$
$\Psi(2s^2 2p^2 P_{1/2}^0)$	$\Psi(2s^2 2p^2 P_{1/2}^0)$
$\Psi(2s^2 2p^2 P_{3/2}^0)$	$\Psi(2s^2 2p^2 P_{3/2}^0), \Psi(2p^3 2D_{3/2}^0), \Psi(2p^3 4S_{3/2}^0)$
$\Psi(2p^3 2D_{3/2}^0)$	
$\Psi(2p^3 2P_{3/2}^0)$	
$\Psi(2p^3 4S_{3/2}^0)$	
$\Psi(2p^3 2D_{5/2}^0)$	$\Psi(2p^3 2D_{5/2}^0)$
$\Psi(2p^3 2P_{1/2}^0)$	$\Psi(2p^3 2P_{1/2}^0)$
$\Psi(2s 2p^2 2S_{1/2})$	$\Psi(2s 2p^2 2S_{1/2}), \Psi(2s 2p^2 2P_{1/2}), \Psi(2s 2p^2 4P_{1/2})$
$\Psi(2s 2p^2 2P_{1/2})$	
$\Psi(2s 2p^2 4P_{1/2})$	

Table 1 (Continued)

State	Configurations
$\Psi(2s\ 2p^2\ ^2P_{3/2})$ $\Psi(2s\ 2p^2\ ^4P_{3/2})$ $\Psi(2s\ 2p^2\ ^2D_{3/2})$	$\Psi(2s\ 2p^2\ ^2P_{3/2}), \Psi(2s\ 2p^2\ ^4P_{3/2}), \Psi(2s\ 2p^2\ ^2D_{3/2})$
$\Psi(2s\ 2p^2\ ^4P_{5/2})$ $\Psi(2s\ 2p^2\ ^2D_{5/2})$	$\Psi(2s\ 2p^2\ ^4P_{5/2}), \Psi(2s\ 2p^2\ ^2D_{5/2})$

Table 2: Eigenvalue and Eigenvectors (All Energies in Atomic Units)

	$2s^2 2p^2 P_{1/2}^0$	$2s^2 2p^2 P_{3/2}^0$	$2s 2p^2 4P_{1/2}$	$2s 2p^2 4P_{3/2}$	$2s 2p^2 4P_{5/2}$	$2s 2p^2 2D_{3/2}$	$2s 2p^2 2D_{5/2}$	$2s 2p^2 2P_{1/2}$
Calculation a: E	-878.64489	-878.06232	-876.84632	-876.56411	-876.28987	-875.27793	-875.14966	-874.76860
{a _i }	0.9893	0.9870	-0.1978	-0.0533	-0.9667	0.2301	-0.2555	-0.5802
	-0.1439	-0.1581	0.0030	0.0015	0.0096	-0.0065	0.0025	0.0090
	-0.0187	-0.0186	-0.0002	0.0010	0.0071	-0.0044	0.0019	-0.0004
	0.0131	0.0135	-0.0680	0.0004	0.0001	-0.0016	0.0000	-0.7954
	-0.0054	-0.0052	0.0019	-0.0000	0.2555	0.0001	-0.9664	0.0226
	-0.0014	-0.0015	0.0012	-0.9957	-0.0055	0.0611	0.0212	0.0149
	-0.0011	-0.0012	0.0005	0.0098	0.0041	-0.0006	-0.0159	0.0056
		0.0119	-0.0000	0.0073	-0.0019	-0.0004	0.0071	-0.0002
		0.0003	-0.9778	0.0001	0.0001	-0.0000	-0.0006	0.1728
		0.0002	0.0096	0.0752	0.0000	0.9708	0.0001	-0.0017
		-0.0001	0.0071	-0.0016	-0.0000	-0.0213	0.0001	-0.0013
		0.0001	0.0001	0.0012	-0.0000	0.0160	0.0001	-0.0000
		-0.0000		-0.0006		-0.0072		
		-0.0120		0.0000		0.0005		
		0.0001		0.0000		-0.0003		
				-0.0000		-0.0001		
				-0.0000		-0.0001		

a: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact term + nuclear spin-orbit interaction)

Table 2 (Continued)

	$2s\ 2p^2\ ^2S_{1/2}$	$2s\ 2p^2\ ^2P_{3/2}$	$2p^3\ ^4S_{3/2}^0$	$2p^3\ ^2D_{3/2}^0$	$2p^3\ ^2D_{5/2}^0$	$2p^3\ ^2P_{1/2}^0$	$2p^3\ ^2P_{3/2}^0$
Calculation a: E	-874.14327	-874.08319	-872.95609	-872.30112	-872.12941	-871.48029	-871.17142
{a _i }	0.7899	-0.9711	-0.0597	0.0631	-0.9995	-0.1438	0.1331
	-0.0124	0.0279	-0.2892	0.3463	-0.0250	-0.9892	0.8779
	0.0006	0.0184	0.0043	-0.0051	-0.0138	0.0137	-0.0123
	-0.6012	0.0068	0.0045	-0.0057	0.0089	0.0165	-0.0147
	0.0173	-0.0003	0.0041	-0.0049	-0.0089	0.0138	-0.0122
	0.0114	0.0691	-0.0025	0.0030	0.0003	-0.0086	0.0077
	0.0042	-0.0005	-0.0019	0.0023		-0.0066	0.0059
	-0.0002	-0.0005	0.1558	-0.8989			0.4081
	-0.1179	-0.0000	0.0039	-0.0225			0.0103
	0.0013	0.2259	0.0021	-0.0125			0.0058
	0.0009	-0.0049	-0.0014	0.0080			-0.0036
	0.0000	0.0038	0.0014	-0.0080			0.0036
		-0.0017	-0.0000	0.0003			-0.0001
		0.0000	-0.9425	-0.2591			-0.2105
		0.0000	0.0120	0.0033			0.0027
		-0.0000					
		-0.0000					

Table 3: Eigenvalue and Eigenvectors (All Energies in Atomic Units)

	$2s^2 2p^2 P_{1/2}^0$	$2s^2 2p^2 P_{3/2}^0$	$2s 2p^2 4P_{1/2}$	$2s 2p^2 4P_{3/2}$	$2s 2p^2 4P_{5/2}$	$2s 2p^2 2D_{3/2}$	$2s 2p^2 2D_{5/2}$	$2s 2p^2 2P_{1/2}$
Calculation b: E	-878.60663	-878.08103	-876.79045	-876.54198	-876.30202	-875.26745	-875.16449	-874.72970
{a _i }	0.9892	0.9871	-0.1828	-0.0482	-0.9727	0.2141	-0.2316	0.6031
	-0.1446	-0.1573	0.0028	0.0013	0.0097	-0.0060	0.0023	-0.0094
	-0.0187	-0.0186	-0.0002	0.0009	0.0071	-0.0041	0.0017	0.0004
	0.0132	0.0135	-0.0602	0.0004	0.0001	-0.0015	0.0000	0.7808
	-0.0054	-0.0052	0.0017	-0.0000	0.2315	0.0001	-0.9724	-0.0222
	-0.0014	-0.0015	0.0011	-0.9964	-0.0050	0.0571	0.0214	-0.0147
	-0.0011	-0.0012	0.0004	0.0098	0.0037	-0.0006	-0.0160	-0.0055
		0.0104	-0.0000	0.0073	-0.0017	-0.0004	0.0072	0.0002
		0.0002	-0.9812	0.0001	0.0000	-0.0000	-0.0006	-0.1603
		0.0001	0.0095	0.0689	0.0001	0.9747	0.0001	0.0015
		-0.0001	0.0072	-0.0015	-0.0000	-0.0214	0.0001	0.0012
		0.0001	0.0001	0.0011	-0.0000	0.0161	0.0001	0.0000
		-0.0000		-0.0005		-0.0072		
		-0.0106		0.0000		0.0005		
		0.0001		0.0000		-0.0003		
				-0.0000		-0.0001		
				-0.0000		-0.0001		

b: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact term + nuclear spin-orbit + spin-other orbit + spin-spin interactions)

Table 3 (Continued)

		$2s\ 2p^2\ ^2S_{1/2}$	$2s\ 2p^2\ ^2P_{3/2}$	$2p^3\ ^4S_{3/2}^0$	$2p^3\ ^2D_{3/2}^0$	$2p^3\ ^2D_{5/2}^0$	$2p^3\ ^2P_{1/2}^0$	$2p^3\ ^2P_{3/2}^0$
Calcula-	E	-874.16724	-874.11072	-872.93168	-872.27132	-872.13539	-871.47537	-871.21954
{a _i }		-0.7763	-0.9750	-0.0532	-0.0621	-0.9995	-0.1445	-0.1351
		0.0121	0.0280	-0.2607	-0.3444	-0.0250	-0.9891	-0.8877
		-0.0006	0.0184	0.0038	0.0050	-0.0134	0.0137	0.0125
		0.6209	0.0068	0.0041	0.0057	0.0089	0.0165	0.0149
		-0.0179	-0.0003	0.0037	0.0048	-0.0088	0.0138	0.0124
		-0.0118	0.0618	-0.0023	-0.0030	0.0003	-0.0086	-0.0077
		-0.0044	-0.0004	-0.0017	-0.0023		-0.0066	-0.0060
		0.0002	-0.0004	0.1310	0.9095			-0.3931
		0.1065	-0.0000	0.0033	0.0228			-0.0100
		-0.0011	0.2106	0.0018	0.0127			-0.0055
		-0.0008	-0.0046	-0.0012	-0.0081			0.0035
		-0.0000	0.0035	0.0012	0.0081			-0.0035
			-0.0016	-0.0001	-0.0003			0.0001
			0.0000	-0.9549	0.2224			0.1960
			-0.0000	0.0122	-0.0028			-0.0025
			-0.0000					
			-0.0000					

Table 4: Fine structure splitting of $2s^2 2p^2 {}^2P_J^0$, $2s 2p^2 {}^4P_J$, 2D_J , 2P_J and $2p^3 {}^2D_J^0$, ${}^2P_J^0$ levels.

Levels		Unit	Calculation	Fine Structure Splitting
$2s^2 2p^2 {}^2P_J^0$	$E({}^2P_{3/2}^0 - {}^2P_{1/2}^0)$	cm^{-1}	a	127859
			b	115354
$2s 2p^2 {}^4P_J$	$E({}^4P_{3/2} - {}^4P_{1/2})$	cm^{-1}	a	61938
			b	54532
	$E({}^4P_{5/2} - {}^4P_{3/2})$	cm^{-1}	a	60190
			b	52666
$2s 2p^2 {}^2D_J$	$E({}^2D_{5/2} - {}^2D_{3/2})$	cm^{-1}	a	28154
			b	22598
$2s 2p^2 {}^2P_J$	$E({}^2P_{3/2} - {}^2P_{1/2})$	cm^{-1}	a	150430
			b	135850
$2p^3 {}^2D_J^0$	$E({}^2D_{5/2}^0 - {}^2D_{3/2}^0)$	cm^{-1}	a	37686
			b	29832
$2p^3 {}^2P_J^0$	$E({}^2P_{3/2}^0 - {}^2P_{1/2}^0)$	cm^{-1}	a	67790
			b	56150

a: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact term + nuclear spin-orbit interaction)

b: CI (a: + spin-other-orbit + spin-spin interactions)

Table 5: Energy differences, wavelengths $\{\lambda\}$, oscillator strengths $\{f\}$, transition probabilities $\{A\}$ for intercombination transition $2s^2 2p^2 P_J^0 \rightarrow 2s 2p^2 4P_J$,

	Unit	Calculation	1/2 - 1/2	1/2 - 3/2	3/2 - 1/2	3/2 - 3/2	3/2 - 5/2
$E(2P_J^0 \rightarrow 4P_J)$	au	a	1.7986	2.0808	1.2160	1.4982	1.7725
		b	1.8162	2.0646	1.2906	1.5390	1.7790
		c	1.8477	2.0968	1.3093	1.5583	1.7981
		d	1.8432	2.0968	1.3044	1.5577	1.7995
$\lambda(2P_J^0 \rightarrow 4P_J)$	Å	a	253.3	219.0	374.7	304.1	257.1
		b	250.9	220.7	353.0	296.0	256.1
		c	246.6	217.3	348.0	292.4	253.4
		d	247.2	217.3	349.3	292.5	253.2
$f_{\ell}(2P_J^0 \rightarrow 4P_J)$		a	0.906(-3) [†]	0.309(-4)	0.132(-3)	0.129(-3)	0.122(-2)
		b	0.756(-3)	0.267(-4)	0.122(-3)	0.110(-3)	0.101(-2)
		c	0.755(-3)	0.275(-4)	0.123(-3)	0.110(-3)	0.102(-2)
$A(4P_J \rightarrow 2P_J^0)$	s ⁻¹	a	9.42(7)	2.15(6)	1.25(7)	9.30(6)	8.20(7)
		b	8.01(7)	1.83(6)	1.31(7)	8.34(6)	6.85(7)
		c	8.29(7)	1.94(6)	1.35(7)	8.54(6)	7.04(7)

† The notation implies $\alpha \times 10^{\beta}$

a: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact terms + nuclear spin-orbit interaction)

b: CI (a: + spin-other-orbit + spin-spin interactions)

c: Facwett 1975

d: Sandlin et al 1976

e: Dankwort and Trefftz (1978)

Table 6: Energy differences, wavelengths $\{\lambda\}$, oscillator strengths $\{f\}$, transition probabilities $\{A\}$ for intercombination transitions $2s\ 2p^2\ ^2L_J^0 \rightarrow 2p^3\ ^4S_J$, $[L = 0, 1, 2]$

	Unit	Calculation	1/2 - 3/2	3/2 - 3/2	5/2 - 3/2
$E(^2S_J \rightarrow ^4S_{J'}^0)$	au	a	1.1872		
		b	1.2356		
$\lambda(^2S_J \rightarrow ^4S_{J'}^0)$	°A	a	383.8		
		b	368.8		
$f_\ell(^2S_J \rightarrow ^4S_{J'}^0)$		a	0.421(-3) [†]		
		b	0.374(-3)		
$A(^4S_{J'}^0 \rightarrow ^2S_J)$	s ⁻¹	a	9.53(6)		
		b	9.16(6)		
$E(^2P_J \rightarrow ^4S_{J'}^0)$	au	a	1.8125	1.1271	
		b	1.7980	1.1790	
$\lambda(^2P_J \rightarrow ^4S_{J'}^0)$	°A	a	251.4	404.3	
		b	253.4	386.4	
$f_\ell(^2P_J \rightarrow ^4S_{J'}^0)$		a	0.302(-2)	0.673(-3)	
		b	0.219(-2)	0.614(-3)	
$A(^4S_{J'}^0 \rightarrow ^2P_J)$	s ⁻¹	a	1.59(8)	2.75(7)	
		b	1.14(8)	2.74(7)	
$E(^2D_J \rightarrow ^4S_{J'}^0)$	au	a		2.3218	2.1936
		b		2.3358	2.2328
$\lambda(^2D_J \rightarrow ^4S_{J'}^0)$	°A	a		196.2	207.7
		b		195.1	204.1
$f_\ell(^2D_J \rightarrow ^4S_{J'}^0)$		a		0.102(-2)	0.759(-4)
		b		0.073(-2)	0.495(-4)
$A(^4S_{J'}^0 \rightarrow ^2D_J)$	s ⁻¹	a		1.77(8)	1.76(7)
		b		1.28(8)	1.19(7)

† The notation implies $\alpha \times 10^\beta$

a: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact term + nuclear spin-orbit interaction)

b: CI (a: + spin-other-orbit + spin-spin interactions)

Table 7: Energy differences, wavelengths $\{\lambda\}$, oscillator strengths $\{f\}$, transition probabilities $\{A\}$ for intercombination transition $2s\ 2p^2\ ^4P_J \rightarrow 2p^3\ ^2D_{J'}$

	Unit	Calculation	1/2 - 3/2	3/2 - 3/2	3/2 - 5/2	5/2 - 3/2	5/2 - 5/2
$E(^4P_J \rightarrow ^2D_{J'})$	au	a	4.5452	4.2630	4.4347	3.9887	4.1605
		b	4.5191	4.2707	4.4066	4.0307	4.1666
$\lambda(^4P_J \rightarrow ^2D_{J'})$	Å	a	100.2	106.9	102.7	114.2	109.5
		b	100.8	106.7	103.4	113.0	109.4
$f_{\ell}(^4P_J \rightarrow ^2D_{J'})$		a	0.229(-3) [†]	0.470(-2)	0.112(-3)	0.425(-3)	0.391(-2)
		b	0.129(-3)	0.360(-2)	0.090(-2)	0.273(-3)	0.322(-2)
$A(^2D_{J'} \rightarrow ^4P_J)$	s ⁻¹	a	7.59(7)	27.42(8)	4.72(7)	3.26(8)	21.73(8)
		b	4.22(7)	21.10(8)	3.72(7)	2.14(8)	17.94(8)

† The notation implies $\alpha \times 10^{\beta}$

a: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact term + nuclear spin-orbit interaction)

b: CI (a: + spin-other-orbit + spin-spin interactions)

Table 8: Energy differences, wavelengths $\{\lambda\}$, oscillator strengths $\{f\}$, transition probabilities $\{A\}$ for intercombination transition $2s\ 2p^2\ ^4P_J \rightarrow 2p^3\ ^2P_{J'}$

	Unit	Calculation	1/2 - 1/2	1/2 - 3/2	3/2 - 1/2	3/2 - 3/2	5/2 - 3/2
$E(^4P_J \rightarrow ^2P_{J'}^0)$	au	a	5.3660	5.6749	5.0838	5.3927	5.1185
		b	5.3151	5.5709	5.0666	5.3224	5.0825
$\lambda(^4P_J \rightarrow ^2P_{J'}^0)$	Å	a	84.9	80.3	89.6	84.5	89.0
		b	85.7	81.8	89.9	85.6	89.6
$f_{\lambda}(^4P_J \rightarrow ^2P_{J'}^0)$		a	0.235(-3) [†]	0.226(-4)	0.360(-4)	0.352(-3)	0.117(-3)
		b	0.219(-3)	0.165(-4)	0.310(-4)	0.332(-3)	0.111(-3)
$A(^2P_{J'}^0 \rightarrow ^4P_J)$	s ⁻¹	a	2.17(8)	1.17(7)	5.98(7)	3.27(8)	1.48(8)
		b	1.98(8)	0.82(7)	5.12(7)	3.02(8)	1.38(8)

[†] The notation implies $\alpha \times 10^{\beta}$

a: CI (Non-relativistic + one-electron mass correction + one-electron Darwin contact term + nuclear spin-orbit interaction)

b: CI (a: + spin-other-orbit + spin-spin interactions)