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ABSTRACT

The authors describe the theoretical methods, together with the wavelengths and the radiative transition and autoionization probabilities, for Cr XXI, Cr XXII and Cr XXIII. Electron transitions from the 2p- to the 1s-shell are considered. Calculations in a single-configuration Hartree-Fock-Pauli approximation are made for electric dipole and quadrupole and magnetic dipole transitions using numerical solutions of the Hartree-Fock equations and analytical radial orbitals. The results obtained by the two methods are compared with one another and with the calculated and experimental data of other authors. On the basis of this comparison it is possible to evaluate the accuracy of the calculation methods used.

1. INTRODUCTION

The spectroscopic diagnostics for a hot plasma associated with the study of the X-ray spectra of multicharged ions should be based on calculated data for a wide range of atomic processes [1,2]. These include calculations of the characteristics of atomic transitions (wavelengths and radiative (A) and autoionization (Γ) decay probabilities) as well as a number of cross-sections and the rates of processes resulting in the formation of ions of a given ionization state Z and in the filling of the radiating configurations (ionization, photo- and dielectron recombination and excitation by electron impact). Here the interpretation of the measurements in a wide band of wavelengths requires such calculations on a mass scale for a great number of individual transitions. For this purpose, we have to prepare general-purpose computer programs for calculation of both atomic transition characteristics and the cross-sections of the different processes. These programs should not only ensure a sufficiently high accuracy but also take up a minimum amount of computer time. The optimal choice can be made by carrying out a comparative analysis of the results obtained in dfferent approximations and by different methods and by comparing these data with experiment.

The matter is rather more satisfactory in the case of transitions in a discrete spectrum. In any event, for transitions with $\Delta n \neq 0$ (which are important for X-ray diagnostics) the wavelengths obtained by different methods agree with one another with an accuracy of the order of 10^{-3} and the radiative transition probabilities with an accuracy of about 20%, which is quite sufficient for diagnostic purposes. The accuracy of the calculations of atomic characteristics, including interaction with a continuous spectrum (continuum), is much lower. Thus, the individual values of autionization level widths obtained by different calculation methods may differ by almost an order of magnitude. This applies to a still greater extent to excitation cross-sections, especially for dipole-forbidden transitions in fairly complex ions. Essentially, the only method of large-scale calculation of cross-sections here is the Coulomb-Born method [2]. Therefore, the choice of "sufficiently good" wave functions of the continuous spectrum is still a matter of current interest.

In this study we have carried out a comparative analysis of the calculations of atomic transition characteristics for chromium ions. It is of particular importance to compare the autoionization level widths Γ obtained by different methods. On the basis of such a comparison we can expect to choose fairly simple and, at the same time, reliable analytical approximations for the continuous spectrum functions.

It should be noted that from an experimental standpoint there is interest in calculating spectra not only with the maximum possible accuracy ($\lambda/\Delta\lambda \gtrsim 10^3$-$10^4$) but also with a lower accuracy ($\lambda/\Delta\lambda \sim 10^2$) covering a wider spectral band. The information obtained from lower-resolution measurements in a wide band of wavelengths should then be compared with higher-resolution measurements in a narrow spectral band. These conditions correspond to the contemporary experimental set-up in the tokamak plasma.

Below we give the calculated values of wavelengths and probabilities of radiative transitions and autoionization widths for two-, three- and four-electron chromium ions having a k-vacancy. The calculations were performed with the use of numerical solutions of the Hartree-Fock equations and analytical radial orbitals. The characteristics of electron transition from the 2p- to the 1s-shell were determined. We carried out a comparative analysis of the results with one another and also with the available calculation data obtained by the method of the perturbation theory (perturbutations with respect to 1/Z) [3-5]. The wavelengths are compared with the available experimental data. The spectra of the dielectron satellites of the $1s2p\ ^1P_1 - 1s^2\ ^1S_0$ resonance line of Cr XXIII were experimentally recorded in Ref. [6] and the wavelengths of two transitions between configuration states $1s2s2p^2$ - $1s^22s2p$ in Ref. [7].

Our calculations were performed in a single-configuration approximation with allowance for relativistic effects in the form of corrections. The exception is two-electron transitions, which were calculated in a two-configuration approximation. We considered the following configurations: $1s2p$ $2s^2$, $2s2p$, $2p^2$ – for Cr XXIII, $1s2s^2$, $1s2s2p$, $1s2p^2$, $1s2p3s$, $1s2p3p$, $1s2p4p$, $1s2p5p$, $1s2p3d$ – for Cr XXII, $1s2s^22p$, $1s2s2p3s$, $1s2s2p^2$, $1s2s2p3p$, $1s2s2p4p$, $1s2s2p5p$, $1s2s2p3d$ – for Cr XXI.

In section 2 we describe the methods of calculating energy spectra and in section 3 those for the radiative transition and autoionization probabilities. The obtained wavelengths and radiative and non-radiative transition probabilities are compared in detail in section 4. In the same section we compare the results obtained by the two methods, discuss their accuracies and make recommendations on their use. The numerical data needed for calculating the intensities of dielectron satellites are given in Appendices 1-5. The latter contain the wavelengths, the probabilities of electric dipole and quadrupole as well as magnetic dipole transitions and autoionization for each ion separately: Cr XXIII in Appendix 1, Cr XXII in Appendix 2 and Cr XXI (electric dipole transitions) in Appendix 3. Appendix 4 gives the probabilities of electric quadrupole and Appendix 5 those of magnetic dipole transitions. The autionization probabilities for Cr XXI are summed over the $1s^2 2s\varepsilon\ell$ and $1s^2 2p\varepsilon'\ell$ decay channels.

The following notations have been used in the Appendices: GHRO means the wavelengths λ and the probabilities of radiative transition A and of autoionization Γ determined with the help of generalized hydrogen-like analytical radial orbitals [9], while HFRO denotes those determined by the use of numerical solutions of the Hartree-Fock equations [8]. The figures in columns $SL\mathcal{J}$ and $S'L'\mathcal{J}'$ denote $(2s+1)L(2\mathcal{J}+1)$ and $(2s'+1)L'(2\mathcal{J}'+1)$. For transition probabilities the symbol 3.62 + 2 means $(3.62\cdot 10^{2})\cdot 10^{13}\,s^{-1}$.

2. CALCULATION METHOD FOR ENERGY SPECTRA

The energy spectra are calculated by means of both the numerical solutions of the Hartree-Fock equations [8] and the analytical radial wave functions [9] in the form:

$$P(n\ell|r) = A_{n\ell} \sum_{i=1}^{\max(2,n-\ell)} C_i^{n\ell}\, r^{\min(\ell+i,n)}\, e^{-\alpha_i^{n\ell} r}, \qquad C_1^{n\ell} = 1. \quad (1)$$

The radial orbital parameters $\alpha_i^{n\ell}$ and $C_i^{n\ell}$ in Eq. (1) in the case $n-\ell = 1$ are determined from the minimum non-relativistic energy and $C_i^{n\ell}$ for orbitals $n - \ell > 1$ from the conditions of the orthogonality of the single-electron wave functions.

The wave functions - numerical as well as analytical - were used for the energy spectrum calculation by means of the program described in Ref. [10] and its additions, which cover the cases of numerical [11] and analytical [12] radial orbitals.

In the calculations of the atomic characteristics of multicharged ions the relativistic effects make a substantial contribution. These were taken into account in the Hartree-Fock-Pauli approximation [13], where the relativistic effects for energy are calculated in the form of corrections to the non-relativistic Hamiltonian of an atom. In this method all terms of the order α^2 entering into the Breit operator are regarded as perturbations and taken into account in the first order with respect to the functions of the non-relativistic Hartree-Fock Hamiltonian. In accordance with Ref. [13], we took into account the following relativistic corrections: the correction due to the dependence of electron mass on velocity; the correction for the orbit-orbit interaction; the corrections due to the contact and spin-contact interaction and the correction for the spin-orbital interaction. The energy matrix including the above-mentioned relativistic corrections was calculated for each total moment J within the framework of the LS coupling. After diagonalization, the eigenvectors obtained characterize the energy levels in the intermediate type of coupling.

3. CALCULATION OF RADIATIVE AND AUTOIONIZATION TRANSITION PROBABILITIES

The electric dipole transition probabilities were calculated with the use of the transition operator in the form of length. The matrix elements were calculated from both the numerical and analytical radial orbitals determined with the term-averaged expression for energy. A computer program was prepared to calculate the characteristics of radiative and non-radiative transitions. It can be used to perform calculations immediately after determining the energy spectrum and wave functions by the program given in Ref. [10] or by the use of these data stored in advance on an external magnetic carrier. The program determines transition energies, wavelengths, the matrix elements of the transition operators in the form of "length", "velocity" and in a form with an arbitrary calibration constant [14], oscillator strengths and transition probabilities as well as level widths and autionization probabilities. Since it is a general-purpose program it is possible at the same time to calculate any desired set of the above characteristics. It is capable of performing calculations with numerical or analytical Slater radial orbitals. The latter can be used both in the form of (1) with an arbitrary number of exponential terms and any values of exponent λ and in the form

$$P(nl|r) = \sum_i N_i C_i r^{n_i} e^{-\alpha_i r}, \tag{2}$$

where

$$N_i = [(2\alpha_i)^{2n_i+1}/(2n_i)!]^{1/2}. \tag{3}$$

The program calculates the transition characteristics for the discrete terms in the LS coupling scheme and for the discrete values of J in the intermediate coupling in the single-configuration approximation as well as in the case where multi-configuration wave functions are used.

The autoionization probabilities were calculated in the first order of the theory of perturbations with respect to interelectron interaction. In the case of the wave functions represented in the intermediate type of coupling, the autoionization probability of level j(s^{-1}) can be written as:

$$\Gamma(j) = \frac{2\pi\, 10^{17}}{2{,}42} \sum_i \left| \sum_{b,b'} (j|b)(b|H|b')(b'|i) \right|^2, \tag{4}$$

where H denotes the operator of electrostatic interaction energy, (j|b) and (b'|i) are the coefficients of expansion of the wave functions in the intermediate coupling within the framework of the LS coupling and i denotes the states of an ion with an electron in the continuous spectrum.

The radial integrals of electrostatic interaction of electrons were calcualted with the use of numerical solutions of the Hartree-Fock equations (11) and with the analytical radial wave functions (1).

Numerical solutions of the Hartree-Fock equations of the continuous spectrum were determined by the programs given in Ref. [15]. The radial orbital of an electron in the continuum was determined in the field of the "frozen" core of an ion having one electron less than an ion in the autoionized state. The radial orbitals of an electron in the continuous spectrum were orthogonalized to the corresponding orbitals of the core. The radial integrals were calculated with the use of the radial function of an electron in the continuum determined for the Hartree-Fock Hamiltonian, averaged over all terms.

In the calculations with analytical radial orbitals an electron in the continuous spectrum was described by the Coulomb wave function [16] with an effective nuclear charge. The value of the effective nuclear charge was chosen as the difference between the nuclear charge of the ion and the number of electrons remaining after autoionization. In this case, the electrostatic interaction integrals were calculated with the help of the recurrence formulae of Ref. [17].

4. DISCUSSION OF RESULTS

4.1. Two-electron chromium ion

In Table 1 we compare the wavelengths λ and the probabilities of autoionization Γ and radiative decay A for the two-electron chromium ion. From the results given in Table 1 it will be seen that the probabilities of both radiative transitions and autoionization obtained by means of the anlaytical functions and numerical solutions of the Hartree-Fock equations are in satisfactory agreement. The radiative transition probabilities virtually coincide, while the autoionization probabilities differ by less than 2%.

The radiative transition probabilities calculated in Ref. [3] by the perturbation theory (perturbations with respect to 1/Z) agree satisfactorily with those obtained in our work. At the same time, the autoionization probabilities determined in Ref. [3] differ from our calculations by up to 14% and, in the case of the metastable state $2p^2\ ^3P_0$ with respect to autoionization, by a factor of 3.5.

The wavelengths of electric dipole transitions determined with the use of the analytical radial orbitals are shifted towards lower values by (0.0056 $\pm$ 0.0002) Å in comparison with those obtained with the numerical functions and by (0.0059 $\pm$ 0.0007) Å in comparison with those found by the perturbation theory [3]. Comparing the wavelengths obtained with the numerical functions and those by the perturbation theory, we find that they agree satisfactorily. The greatest deviation does not exceed 0.0013 Å.

4.2. Three-electron chromium ion

The characteristics of the radiative and non-radiative transitions for the three-electron chromium ion obtained with analytical and numerical radial functions and also those obtained by the perturbation theory (perturbations with respect to I/Z) [3,5] are given in Table 2. The comparison of the wavelengths in this table shows a very good agreement between the data obtained by the perturbation theory [3,5] and those derived from numerical solutions of the Hartree-Fock equations. The greatest deviation does not exceed 0.06%. The wavelengths of radiative transitions calculated with the use of analytical radial orbitals are shifted towards lower values by 0.0059 Å on an average, which amounts to less than 0.3%. The shift is the same as in the case of the two-electron chromium ion (see Table 1).

The electric dipole transition probabilities calculated with the use of numerical solutions of the Hartree-Fock equations and analytical radial orbitals display satisfactory agreement. The greatest deviation, amounting to 3.6%, is observed in the case of the $1s2p(^1p)3p\ ^2D_{5/2}$ - $1s^23p\ ^2p_{3/2}$ transition. In all other cases, they differ by less than 2.5%. In comparison with the radiative transition probabilities obtained by the perturbation theory [3,5] we note much higher deviations. For most transitions the deviations vary from 3 to 15%, although for some of them they are still higher. This refers to the probabilities of transitions between configurations 1s2p3p and $1s^23p$ ($\Delta L = \pm 1$) and of the intercombination transition $1s2p^2\ ^4p_{5/2}$ - $1s^22p\ ^2p_{3/2}$. In the latter case, the radiative transition probabilities found by the perturbation theory and those by the variational methods differ by up to two orders.

The autoionization probabilities determined with analytical functions agree satisfactorily with those determined with numerical solutions of the Hartree-Fock. The greatest deviation is found for the level $1s2p(^1p)3p\ ^2p_{3/2}$ (12.6%). In all the other cases given in Table 2, the deviation from the values calculated with analytical functions is less than 7%. There is much less agreement between the autoionization probabilities obtained by both the variational methods and the results obtained by the perturbation theory [3,5]. The deviation varies from 7 to 30%, but in some cases it is twice as high and, for the level $1s2p(^3p)3p\ ^2p_{3/2}$, goes up to three orders.

Appendix 2 gives the calculation results in full for wavelengths (λ) and the radiative transition (A) and autoionization (Γ) probabilities. The radiative and non-radiative transition probabilities obtained with the use of numerical and analytical functions agree satisfactorily, while the wavelengths differ on an average by 0.3%. The autoionization probabilities for configurations 1s2p3s and 1s2p5p were not calculated since it is impossible to find numerical solutions of the Hartree-Fock equations for an electron in the continuum, owing to the inadequacy of the operational memory of the BEhSM-6 computer.

4.3. Four-electron chromium ion

In Table 3, the wavelengths and the electric dipole transition and autoionization probabilities determined with analytical and numerical radial orbitals are compared with each other and with the data of Ref. [4] obtained by the perturbation theory. It will be seen that the wavelengths calculated with the use of numerical solutions of the Hartree-Fock equations agree very satisfactorily with those obtained by the perturbation theory. The wavelengths determined with the help of analytical radial orbitals are shifted towards lower values on an average by 0.007 Å. This value is somewhat higher than in the case of the two-electron and three-electron chromium ions although the percentage ratio remains the same - 0.3%.

The electric dipole transition probabilities calculated with the help of variational analytical and numerical wave functions exhibit very good agreement with each other, except for the intercombination transition $1s2p^3\ ^1D_2 - 1s^22p^2\ ^3P_2$, for which the difference is 23%. Comparison of these radiative transition probabilities with the data of Ref. [4] obtained by the perturbation theory (perturbations with respect of 1/Z) reveals satisfactory agreement (the difference between the probabilities varies from 10 to 20% for most of the transitions considered); the probability of the transition $1s(2s2p^2\ ^2P)\ ^3P_o - 1s^22s2p\ ^3P_1$ obtained by the perturbation theory is twice the probabilities obtained in our work. The autoionization probabilities calculated with the use of numerical solutions of the Hartree-Fock equations are close to those obtained with analytical functions (in most cases they differ by less than 4%). The autoionization probabilities determined in Ref. [4] by the method of the perturbation theory (perturbations with respect to 1/Z) differ considerably from those found in the present study. These probabilities for the $1s^2p^3$ LS $\not{J}$ states reveal the greatest difference: up to 37% in the case of numerical functions and up to 40% in the case of analytical functions.

The radiative transition and autoionization probabilities given in Appendix 3 show satisfactory agreement with each other. The wavelengths calculated with analytical functions differ by less than 0.3% from those obtained with numerical solutions of the Hartree-Fock equations. For an electron in the continuous spectrum, in the case of the configurations $1s^2 2s\ \varepsilon \ell$, where $\ell = 0,1,2,3$, it was not possible to find the radial wave function by numerically solving the Hartree-Fock equations, owing to the inadequacy of the operational memory of the BEhSM-6 computer or for lack of the necessary degree of agreement. For this reason, the autoionization probabilities for configurations $1s2s2p\ n\ell$ ($n\ell$ = 3s, 3p, 3d, 4p, 5p) were not determined with numerical wave functions.

4.4. Comparison with experiment

The experimentally measured wavelengths 2.212 Å and 2.216 Å given in Ref. [7] for transitions $1s2s2p^2\ ^3D_2 - 1s^2 2s2p\ ^1P_1$ and $1s2s2p^2\ ^1D_2 - 1s^2 2s2p\ ^1P_1$, respectively, agree satisfactorily with our calculated values obtained with the use of numerical solutions of the Hartree-Fock equations (2.2086 Å and 2.2170 Å).

A well-resolved spectrum of chromium ions in the 2.18-2.24 Å wavelength region emitted by a tokamak plasma was recorded in Ref. [18]. This wavelength region covers the resonance, intercombination and forbidden lines of Cr XXIII and also the lines emitted during the filling of the 1s-vacancy in Cr XXII, Cr XXI, Cr XX and Cr XIX formed by dielectron recombination or electron excitation.

Spectrum identification [18] was based on the calculated wavelengths found in the same study. Use was made of the energies and wave functions determined by the method of superposition of configurations with allowance for relativistic corrections in the intermediate coupling. The radial wave functions were found for the Hartree-Fock-Slater Hamiltonian averaged over all terms. The autoionization and radiative transition probabilities were also calculated. Table 4 contains a comparison of the wavelengths and the autoionization and radiative transition probabilities calculated by the different methods and those measured experimentally. Since it is difficult in a theoretical calculation to take full account of all correlation, relativistic and radiative corrections, the wavelengths in Ref. [18] are shifted towards higher values by $\Delta\lambda = 2.9 \times 10^{-3}$ Å for Cr XXIII, by $\Delta\lambda = 3.4 \times 10^{-3}$ Å for Cr XXII and by $\Delta\lambda = 3.9 \times 10^{-3}$ Å for Cr XXI until they coincide with the well-known lines of transitions $1s2p\ ^1P_1 - 1s^2\ ^1S_0$, $1s(2s2p\ ^3P)\ ^2P_{3/2} - 1s^2 2s\ ^2S_{1/2}$ and $1s2s2p^2\ ^3D_3 - 1s^2 2s2p\ ^3P_2$, respectively. The wavelengths (λ_k) in Table 4, which were determined in our work, are also shifted towards higher values. The corrections are as follows (in 10^{-3} Å): Cr XXIII - 6.2, 0.6; Cr XXII - 7.4, 0.7 and Cr XXI - 7.8, 0.2 for GHRO and HFRO, respectively.

Table 4 shows that there is satisfactory agreement between the theoretical wavelengths and between them and the experimental data. The autoionization and radiative transition probabilities also agree satisfactorily. The exception is the probabilities of autoionization decay of states $1s(2s2p\ ^3P)\ ^2P_{3/2}$, $1s2s2p^2\ ^3D_1$ and $1s(2s2p^2\ ^4P)\ ^3P_1$ calculated with the numerical functions of the continuous spectrum.

4.5. Magnetic dipole and quadrupole and electric quadrupole transitions

In Table 5 we compare the oscillator strengths of the magnetic dipole and electric quadrupole transitions. The oscillator strengths calculated with the use of numerical solutions of the Hartree-Fock equations are in satisfactory agreement with the theoretical data taken from Ref. [9].

In Ref. [20] it is pointed out that the spectra of multicharged iron ions show intensive lines corresponding to the magnetic quadrupole transition $1s2p\ ^3P_2 - 1s^2\ ^1S_0$ and to the relativistic magnetic dipole transition $1s2s\ ^3S_1 - 1s^2\ ^1S_0$. We calculated the wavelengths and the probabilities of these transitions and obtained the value of 3.47×10^{-9} s^{-1} for the probability of the magnetic quadrupole transition $1s2p\ ^3P_2 - 1s^2\ ^1S_0$ in Cr XXIII. This value is lower by only two orders than in the case of electric dipole transitions and higher by five orders as compared with electric quadrupole transitions. The wavelength 2.1882 Å lies within the band of lines emitted during the filling of the 1s-vacancy through transition from the 2p-shell.

The wavelength of the allowed magnetic dipole transition $1s2s\ ^3S_1 - 1s^2\ ^1S_0$ in the relativistic approximation with the use of the numerical and analytical non-relativistic wave functions is found to be 2.2025 Å and 2.1937 Å, respectively, while the solution of the relativistic Dirac-Hartree-Fock equations gives 2.1964 Å (the probability equals 4.12×10^7 s^{-1}), λ_{exp} being 2.2035 Å [18].

CONCLUSIONS

From the foregoing analysis of the results obtained in this work the following conclusions can be drawn:

1. The wavelengths of electric dipole transitions determined with the help of solutions of the Hartree-Fock equations show better agreement with the experimental values than in the case where analytical radial orbitals are used. It is therefore recommended that theoretical studies should use wavelengths obtained with numerical radial functions. In cases where calculations are performed on the basis of analytical radial orbitals the wavelengths obtained in the present study should be shifted towards higher values on an average by 0.3% of the calculated wavelength. Both these methods are most universal and effective and enable further refinements to be applied easily.

2. Numerical solutions of the Hartree-Fock equations and analytical radial orbitals are equally suitable for calculating the radiative transition and autoionization probabilities since within the required accuracy both these methods yield results of approximately the same quality. Somewhat greater deviations are observed in the case of the data of the perturbation theory (perturbations with respect to 1/Z), which in a number of cases result in changes of the order of the quantity itself.

3. It is advisable to use analytical radial orbitals for large-scale calculation of the autoionization characteristics of multicharged ions. This will save computer time and make it possible to take more accurate account of the energy dependence of the wave function of an electron in the continuous spectrum.

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Table 1. Comparison of wavelengths (Å) and radiative transition and autoionization probabilities ($10^{13}\ s^{-1}$) for Cr^{22+}

State		GHRO			HFRO			Theor. [3,5]		
initial	final	λ	A	Γ	λ	A	Γ	λ	A	Γ
$1s2p\ ^1P_1$	$1s^2\ ^1S_0$	2.I756	3.62+I	0	2.I8I2	3.59+I	0	2.I8I4	3.46+I	0
$2s2p\ ^1P_1$	$1s2s\ ^3S_1$	2.0842	5.04-I	I.82+I	2.0898	5.04-I	I.89+I	2.0905	5.36-I	I.97+I
$2s2p\ ^1P_1$	$1s2s\ ^1S_0$	2.0937	2.03+I	I.82+I	2.0994	2.02+I	I.89+I	2.I007	2.03+I	I.97+I
$2s2p\ ^3P_2$	$1s2s\ ^3S_1$	2.0963	2.07+I	I.46+0	2.I0I9	2.06+I	I.44+0	2.I022	2.05+I	I.35+0
$2s2p\ ^3P_1$	$1s2s\ ^3S_1$	2.I002	2.0I+I	I.88+0	2.I058	2.00+I	I.87+0	2.I06I	I.99+I	I.84+0
$2s2p\ ^3P_0$	$1s2s\ ^3S_1$	2.I0I5	2.05+I	I.42+0	2.I07I	2.05+I	I.44+0	2.I074	2.04+I	I.35+0
$2s2p\ ^3P_1$	$1s2s\ ^1S_0$	2.I098	4.86-I	I.88+0	2.II56	4.86-I	I.87+0	2.II64	5.22-I	I.84+0
$2p^2\ ^1D_2$	$1s2p\ ^3P_2$	2.0952	7.48+0	2.65+I	2.I005	7.28+0	2.68+I	2.I0I0	7.85+0	2.79+I
$2p^2\ ^3P_2$	$1s2p\ ^3P_1$	2.0970	I.2I+I	8.32+0	2.I024	I.20+I	8.I7+0	2.I03I	I.22+I	9.46+0
$2p^2\ ^3P_2$	$1s2p\ ^3P_2$	2.I008	2.37+I	8.32+0	2.I062	2.37+I	8.I7+0	2.I066	2.29+I	9.46+0
$2p^2\ ^1D_2$	$1s2p\ ^1P_1$	2.I0I4	3.40+I	2.65+I	2.I068	3.39+I	2.66+I	2.I070	3.33+I	2.79+I
$2p^2\ ^3P_0$	$1s2p\ ^3P_1$	2.I022	4.I3+I	I.I2+0	2.I076	4.II+I	I.I2+0	2.I074	3.8I-I	3.I2-I

Table 2. Comparison of wavelengths (Å) and radiative transition and autoionization probabilities (10^{13} s^{-1}) for Cr^{21+}

State		GHRO			HFRO			Theor. [3]		
initial	final	λ	A	Γ	λ	A	Γ	λ	A	Γ
$1s(2s2p\ ^1P)\ ^2P_{3/2}$	$1s^2 2s\ ^2S_{1/2}$	2.I838	I.27+I	7.83+0	2.I896	I.30+I	7.29+0	2.I898	I.08+I	9.5I+0
$1s(2s2p\ ^3P)\ ^2P_{1/2}$	$^2S_{1/2}$	2.I9I9	2.39+I	2.96+0	2.I977	2.35+I	2.89+0	2.I972	2.46+I	2.6I+0
$1s2p^2\ ^2P_{3/2}$	$1s^2 2p\ ^2P_{3/2}$	2.I903	4.78+I	2.75+0	2.I974	4.67+I	2.82+0	2.I965	4.52+I	3.52+0
$^2D_{3/2}$	$^2P_{1/2}$	2.I920	2.36+I	I.33+I	2.I948	2.32+I	I.34+I	2.I978	2.28+I	I.50+I
$^2D_{5/2}$	$^2P_{3/2}$	2.I946	I.70+I	I.48+I	2.20I7	I.66+I	I.49+I	2.2009	I.62+I	I.69+I
$^2D_{3/2}$	$^2P_{3/2}$	2.I963	I.57+0	I.33+I	2.2034	I.60+0	I.34+I	2.202I	I.88+0	I.50+I
$^4P_{5/2}$	$^2P_{3/2}$	2.2032	I.57+0	I.39+0	2.2I05	I.52+0	I.37+0	2.209I	I.6I+0	I.7I+0
$^4P_{3/2}$	$^2P_{3/2}$	2.2055	4.37+0	I.03–I	2.2I28	4.27+0	I.02–I	2.2I09	5.I5–I[a]	7.40–2[a]
$1s2p(^3P)3p\ ^2S_{1/2}$	$1s^2 3p\ ^2P_{3/2}$	2.I833	8.85+0	6.49–I	2.I890	9.05+0	5.67–I	2.I879[a]	I.22+I[a]	I.57–I[a]
$1s2p(^1P)3p\ ^2P_{3/2}$	$^2P_{3/2}$	2.I784	3.3I+I	I.0I+0	2.I84I	3.I9+I	I.08+0	2.I837[a]	3.06+I[a]	5.27–I[a]
$1s2p(^3P)3p\ ^2P_{3/2}$	$^2P_{3/2}$	2.I9I6	9.I0–I	I.39–I	2.I975	9.II–I	I.38–I	2.I96I[a]	I.I9+0[a]	7.77–4[a]
$1s2p(^1P)3p\ ^2D_{5/2}$	$^2P_{3/2}$	2.I798	3.64+I	2.92+0	2.I856	3.5I+I	3.I8+0	2.I848[a]	3.I9+I[a]	2.96+0[a]

N.B. a – Values taken from [5].

Table 3. Comparison of wavelengths (Å) and radiative transition and autoionization probabilities ($10^{13}\ s^{-1}$) for Cr^{20+}.

State		GHRO			HFRO			Theor. [4]		
initial	final	λ	A	Γ	λ	A	Γ	λ	A	Γ
$1s2s^2 2p\ ^1P_1$	$1s^2 2s^2\ ^1S_0$	2.20I6	3.36+I	9.I4+0	2.2067	3.35+I	9.94+0	2.2070	2.75+I	8.42+0
$^3P_1$	$^1S_0$	2.2I20	I.95+0	I.46+I	2.2I73	I.87+0	I.63+I	2.2I70	I.66+0	I.52+I
$1s(2s2p^2\ ^2P)\ ^3P_0$	$1s^2 2s2p\ ^3P_1$	2.I955	5.88+0	I.36+I	2.2000	5.86+0	I.38+I	2.2023	I.38+I	I.38+I
$1s2s2p^2\ ^1S_0$	$^1P_1$	2.2003	I.64+I	2.03+I	2.2073	I.65+I	I.96+I	2.2064	I.65+I	2.36+I
$^3D_2$	$^1P_1$	2.2045	2.43+I	I.35+I	2.2086	2.40+I	I.40+I	2.2II0	2.I9+I	I.83+I
$^3D_3$	$^3P_2$	2.2062	I.7I+I	I.69+I	2.2I38	I.72+I	I.7I+I	2.2I34	I.66+I	2.09+I
$^1D_2$	$^1P_1$	2.2I0I	I.27+I	2.50+I	2.2I70	I.24+I	2.60+I	2.2I58	I.08+I	2.50+I
$^5P_3$	$^3P_2$	2.22I5	4.I8-I	4.25-I	2.2292	4.24-I	4.32-I	2.228I	4.30-I	5.5I-I
$1s2p^3\ ^3P_0$	$1s^2 2p^2\ ^3P_1$	2.2030	I.77+I	I.68+I	2.2076	I.78+I	I.7I+I	2.2075	I.64+I	2.34+I
$^1D_2$	$^3P_2$	2.2049	2.32+I	2.45+I	2.2I03	2.86+I	2.08+I	2.2I09	2.I6+I	2.66+I
$^1P_1$	$^1S_0$	2.2087	2.I8+I	I.6I+I	2.2I67	2.I5+I	I.7I+I	2.2I64	I.8I+I	2.22+I
$^3D_1$	$^3P_2$	2.2II6	2.34+0	2.07+I	2.2I69	2.72+0	2.02+I	2.2I76	2.48+0	2.62+I

Table 4. Comparison of wavelengths λ_k (Å) and radiative transition A ($10^{13}\ s^{-1}$) and autoionization Γ ($10^{13}\ s^{-1}$) probabilities

State		GHRO			HFRO			18			
initial	final	λ_K	A	Γ	λ_K	A	Γ	λ_K	λ_{exp}	A	Γ
$1s2p\ ^1P_1$	$1s^2\ ^1S_0$	2.1818	36.22		2.1818	35.35		2.1818	2.1818	34.67	
$^3P_2$	$^1S_0$	2.1885						2.1885	2.1886		
$^3P_1$	$^1S_0$	2.1926	2.07		2.1927	2.06		2.1926	2.1927		
$1s(2s2p\ ^1P)\ ^2P_{1/2}$	$1s^22s\ ^2S_{1/2}$	2.1902	12.73	7.83	2.1903	12.98	7.28	2.1904	2.1907	12.48	7.63
$1s(2s2p\ ^3P)\ ^2P_{3/2}$	$^2S_{1/2}$	2.1955	35.19	0.14	2.1955	35.04	10.0	2.1955	2.1955	34.16	0.06
$^2P_{1/2}$	$^2S_{1/2}$	2.1983	23.94	2.96	2.1984	23.5	2.89	2.1983	2.1982	22.95	2.91
$1s2p^2\ ^2D_{3/2}$	$1s^22p\ ^2P_{1/2}$	2.1994	23.55	13.34	2.1955	23.23	13,36	2.1983		22.19	13.10
$^2D_{5/2}$	$^2P_{3/2}$	2.2010	16.98	14.80	2.2024	16.64	14.91	2.2018	2.2016	15.87	14.61
$1s2s2p^2\ ^1D_2$	$1s^22s2p\ ^3P_2$	2.2044	3.73	25.0	2.2047	4.32	26.0	2.2018		4.37	23.30
$1s2s^22p\ ^1P_1$	$1s^22s^2\ ^1S_0$	2.2094	33.57	9.14	2.2069	34.34	9.94	2.2075	2.2079	32.42	12.40
$1s2s2p^2\ ^3D_1$	$1s^22s2p\ ^3P_1$	2.2110	19.54	13.40	2.2075	19.70	488.0	2.2103	2.2103	19.6[illegible]	12.95
$1s(2s2p^2\ ^4P)\ ^3P_1$	$^3P_0$	2.2118	28.43	[illegible].97	2.2075	28.70	91.46	2.2109		28.01	6.88
$1s2s2p^2\ ^3D_2$	$^3P_1$	2.2123	24.31	13.47	2.2088	24.00	13.95	2.2116	2.2115	23.23	13.85
$1s(2s2p^2\ ^4P)\ ^3P_2$	$^3P_2$	2.2119	37.92	7.55	2.2119	37.66	7.35	2.2118		37.11	7.17
$1s2s2p^2\ ^3D_3$	$^3P_2$	2.2140	17.10	16.93	2.2140	17.19	17.14	2.2140	2.2140	16.38	17.37
$^3D_1$	$^3P_2$	2.2141	6.70	13.40	2.2140	6.62	488.0	2.2141		6.95	12.95
$1s(2s2p^2\ ^2P)\ ^3P_2$	$^1P_1$	2.2142	4.30	18.18	2.2137	4.55	16.19	2.2145		5.07	21.05
$1s2s2p^2\ ^1D_2$	$^1P_1$	2.2179	12.73	25.02	2.2172	12.43	26.02	2.2180	2.2173	11.56	23.30

Table 5. Comparison of oscillator strengths for magnetic dipole and electric quadrupole transitions in chromium ions

Configuration	States		Magnetic dipole		Electric quadrupole	
	initial	final	f	f /I9/	f	f /I9/
$1s^2 2s^2 2p^2$	$^1D_2$	$^3P_2$	8,36-7	8,49-7	—	—
	$^3P_2$	$^3P_1$	6,27-7	5,88-7	5,72-I2	4,46-I2
	$^1D_2$	$^3P_1$	4,50-7	4,48-7	—	—
	$^1S_0$	$^3P_1$	I,26-6	I,39-6	—	—
	$^3P_2$	$^3P_0$ ×	—	—	3,78-II	3,83-II
$1s^2 2s^2 2p^3$	$^2D_{5/2}$	$^4S_{3/2}$	I,60-8	I,90-8	7,74-II	7,83-II
	$^2D_{3/2}$	$^4S_{3/2}$	3,95-7	4,9I-7	3,39-II	3,I0-II
	$^2P_{3/2}$	$^4S_{3/2}$	3,69-7	3,36-7	—	—
	$^2P_{1/2}$	$^4S_{3/2}$	3,I5-7	3,52-7	—	—
$1s^2 2s^2 2p^4$	$^3P_1$	$^3P_2$	I,82-6	I,89-6	—	—
	$^3P_0$	$^3P_1$	I,20-2	I,5I-7	—	—
	$^1D_2$	$^3P_2$	5,28-7	5,55-7	—	—
	$^1D_2$	$^3P_1$	I,08-7	I,II-7	—	—
	$^1S_0$	$^3P_1$	I,84-6	2,I5-6	—	—
	$^3P_0$	$^3P_2$	—	—	8,8I-II	8,II-II
	$^1D_2$	$^3P_0$	—	—	3,95-I2	6,25-I2
	$^1S_0$	$^3P_2$	—	—	3,39-I0	I,43-I0

Appendix 1. Wavelengths (Å) and radiative transition and autoionization probabilities (10^{13} s^{-1}) for Cr XXIII

SLJ	$S'L'J'$	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
			$1s2p - 1s^2$				
II3	IOI	2.I756	3.62+I	—	2.I8I2	3.59+I	—
3I3	IOI	2.I864	2.07+0	—	2.I92I	2.06+0	—
			$2s2p - 1s2s$				
II3	303	2.0842	5.04-I	I.82+I	2.0898	5.04-I	I.89+I
II3	IOI	2.0937	2.03+I	I.8I+I	2.0994	2.02+I	I.89+I
3I5	303	2.0963	2.07+I	I.46+0	2.IOI9	2.06+I	1.44+0
3I3	303	2.I002	2.0I+I	I.88+0	2.I058	2.00+I	I.87+0
3II	303	2.IOI5	2.05+I	I.42+0	2.I07I	2.05+I	I.44+0
3I3	IOI	2.I098	4.86-I	I.88+0	2.II56	4.86-I	I.87+0
			$2p^2 - 1s2p$				
IOI	3I3	2.0840	7.83-2	I.34+I	2.0899	7.49-2	I.37+I
IOI	II3	2.0939	4.I8+I	I.34+I	2.0993	4.I6+I	I.37+I
I25	3I3	2.09I4	4.62-2	2.65+I	2.0967	3.62-2	2.68+I
I25	3I5	2.095I	7.48+0	2.65+I	2.I005	7.28+0	2.68+I
3I5	3I3	2.0970	I.2I+I	8.32+0	2.I024	I.20+I	8.I7+0
3I3	3II	2.0980	I.39+I	0	2.I034	I.38+I	0
3I3	3I3	2.099I	9.82+0	0	2.I045	9.73+0	0
3I5	3I5	2.I008	2.37+I	8.32+0	2.I062	2.37+I	8.I7+0
I25	II3	2.I0I4	3.40+I	2.65+I	2.I068	3.39+I	2.68+I
3II	3I3	2.I022	4.I3+I	I.I2+0	2.I076	4.II+I	I.I2+0
3I3	3I5	2.I029	I.72+I	0	2.I083	I.7I+I	0
3I5	II3	2.I07I	5.7I+0	8.32+0	2.II25	5.50+0	8.I7+0
3I3	II3	2.I092	5.62-I	0	2.II47	5.6I-I	0
3II	II3	2.II23	7.52-2	I.I2+0	2.II78	7.20-2	I.I2+0

Appendix 2. Wavelengths (Å) and radiative transition and autoionization probabilities (10^{13} s^{-1}) for Cr XXII

SLJ	$S'L'J'$	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
			$1s2s^2 - 1s^22p$				
202	2I2	2.2228	9.27-I	I.I7+I	2.2334	6.52-I	—
202	2I4	2.2272	9.52-I	I.I7+I	2.2379	7.39-I	—
			$1s(2s2p\,^1P) - 1s^22s$				
2I2	202	2.I838	I.27+I	7.83+0	2.I896	I.30+I	7.29+0
2I4	202	2.I830	I.0I+0	9.79+0	2.I888	I.0I+0	9.89-2
			$1s(2s2p\,^3P) - 1s^22s$				
2I4	202	2.I89I	3.52+I	I.43-I	2.I948	3.50+I	I.00+I
2I2	202	2.I9I9	2.39+I	2.96+0	2.I977	2.35+I	2.89+0
4I4	202	2.2048	6.83-I	3.57-2	2.2I06	6.87-I	4.I6-2
4I2	202	2.2062	2.08-I	8.94-2	2.2I2I	2.09-I	I.06-2
			$1s2p^2 - 1s^22p$				
202	2I2	2.I8I8	4.04-I	6.00+0	2.I847	3.88-I	6.08+0
202	2I4	2.I860	2.09+I	6.00+0	2.I932	2.05+I	6.08+0
2I4	2I2	2.I860	I.30+0	2.75+0	2.I888	I.24+0	2.82+0
2I4	2I4	2.I903	4.78+I	2.75+0	2.I974	4.67+I	2.82+0
2I2	2I2	2.I9I2	4.I9+I	4.50-I	2.I940	4.I2+I	4.57-I
224	2I2	2.I920	2.36+I	I.33+I	2.I948	2.32+I	I.34+I
226	2I4	2.I946	I.70+I	I.48+I	2.20I7	I.66+I	I.49+I
2I2	2I4	2.I954	I.02+I	4.50-I	2.2026	9.99+0	4.57-I
224	2I4	2.I963	I.57+0	I.33+I	2.2034	I.60+0	I.34+I
4I4	2I2	2.20I2	5.94-3	I.03-I	2.204I	5.54-3	I.02-I
4I2	2I2	2.2036	I.25+0	2.78-I	2.2065	I.24+0	2.78-I
4I6	2I4	2.2032	I.57+0	I.38+0	2.2I05	I.52+0	I.37+0
4I4	2I4	2.2055	4.37+0	I.03-I	2.2I28	4.27+0	I.02-I
4I2	2I4	2.2079	7.04-2	2.78-I	2.2I52	6.95-2	2.78-I
			$1s2p(^1P)3s - 1s^23s$				
2I4	202	2.I786	3.45+I	I.07-2	2.I838	3.46+I	—
2I2	202	2.I788	3.55+I	2.05-I	2.I84I	3.58+I	—

Appendix 2 (cont.)

SLJ	$S'L'J'$	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
				$1s\,2p(^3P)3s - 1s^2 3s$			
2I4	202	2.I837	9.79-I	I.75+0	2.I89I	I.06+0	--
2I2	202	2.I874	I.54+0	I.64+0	2.I929	I.52+0	—
4I4	202	2.I899	I.9I+0	I.49-I	2.I956	I.9I+0	—
4I2	202	2.I9I0	3.25-I	6.28-2	2.I967	3.30-I	—
				$1s\,2p(^1P)3p - 1s^2 3p$			
202	212	2.I76I	I.57+0	2.43+0	2.I806	I.4I+0	3.I4+0
2I2	2I2	2.I788	3.44+I	4.27-2	2.I834	3.33+I	9.20-2
202	2I4	2.I774	2.85+I	2.43+0	2.I83I	2.73+I	3.I4+0
2I2	2I4	2.I80I	8.I2-I	4.27-2	2.I859	6.60-I	9.20-2
2I4	2I2	2.I77I	3.55-I	I.0I+0	2.I8I6	3.55-I	I.08+0
224	2I2	2.I79I	3.39+I	3.89+0	2.I837	3.26+I	4.22+0
2I4	2I4	2.I784	3.3I+I	I.0I+0	2.I84I	3.I9+I	I.08+0
224	2I4	2.I803	I.66-I	3.89+0	2.I862	I.60-I	4.22+0
220	2I4	2.I798	3.64+I	2.92+0	2.I856	3.5I+I	3.I8+0
				$1s2p(^3P)3p - 1s^2 3p$			
202	2I2	2.I820	4.56-I	6.49-I	2.I865	4.82-I	5.67-I
2I2	2I2	2.I887	6.I8-3	I.96-I	2.I933	3.80-6	I.8I-I
4I2	2I2	2.I892	I.80+0	6.8I-2	2.I938	I.82+0	I.I2-I
422	2I2	2.I932	6.42-I	I.57-3	2.I979	6.36-I	I.0I-3
202	2I4	2.I833	8.85+0	6.49-I	2.I890	9.05+0	5.67-I
2I2	2I4	2.I900	I.69-I	I.96-I	2.I958	I.62-I	I.8I-I
4I2	2I4	2.I905	4.3I-I	6.8I-2	2.I963	3.8I-I	I.I2-I
422	2I4	2.I945	7.97-2	I.57-3	2.2004	7.95-2	I.0I-3
404	2I2	2.I853	2.27-I	8.48-I	2.I898	2.55-I	8.59-I
2I4	2I2	2.I904	5.99-I	I.39-I	2.I949	5.77-I	I.38-I
4I4	2I2	2.I862	2.79-2	2.54-I	2.I908	3.I6-2	2.57-I
224	2I2	2.I878	I.93+0	I.I0+0	2.I923	I.97+0	I.08+0
424	2I2	2.I922	I.80+0	I.77-2	2.I969	I.76+0	2.00-2
404	2I4	2.I866	3.I2+0	8.48-I	2.I924	3.24+0	8.59-I
2I4	2I4	2.I9I6	9.I0-I	I.39-I	2.I975	9.II-I	I.38-I
4I4	2I4	2.I874	I.98-I	2.54-I	2.I933	I.76-I	2.57-I
224	2I4	2.I890	I.II+0	I.I0+0	2.I948	I.[illegible]0+0	I.08+0

Appendix 2 (cont.)

SLJ	$S'L'J'$	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
			$1s2p(^3P)3p - 1s^2 3p$				
424	2I4	2.I935	2.00-I	I.77-2	2.I994	2.02-I	2.00-2
4I6	2I4	2.I868	2.00-I	7.3I-I	2.I926	2.08-I	7.67-I
226	2I4	2.I840	8.49-I	3.34+0	2.I898	8.88-I	3.4I+0
426	2I4	2.I9I4	I.34+0	2.75-I	2.I973	I.29+0	2.84-I
			$1s2p(^1P)3d - 1s^2 3d$				
2I2	224	2.I758	3.55+I	6.85-2	2.I8I2	3.50+I	I.2I-I
2I4	224	2.I749	I.3I+0	6.43-2	2.I803	I.28+0	I.I5-I
224	224	2.I774	3.43+I	2.II-3	2.I829	3.38+I	3.46-3
2I4	226	2.I753	3.29+I	6.43-2	2.I8II	3.24+I	I.I5-I
224	226	2.I778	8.20-I	2.II-3	2.I837	7.86-I	3.46-3
226	224	2.I772	I.30+I	I.94-I	2.I826	I.28+I	2.30-I
236	224	2.I750	I.83+I	I.35+0	2.I8I0	I.80+I	I.56+0
226	226	2.I776	2.28+I	I.94-I	2.I834	2.25+I	2.30-I
236	226	2.I760	I.I2+I	I.35+0	2.I8I9	I.I0+I	I.56+0
238	226	2.I769	3.06+I	I.50+0	2.I827	2.99+I	I.75+0
			$1s2p(^3P)3d - 1s^2 3d$				
2I2	224	2.I807	I.42+0	3.88-3	2.I86I	I.46+0	5.I4-3
4I2	224	2.I834	5.I9-4	3.27-7	2.I889	4.80-4	I.64-6
422	224	2.I873	I.33+0	2.44-3	2.I927	I.32+0	4.63-3
2I4	224	2.I825	7.20-I	4.69-3	2.I879	7.29-I	6.60-3
4I4	224	2.I835	I.I5-I	2.05-4	2.I890	I.I5-I	2.66-4
224	224	2.I882	I.5I-I	3.35-3	2.I937	I.52-I	5.35-3
424	224	2.I873	I.04+0	6.42-5	2.I928	I.02+0	2.46-4
434	224	2.I9I0	5.79-I	8.88-5	2.I965	5.76-I	I.28-4
2I4	226	2.I829	2.96+0	4.69-3	2.I887	2.98+0	6.60-3
4I4	226	2.I839	I.6I-I	2.05-4	2.I898	I.62-I	2.66-4
224	226	2.I886	I.38+0	3.35-3	2.I945	I.36+0	5.35-3
424	226	2.I877	3.44-3	6.42-5	2.I936	3.06-3	2.46-4
434	226	2.I9I4	2.7I-3	8.88-5	2.I973	2.77-3	I.28-4
4I6	224	2.I87I	I.85+0	4.27-3	2.I925	I.85+0	9.73-3
226	224	2.I886	I.46+0	4.57-4	2.I943	I.45+0	I.7I-3

Appendix 2 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
		$1s2p(^3P)3d - 1s^2 3d$					
426	224	2.I835	4.75-I	3.35-3	2.I889	4.72-I	5.22-3
236	224	2.I846	I.56+0	I.06-3	2.I900	I.57+0	3.87-3
436	224	2.I90I	I.59+0	3.44-2	2.I956	I.58+0	4.20-2
4I6	226	2.I875	2.64+0	4.27-3	2.I933	2.62+0	9.73-3
226	226	2.I892	I.33-I	4.57-4	2.I95I	I.3I-I	I.7I-3
426	226	2.I839	6.I7-2	3.35-3	2.I897	6.07-2	5.22-3
236	226	2.I850	I.22+0	I.06-3	2.I908	I.22+0	3.87-3
436	226	2.I905	I.08-I	3.44-2	2.I964	I.08-I	4.20-2
428	226	2.I845	8.26-2	I.64-2	2.I903	8.38-2	I.80-2
238	226	2.I826	6.33+0	2.53-3	2.I884	6.43+0	I.07-2
438	226	2.I890	I.20+0	6.69-2	2.I949	I.I9+0	7.63-2
		$1s2p(^1P)4p - 1s^2 4p$					
202	2I2	2.I762	3.39+0	6.98-I	2.I8I6	3.20+0	7.60-I
2I4	2I2	2.I766	2.80-I	3.29-I	2.I8I9	2.76-I	3.25-I
202	2I4	2.I768	3.32+I	6.98-I	2.I82I	3.22+I	7.60-I
2I4	2I4	2.I77I	3.58+I	3.29-I	2.I825	3.47+I	3.25-I
2I2	2I2	2.I772	3.35+I	5.6I-3	2.I826	3.24+I	7.4I-3
224	2I2	2.I772	3.6I+I	I.25+0	2.I826	3.49+I	I.22+0
226	2I4	2.I774	3.7I+I	8.I0-I	2.I828	3.58+I	7.80-I
2I2	2I4	2.I777	3.25+0	5.6I-3	2.I83I	3.06+0	7.4I-3
224	2I4	2.I778	2.66-I	I.25+0	2.I83I	2.64-I	I.22+0
		$1s2p(^3P)4p - 1s^2 4p$					
202	2I2	2.I823	I.88-I	4.78-I	2.I876	I.93-I	4.88-I
202	2I4	2.I828	9.08-I	4.78-I	2.I882	8.67-I	4.88-I
226	2I4	2.I833	3.25-3	I.49+0	2.I886	2.00-3	I.49+0
2I4	2I2	2.I835	8.28-4	2.49-I	2.I889	I.28-3	2.5I-I
2I4	2I4	2.I84I	4.24-I	2.49-I	2.I894	4.I6-I	2.5I-I
404	2I2	2.I84I	2.42-3	6.30-2	2.I895	2.60-3	6.2I-2
4I6	2I4	2.I845	3.82-2	2.55-I	2.I899	3.82-2	2.59-I
404	2I4	2.I846	5.72-2	6.30-2	2.I900	5.47-2	6.2I-2
224	2I2	2.I870	4.57-I	8.I3-I	2.I924	4.38-I	8.22-I

Appendix 2 (cont.)

sLJ	s'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
				$1s2p(^3P)4p - 1s^2 4p$			
2I2	2I2	2.I873	I.I9-I	9.95-2	2.I926	9.82-2	9.63-2
224	2I4	2.I876	I.87+0	8.I3-I	2.I929	I.8I+0	8.22-I
4I2	2I2	2.I877	I.5I+0	I.I3-I	2.I932	I.49+0	I.25-I
2I2	2I4	2.I878	I.25+0	9.95-2	2.I932	I.23+0	9.63-2
4I2	2I4	2.I883	3.56-I	I.I3-I	2.I937	3.I8-I	I.25-I
426	2I4	2.I883	I.85+0	3.5I-I	2.I937	I.8I+0	3.5I-I
4I4	2I2	2.I884	I.30+0	9.I9-2	2.I938	I.23+0	9.4I-2
4I4	2I4	2.I890	4.68-I	9.I9-2	2.I943	4.57-I	9.4I-2
424	2I2	2.I890	7.86-I	I.06-I	2.I943	7.95-I	I.05-I
424	2I4	2.I895	2.39-3	I.06-I	2.I949	3.00-3	I.05-I
422	2I2	2.I898	2.89-I	8.59-3	2.I95I	2.8I-I	8.87-3
422	2I4	2.I903	3.62-2	8.59-3	2.I957	3.57-2	8.87-3
				$1s2p(^1P)5p - 1s^2 5p$			
202	2I2	2.I76I	3.96+0	3.22-I	2.I8I4	3.7I+0	—
2I2	2I2	2.I766	3.30+I	3.07-3	2.I8I9	3.20+I	—
202	2I4	2.I763	3.30+I	3.22-I	2.I8I7	3.20+I	—
2I2	2I4	2.I768	3.95+0	3.07-3	2.I822	3.70+0	—
2I4	2I2	2.I762	2.07-I	I.59-I	2.I8I6	2.08-I	—
224	2I2	2.I766	3.65+I	5.99-I	2.I8I9	3.53+I	—
2I4	2I4	2.I765	3.65+I	I.59-I	2.I8I9	3.52+I	—
224	2I4	2.I768	2.04-I	5.99-I	2.I82I	2.07-I	—
226	2I4	2.I766	3.70+I	7.96-I	2.I820	3.57+I	—
				$1s2p(^3P)5p - 1s^2 5p$			
202	2I2	2.I825	5.36-2	2.40-I	2.I878	5.35-2	—
2I2	2I2	2.I870	2.52-I	5.86-2	2.I923	2.22-I	—
4I2	2I2	2.I873	I.64+0	7.34-2	2.I926	I.62+0	—
422	2I2	2.I887	I.I8-I	I.29-2	2.I94I	I.I3-I	—
202	2I4	2.I827	I.73-I	2.40-I	2.I88I	I.62-I	—
2I2	2I4	2.I872	I.54+0	5.86-2	2.I926	I.52+0	—
4I2	2I4	2.I876	3.47-I	7.34-2	2.I929	3.II-I	—
422	2I4	2.I890	I.80-2	I.29-2	2.I944	I.78-2	—

Appendix 2 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
				$1s2p(^3P)5p - 1s^2 5p$			
404	2I2	2.I834	I.3I-3	2.45-2	2.I887	I.35-3	—
2I4	2I2	2.I830	I.I4-3	I.I2-I	2.I884	I.38-3	—
4I4	2I2	2.I876	I.95+0	I.09-2	2.I930	I.89+0	—
224	2I2	2.I869	2.53-I	3.89-I	2.I922	2.43-I	—
424	2I2	2.I883	7.53-2	I.43-I	2.I936	7.57-2	—
404	2I4	2.I836	I.45-2	2.45-2	2.I890	I.36-2	—
2I4	2I4	2.I833	9.62-2	I.I2-I	2.I886	9.34-2	—
4I4	2I4	2.I879	2.60-I	I.09-2	2.I932	2.52-I	—
224	2I4	2.I87I	I.95+0	3.89-I	2.I925	I.90+0	—
424	2I4	2.I886	I.7I-2	I.43-I	2.I93[illegible]	I.68-2	—
4I6	2I4	2.I836	8.84-3	I.I2-I	2.I889	8.77-3	—
226	2I4	2.I830	4.53-5	6.95-I	2.I883	I.42-4	—
426	2I4	2.I875	2.00+0	2.35-I	2.I928	I.95+0	—

Appendix 3. Wavelengths (Å) and radiative transition and autoionization probabilities (10^{13} s^{-1}) for Cr XXI

SLJ	$S'L'J'$	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
			$1s2s^22p - 1s^22s^2$				
II3	I0I	2.20I6	3.36+I	9.I4+0	2.2067	3.35+I	9.94+0
3I3	I0I	2.2I20	I.95+0	I.46+I	2.2I73	I.87+0	I.63+I
			$1s2s^22p - 1s^22p^2$				
II3	3II	2.2382	3.0I-I	9.I4+0	2.2490	2.07-I	9.94+0
II3	3I3	2.2406	2.73-2	9.I4+0	2.25I4	I.88-2	9.94+0
II3	3I5	2.2425	2.33-I	9.I4+0	2.2534	I.63-I	9.94+0
3I5	3I3	2.2473	3.I8-I	I.49+I	2.2584	2.29-I	I.67+I
II3	I25	2.2479	I.25+0	9.I4+0	2.2589	9.6I-I	9.94+0
3I3	3II	2.2487	2.40-I	I.46+I	2.2598	I.78-I	I.63+I
3I5	3I5	2.2492	6.I8-I	I.49+I	2.2604	4.62-I	I.67+I
3I3	3I3	2.25II	2.03-I	I.46+I	2.2623	I.54-I	I.63+I
3II	3I3	2.2522	7.80-I	I.50+I	2.2634	5.96-I	I.67+I
3I3	3I5	2.2530	3.I3-I	I.46+I	2.2643	2.5I-I	I.63+I
3I5	I25	2.2546	6.5I-2	I.49+I	2.2659	5.27-2	I.67+I
II3	I0I	2.2559	9.66-I	9.I4+0	2.2668	7.40-I	9.94+0
3I3	I25	2.2585	I.I3-4	I.46+I	2.2698	7.66-5	I.63+I
3I3	I0I	2.2665	I.03-I	I.46+I	2.2778	7.94-2	I.63+I
			$1s(2s2p^2\,{}^2P) - 1s^22s2p$				
3I5	3I3	2.I900	5.78-2	I.82+I	2.I945	2.03-I	I.64+I
3I3	3II	2.I9II	I.I3-2	I.64+I	2.I947	8.97-3	I.90+I
3I3	3I3	2.I922	I.53-2	I.64+I	2.I966	I.38-2	I.90+I
3I5	3I5	2.I930	5.0I-I	I.82+I	2.2009	5.08-I	I.64+I
3I3	3I5	2.I952	9.69+0	I.64+I	2.2030	I.08+I	I.90+I
3II	3I3	2.I955	5.88+0	I.36+I	2.2000	5.86+0	I.38+I
3I5	II3	2.2064	4.30+0	I.82+I	2.2I05	4.55+0	I.64+I
3I3	II3	2.2086	3.89-I	I.64+I	2.2I58	3.I6-I	I.90+I
3II	II3	2.2II9	I.76+0	I.36+I	2.2I90	2.40+0	I.38+I
			$1s(2s2p^2\,{}^4P) - 1s^22s2p$				
3I5	3I3	2.20II	I.83+0	7.55+0	2.2052	2.0I+0	7.35+0
3I3	3II	2.2040	2.84+I	6.97+0	2.2073	2.87+I	9.I5+I

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
				$1s(2s\,2p^2\ ^4P) - 1s^2 2s\,2p$			
3I5	3I5	2.204I	3.79+I	7.55+0	2.2II7	3.77+I	7.35+0
3I3	3I3	2.2052	3.34+0	6.97+0	2.2092	3.39+0	9.I5+I
3II	3I3	2.206I	4.63+I	4.45+0	2.2I03	4.57+I	3.9I+0
3I3	3I5	2.2082	8.5I+0	6.97+0	2.2I58	8.60+0	9.I5+I
3I5	II3	2.2I76	4.25-I	7.55+0	2.2240	3.I9-I	7.35+0
3I3	II3	2.22I7	3.79-3	6.97+0	2.2285	5.46-2	9.I5+I
3II	II3	2.2229	3.32-I	4.45+0	2.2295	4.6I-I	3.9I+0
				$1s\,2s\,2p^2 - 1s^2 2s\,2p$			
I0I	3I3	2.I84I	I.58-2	2.03+I	2.I884	6.I4-2	I.96+I
II3	3II	2.I844	5.27-2	3.47+0	2.I879	5.45-2	2.43+2
II3	3I3	2.I855	2.85-3	3.47+0	2.I898	3.84-I	2.43+2
II3	3I5	2.I885	3.79-2	3.47+0	2.I962	3.72-2	2.43+2
I25	3I3	2.I937	3.53-2	2.50+I	2.I980	I.33-2	2.60+I
303	3II	2.I955	5.79-I	I.II+I	2.I990	6.I5-I	I.09+I
I25	3I5	2.I966	3.73+0	2.50+I	2.2045	4.32+0	2.60+I
303	3I3	2.I967	3.57+0	I.II+I	2.20I0	4.09+0	I.09+I
I0I	II3	2.2003	I.64+I	2.03+I	2.2073	I.65+I	I.96+I
303	3I5	2.I997	7.30+0	I.II+I	2.2074	6.45+0	I.09+I
II3	II3	2.20I8	5.09+I	3.47+0	2.208I	5.09+I	2.43+2
323	3II	2.202I	8.84-2	I.34+I	2.2054	I.I3-I	4.88+2
323	3I3	2.2032	I.95+I	I.34+I	2.2073	I.97+I	4.88+2
325	3I3	2.2045	2.43+I	I.35+I	2.2086	2.40+I	I.40+I
323	3I5	2.2063	6.70+0	I.34+I	2.2I38	6.62+0	4.88+2
327	3I5	2.2062	I.7I+I	I.69+I	2.2I38	I.72+I	I.7I+I
325	3I5	2.2075	I.6I+0	I.35+I	2.2I5I	I.6I+0	I.40+I
I25	II3	2.2I0I	I.27+I	2.50+I	2.2I70	I.24+I	2.60+I
303	II3	2.2I3I	I.05+0	I.II+I	2.2200	7.57-I	I.09+I
323	II3	2.2I98	I.58-I	I.34+I	2.2265	5.67-5	4.88+2
325	II3	2.22I0	I.25-I	I.35+I	2.2277	6.57-I	I.40+I
5I5	3I3	2.2208	8.35-4	7.07-2	2.2249	8.I8-4	7.7I-2
5I3	3II	2.22I7	I.40-I	I.69-I	2.2250	I.43-I	8.25-I
5I7	3I5	2.22I5	4.I8-I	4.25-I	2.2292	4.24-I	4.32-I

Appendix 3 (cont.)

SLJ	$S'L'J'$	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s\,2s\,2p^2$ - $1s^2\,2s\,2p$					
5I3	3I3	2.2229	3.32-I	I.69-I	2.2270	3.36-I	8.25-I
5I5	3I5	2.2238	2.I0-I	7.07-2	2.2215	2.I2-I	7.7I-2
5I3	3I5	2.2259	I.95-2	I.69-I	2.2236	2.02-2	8.25-I
5I5	II3	2.2376	6.03-5	7.07-2	2.2444	I.II-4	7.7I-2
5I3	II3	2.2397		I.69-I	2.2465	2.86-3	8.25-I
		$1s\,2s\,(^1S)\,2p\,3s$ - $1s^2\,2s\,3s$					
3I5	303	2.I85I	7.27-I	I.30-I	2.I906	8.I7-I	--
II3	303	2.I896	8.I9+0	3.60-I	2.I949	8.52+0	--
II3	I0I	2.I930	2.29+I	3.60-I	2.I983	2.20+I	--
3I3	303	2.I938	2.28+I	I.67-I	2.I993	2.22+I	--
3II	303	2.I942	2.50+I	2.70-3	2.I997	2.43+I	--
3I3	I0I	2.I972	2.39+0	I.67-I	2.2027	2.33+0	--
		$1s\,2s\,(^3S)\,2p\,(^2P)\,3s$ - $1s^2\,2s\,3s$					
II3	303	2.I836	3.63-I	I.29+0	2.I890	4.22-I	--
3I3	303	2.I856	5.02+0	I.47-I	2.I9II	4.99+0	--
3II	303	2.I862	I.I5+I	2.33-I	2.I9I7	I.I9+I	--
II3	I0I	2.I870	5.82+0	I.29+0	2.I923	6.72+0	--
3I3	I0I	2.I890	5.06+0	I.47-I	2.I945	4.94+0	--
3I5	303	2.I9I6	3.5I+I	2.33-3	2.I969	3.48+I	--
		$1s\,2s\,(^3S)\,2p\,(^4P)\,3s$ - $1s^2\,2s\,3s$					
3I5	303	2.2007	2.I9-I	I.57+0	2.2059	2.59-I	--
3I3	303	2.2039	8.38-2	I.50+0	2.2090	7.58-2	--
3II	303	2.205I	2.24-I	I.52+0	2.2I02	2.I7-I	--
3I3	I0I	2.2073	5.08-I	I.50+0	2.2I24	5.I2-I	--
5I5	303	2.208I	6.35-I	4.68-2	2.2I35	6.35-I	--
5I3	303	2.2096	2.3I-I	2.43-2	2.2I50	2.32-I	--
5I3	I0I	2.2I3I	2.I3-3	2.43-2	2.2I84	I.89-3	--
		$1s\,2s\,(^1S)\,2p\,3p$ - $1s^2\,2s\,3p$					
I0I	II3	2.I830	I.92-I	I.93+0	2.I887	I.85-I	--
3II	II3	2.I955	I.68-2	2.73-I	2.20I2	I.2I-2	--
I0I	3I3	2.I8I0	9.I5-2	I.93+0	2.I867	9.70-2	--

Appendix 3 (cont.)

SLJ	$S'L'J'$	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s2s(^1S)\,2p3p$ - $1s^2 2s\,3p$					
3II	3I3	2.I935	2.76+I	2.73-I	2.I992	2.7I+I	—
303	3II	2.I906	I.I0+0	7.58-I	2.I962	I.I7+0	—
II3	3II	2.I939	I.54+0	3.67-I	2.I995	I.58+0	—
3I3	3II	2.I9I9	2.08+I	2.22-I	2.I974	2.07+I	—
323	3II	2.I963	7.I4+0	4.34-I	2.202I	6.98+0	—
303	II3	2.I928	I.44+I	7.58-I	2.I984	I.4I+I	—
II3	II3	2.I960	7.52+0	3.67-I	2.20I7	7.35+0	—
3I3	II3	2.I94I	I.42+0	2.22-I	2.I996	I.43+0	—
323	II3	2.I986	I.72+0	4.34-I	2.2043	I.70+0	—
303	3I3	2.I908	6.97+0	7.58-I	2.I964	7.04+0	—
II3	3I3	2.I94I	3.42-2	3.67-I	2.I997	2.88-2	—
3I3	3I3	2.I92I	7.42+0	2.22-I	2.I977	7.29+0	—
323	3I3	2.I966	I.2I+I	4.34-I	2.2023	I.I8+I	—
303	3I5	2.I9I8	6.69+0	7.58-I	2.I974	6.46+0	—
II3	3I5	2.I950	I.26+I	3.67-I	2.2007	I.23+I	—
3I3	3I5	2.I930	4.52+0	2.22-I	2.I986	4.62+0	—
323	3I5	2.I975	I.33-2	4.34-I	2.2033	I.I7-2	—
3I5	II3	2.I873	I.I7+0	4.90-I	2.I930	I.40+0	—
I25	II3	2.I856	9.02-2	3.3I+0	2.I9I2	I.20-I	—
325	II3	2.I963	4.44+0	I.23+0	2.2020	4.35+0	—
3I5	3I3	2.I853	4.62-3	4.90-I	2.I9I0	8.57-3	—
I25	3I3	2.I835	I.I7-2	3.3I+0	2.I892	I.26-2	—
325	3I3	2.I944	I.05+I	I.23+0	2.2000	I.03+I	—
3I5	3I5	2.I863	2.30+0	4.90-I	2.I920	2.74+0	—
I25	3I5	2.I844	8.57-2	3.3I+0	2.I902	9.23-2	—
325	3I5	2.I953	9.60+0	I.23+0	2.20I0	9.43+0	—
327	3I5	2.I870	2.I9+0	I.29+0	2.I928	2.47+0	—
		$1s2s(^3S)\,2p(^2P)3p$ - $1s^2 2s\,3p$					
3II	II3	2.I886	2.29+0	3.88-3	2.I943	2.68+0	—
I0I	3I3	2.I895	4.08-I	9.I7-I	2.I950	5.52-I	—
3II	3I3	2.I867	7.99+0	3.88-3	2.I924	8.42+0	—
303	3II	2.I847	5.87-2	9.98-I	2.I903	6.95-2	—

Appendix 3 (cont.)

LJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
		$1s2s(^3S)2p(^2P)3p - 1s^2 2s 3p$					
II3	3II	2.I839	9.92-2	2.6I-I	2.I895	I.0I-I	—
3I3	3II	2.I858	5.36-2	I.47-2	2.I9I6	5.37-2	—
323	3II	2.I870	4.87+0	2.67+0	2.I927	5.I0+0	—
303	II3	2.I869	I.92+0	9.98-I	2.I925	I.56+0	—
II3	II3	2.I860	8.50+0	2.6I-I	2.I9I7	9.49+0	—
3I3	II3	2.I880	3.43-2	I.47-2	2.I938	4.90-2	—
323	II3	2.I892	I.69-I	2.67+0	2.I949	I.39-I	—
303	3I3	2.I849	I.0I+0	9.98-I	2.I905	I.00+0	—
II3	3I3	2.I84I	4.84-2	2.6I-I	2.I897	7.20-2	—
3I3	3I3	2.I860	7.57-I	I.47-2	2.I9I8	I.00+0	—
323	3I3	2.I873	7.72+0	2.67+0	2.I929	7.88+0	—
303	3I5	2.I859	9.74+0	9.98-I	2.I9I5	I.04+I	—
II3	3I5	2.I85I	5.34-2	2.6I-I	2.I907	I.64-2	—
3I3	3I5	2.I870	I.05+0	I.47-2	2.I927	9.93-I	—
323	3I5	2.I882	6.II-I	2.67+0	2.I939	5.89-I	—
3I5	II3	2.I926	2.II+I	I.I8+0	2.I98I	2.I2+I	—
I25	II3	2.I937	6.32+0	2.0I+0	2.I993	6.I6+0	—
325	II3	2.I886	3.I3+0	2.I5+0	2.I943	3.I2+0	—
3I5	3I3	2.I906	4.I8-I	I.I8+0	2.I96I	3.96-I	—
I25	3I3	2.I9I7	2.26+I	2.0I+0	2.I973	2.28+I	—
325	3I3	2.I867	I.89+0	2.I5+0	2.I924	2.00+0	—
3I5	3I5	2.I9I5	I.40+I	I.I8+0	2.I97I	I.40+I	—
I25	3I5	2.I927	4.83+0	2.0I+0	2.I982	4.77+0	—
325	3I5	2.I876	4.5I+0	2.I5+0	2.I933	4.40+0	—
327	3I5	2.I929	3.38+I	I.74+0	2.I985	3.36+I	—
		$1s2s(^3S)2p(^4P)3p - 1s^2 2s 3p$					
3II	II3	2.2089	2.74-I	3.96-3	2.2I44	2.74-I	—
52I	II3	2.2I37	6.37-4	2.I0-4	2.2I93	7.I5-4	—
3II	3I3	2.2069	3.02-I	3.96-3	2.2I24	3.23-I	—
52I	3I3	2.2II7	3.25-I	2.I0-4	2.2I73	3.30-I	—
303	3II	2.200I	6.53-3	I.05+0	2.2055	7.09-3	—
3I3	3II	2.2070	6.92-2	4.52-I	2.2I25	I.09-I	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
				$1s2s(^3S)2p(^4P)3p - 1s^22s3p$			
5I3	3II	2.2073	4.62-I	2.06-I	2.2I28	4.38-I	—
323	3II	2.2047	9.II-2	2.49+0	2.2I02	9.24-2	—
523	3II	2.2II0	3.44-I	4.86-3	2.2I66	3.50-I	—
303	II3	2.2023	I.59-I	I.05+0	2.2077	I.63-I	—
3I3	II3	2.2092	2.66-2	4.52-I	2.2I47	3.36-2	—
5I3	II3	2.2095	3.26-2	2.06-I	2.2I50	2.82-2	—
323	II3	2.2069	7.46-I	2.49+0	2.2I24	7.58-I	—
523	II3	2.2I32	4.36-3	4.86-3	2.2I88	4.33-3	—
303	3I3	2.2003	8.90-4	I.05+0	2.2057	6.25-4	—
3I3	3I3	2.2072	3.97-2	4.52-I	2.2I27	2.29-2	—
5I3	3I3	2.2075	2.30-I	2.06-I	2.2I30	2.52-I	—
323	3I3	2.2050	3.90-I	2.49+0	2.2I04	4.02-I	—
523	3I3	2.2II2	I.89-6	4.86-3	2.2I68	9.7I-6	—
303	3I5	2.20I3	I.30+0	I.05+0	2.2067	I.36+0	—
3I3	3I5	2.2082	6.35-3	4.52-I	2.2I37	7.97-3	—
5I3	3I5	2.2085	3.47-2	2.06-I	2.2I40	3.I2-2	—
323	3I5	2.2059	I.86-2	2.49+0	2.2II4	2.02-2	—
523	3I5	2.2I22	4.63-2	4.86-3	2.2I78	4.72-2	—
3I5	II3	2.2078	2.49-I	9.07-I	2.2I33	2.49-I	—
5I5	II3	2.2070	I.78-2	I.94-I	2.2I25	I.96-2	—
325	II3	2.2049	I.50-I	I.98+0	2.2I04	I.57-I	—
525	II3	2.2I22	I.I3-2	I.2I-2	2.2I77	I.I7-2	—
3I5	3I3	2.2058	4.49-I	9.07-I	2.2II3	4.66-I	—
5I5	3I3	2.2050	5.22-3	I.94-I	2.2I05	6.65-3	—
325	3I3	2.2029	2.35-2	I.98+0	2.2084	2.37-2	—
525	3I3	2.2I02	5.I4-I	I.2I-2	2.2I57	5.28-I	—
505	3I5	2.2095	4.7I-I	9.40-2	2.2I5I	4.8I-I	—
3I5	3I5	2.2068	8.77-3	9.07-I	2.2I23	6.60-3	—
5I5	3I5	2.2059	6.00-4	I.94-I	2.2II5	3.93-4	—
325	3I5	2.2039	8.24-I	I.98+0	2.2094	8.57-I	—
525	3I5	2.2III	I.97-3	I.2I-2	2.2I67	2.53-3	—
5I7	3I5	2.2053	6.39-2	3.96-I	2.2I08	6.72-2	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
				$1s2s(^3S)2p(^4P)3p - 1s^2 2s\,3p$			
327	3I5	2.2025	I.50-I	3.29+0	2.2079	I.52-I	—
527	3I5	2.2094	4.6I-I	8.83-2	2.2I50	4.65-I	—
				$1s2s(^1S)2p\,3d - 1s^2 2s\,3d$			
3II	323	2.I824	I.6I+0	2.08-3	2.I880	I.77+0	—
II3	323	2.I8I5	9.20-2	2.37-4	2.I87I	I.0I-I	—
3I3	323	2.I895	2.I0+I	4.55-2	2.I950	2.II+I	—
323	323	2.I92I	I.40+I	3.79-3	2.I976	I.35+I	—
II3	I25	2.I847	2.98-2	2.37-4	2.I904	2.6I-2	—
3I3	I25	2.I928	6.35-I	4.55-2	2.I982	6.I3-I	—
323	I25	2.I954	4.60-I	3.79-3	2.2009	4.7I-I	—
II3	325	2.I8I6	8.24-2	2.37-4	2.I873	I.04-I	—
3I3	325	2.I896	I.I6+I	4.55-2	2.I95I	I.II+I	—
323	325	2.I923	I.38+I	3.79-3	2.I978	I.36+I	—
3I5	323	2.I922	4.45-I	2.25-2	2.I978	3.48-I	—
I25	323	2.I886	4.5I-I	I.05-I	2.I94I	3.97-I	—
325	323	2.I836	I.I3-I	5.2I-3	2.I958	I.38+I	—
335	323	2.I940	I.II+I	5.20-I	2.I996	I.07+I	—
3I5	I25	2.I955	3.64+0	2.25-2	2.20II	3.6I+0	—
I25	I25	2.I9I9	I.I5+I	I.05-I	2.I974	I.07+I	—
325	I25	2.I868	3.90+0	5.2I-3	2.I99I	2.92+0	—
335	I25	2.I972	2.49+0	5.20-I	2.2029	2.46+0	—
3I5	325	2.I924	4.80+0	2.25-2	2.I979	4.5I+0	—
I25	325	2.I888	5.46+0	I.05-I	2.I942	5.59+0	—
325	325	2.I837	2.5I-I	5.2I-3	2.I959	I.5I+I	—
335	325	2.I94I	5.47+0	5.20-I	2.I997	5.22+0	—
3I5	327	2.I926	I.43+I	2.25-2	2.I982	I.39+I	—
I25	327	2.I890	I.I0+I	I.05-I	2.I945	I.09+I	—
325	327	2.I839	4.85+0	5.2I-3	2.I96I	3.08-I	—
335	327	2.I943	2.I0-2	5.20-I	2.I999	I.67-2	—
327	I25	2.I866	6.0I-4	2.82-2	2.I923	I.2I-3	—
I37	I25	2.I85I	I.54+0	3.63-I	2.I907	I.66+0	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
				$1s2s(^1S)2p3d - 1s^2 2s3d$			
337	I25	2.I959	I.70+0	6.72-I	2.20I4	I.68+0	—
327	325	2.I835	I.63-I	2.82-2	2.I89I	I.63-I	—
I37	325	2.I820	4.I2-4	3.63-I	2.I876	2.00-4	—
337	325	2.I927	I.05+I	6.72-I	2.I983	I.0I+I	—
327	327	2.I838	8.I0-I	2.82-2	2.I894	9.4I-I	—
I37	327	2.I822	6.93-3	3.63-I	2.I879	I.23-2	—
337	327	2.I930	I.03+I	6.72-I	2.I985	9.98+0	—
339	327	2.I909	3.I3+I	I.I2+0	2.I964	3.06+I	—
				$1s2s(^3S)2p(^2P)3d - 1s^2 2s3d$			
3II	323	2.I892	3.44+I	5.57-2	2.I946	3.39+I	—
II3	323	2.I864	I.23-I	4.38-2	2.I9I8	I.64-I	—
3I3	323	2.I825	2.59-I	3.37-3	2.I88I	2.76-I	—
323	323	2.I838	8.96-I	2.04-2	2.I893	9.28-I	—
II3	I25	2.I896	2.5I+I	4.38-2	2.I95I	2.36+I	—
3I3	I25	2.I857	I.32-I	3.37-3	2.I9I4	I.90-I	—
323	I25	2.I870	I.02+I	2.04-2	2.I925	I.I3+I	—
II3	325	2.I865	5.07+0	4.38-2	2.I920	5.48+0	—
3I3	325	2.I826	I.88+0	3.37-3	2.I882	2.I0+0	—
323	325	2.I839	3.38+0	2.04-2	2.I894	3.I4+0	—
3I5	323	2.I823	I.7I-3	6.I6-3	2.I879	I.73-3	—
I25	323	2.I842	5.70-I	5.76-2	2.I897	3.26-I	—
325	323	2.I903	I.38+I	I.48-I	2.I89I	9.93-2	—
335	323	2.I845	7.73+0	6.66-I	2.I900	8.27+0	—
3I5	I25	2.I855	I.64-I	6.I6-3	2.I9II	2.I9-I	—
I25	I25	2.I874	8.80+0	5.76-2	2.I930	9.20+0	—
325	I25	2.I936	3.08+0	I.48-I	2.I924	5.I3+0	—
335	I25	2.I877	2.70+0	6.66-I	2.I933	I.84+0	—
3I5	325	2.I824	3.46-I	6.I6-3	2.I880	3.7I-I	—
I25	325	2.I843	2.74-2	5.76-2	2.I899	2.46-3	—
325	325	2.I904	I.5I+I	I.48-I	2.I893	2.85-I	—
335	325	2.I846	4.0I+0	6.66-I	2.I90I	4.I3+0	—
3I5	327	2.I827	4.I4+0	6.I6-3	2.I883	4.6I+0	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s\,2s(^3S)2p(^2P)3d - 1s^2 2s\,3d$					
I25	327	2.I845	7.65-3	5.76-2	2.I90I	I.78-I	—
325	327	2.I907	4.5I-I	I.48-I	2.I895	4.53+0	—
335	327	2.I848	7.07-I	6.66-I	2.I904	7.30-I	—
327	I25	2.I937	7.99-2	I.93-I	2.I992	7.77-2	—
I37	I25	2.I9II	3.I0+I	I.02+0	2.I965	3.05+I	—
337	I25	2.I877	2.03+0	4.56-I	2.I933	2.I3+0	—
327	325	2.I906	I.65+I	I.93-I	2.I96I	I.62+I	—
I37	325	2.I880	I.94+0	I.02+0	2.I934	I.98+0	—
337	325	2.I846	5.29+0	4.56-I	2.I901	5.50+0	—
327	327	2.I909	I.85+I	I.93-I	2.I963	I.84+I	—
I37	327	2.I882	I.07+0	I.02+0	2.I936	I.I0+0	—
337	327	2.I848	4.63+0	4.56-I	2.I904	4.69+0	—
339	327	2.I845	3.09+0	2.I5-I	2.I90I	3.38+0	—
		$1s\,2s(^3S)2p(^4P)3d - 1s^2 2s\,3d$					
3I1	323	2.I980	4.27-I	2.I2-3	2.2033	4.54-I	—
52I	323	2.2057	4.86-I	6.66-4	2.2III	4.87-I	—
3I3	323	2.I986	3.94-3	2.44-3	2.2040	4.02-3	—
5I3	323	2.2024	2.3I-3	I.03-6	2.2078	2.26-3	—
323	323	2.2049	6.88-3	7.89-4	2.2I02	7.66-3	—
523	323	2.2058	3.47-I	6.26-4	2.2II2	3.47-I	—
533	323	2.2095	I.78-I	I 07-5	2.2I49	I.79-I	—
3I3	I25	2.20I9	7.94-2	2.44-3	2.2073	7.93-2	—
5I3	I25	2.2057	5.I9-4	I.03-6	2.2III	5.30-4	—
323	I25	2.2082	3.I2-I	7.89-4	2.2I36	3.09-I	—
523	I25	2.209I	4.47-3	6.26-4	2.2I45	4.2I-3	—
533	I25	2.2I28	3.53-3	I.07-5	2.2I82	3.38-3	—
3I3	325	2.I988	7.35-I	2.44-3	2.204I	7.77-I	—
5I3	325	2.2026	I.44-4	I.03-6	2.2080	I.69-4	—
323	325	2.2050	4.89-2	7.89-4	2.2I04	5.06-2	—
523	325	2.2059	I.80-I	6.26-4	2.2II4	I.79-I	—
533	325	2.2096	7.70-2	I.07-5	2.2I5I	7.66-2	—
3I5	325	2.I998	I.I4 0	2.88-3	2.2052	I.22-2	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
		$1s2s(^3S)2p(^4P)3d - 1s^2 2s\,3d$					
5I5	323	2.2025	8.63-2	7.22-5	2.2079	I.I0-I	—
325	323	2.2052	3.3I-I	I.63-3	2.2I06	3.52-I	—
525	323	2.2060	2.57-I	7.70-4	2.2II4	2.57-I	—
335	323	2.2028	I.58+0	6.9I-3	2.2082	I.32+0	—
535	323	2.2090	2.69-I	5.82-3	2.2I44	2.70-I	—
3I5	I25	2.203I	7.07-2	2.88-3	2.2085	6.99-2	—
5I5	I25	2.2058	2.26-2	7.22-5	2.2II2	2.70-2	—
325	I25	2.2085	6.92-3	I.63-3	2.2I39	6.90-3	—
525	I25	2.2093	8.65-4	7.70-4	2.2I48	8.25-4	—
335	I25	2.206I	3.82-I	6.9I-3	2.2II5	3.69-I	—
535	I25	2.2I23	I.32-3	5.82-3	2.2I78	I.27-3	—
3I5	325	2.2000	I.07-I	2.88-3	2.2053	I.I0-I	—
5I5	325	2.2026	3.9I-3	7.22-5	2.2080	7.95-3	—
325	325	2.2054	I.57-I	I.63-3	2.2I07	I.54-I	—
525	325	2.2062	2.66-I	7.70-4	2.2II6	2.7I-I	—
335	325	2.2030	7.6I-I	6.9I-3	2.2083	7.86-I	—
535	325	2.209I	2.I3-2	5.82-3	2.2I46	2.I6-2	—
3I5	327	2.2002	9.65-I	2.88-3	2.2055	I.0I+0	—
5I5	327	2.2029	I.64-2	7.22-5	2.2083	I.82-2	—
325	327	2.2056	I.4I-I	I.63-3	2.2II0	I.48-I	—
525	327	2.2064	I.47-I	7.70-4	2.2II8	I.44-I	—
335	327	2.2032	3.44-2	6.9I-3	2.2086	3.34-2	—
535	327	2.2094	2.29-2	5.82-3	2.2I48	2.27-2	—
5I7	I25	2.2097	3.32-2	9.50-4	2.2I5I	3.20-2	—
327	I25	2.2075	2.96-I	8.53-3	2.2I29	2.94-I	—
527	I25	2.2060	2.27-2	3.23-3	2.2II4	2.3I-2	—
337	I25	2.2040	9.I9-2	I.28-2	2.2094	9.02-2	—
537	I25	2.2II5	2.3I-5	I.4I-2	2.2I70	I.72-5	—
5I7	325	2.2065	2.69-I	9.50-4	2.2II9	2.66-I	—
327	325	2.2043	5.80-I	8.53-3	2.2097	6.0I-I	—
527	325	2.2028	I.52-2	3.23-3	2.2082	I.67-2	—
337	325	2.2029	I.2I+0	I.28-2	2.2062	I.2I+0	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s2s(^3S)2p(^4P)3d - 1s^22s3d$					
537	325	2.2084	3.53-I	I.4I-2	2.2I38	3.50-I	—
5I7	327	2.2067	3.79-I	9.50-4	2.2I22	3.8I-I	—
327	327	2.2046	I.48-I	8.53-3	2.2099	I.48-I	—
527	327	2.203I	7.5I-2	3.23-3	2.2084	7.62-2	—
337	327	2.20II	8.39-I	I.28-2	2.2065	8.73-I	—
537	327	2.2086	I.37-4	I.4I-2	2.2I40	8.73-5	—
529	327	2.2035	5.02-2	6.20-3	2.2089	5.I6-2	—
339	327	2.I996	I.93+0	2.59-2	2.2050	2.03+0	—
539	327	2.2073	4.32-I	2.30-2	2.2I28	4.32-I	—
		$1s2s(^1S)2p4p - 1s^22s4p$					
IOI	II3	2.I832	3.03-I	5.22-I	2.I892	3.85-I	—
30I	II3	2.I933	2.5I-I	2.30-I	2.I993	2.50-I	—
IOI	3I3	2.I824	I.80-I	5.22-I	2.I864	2.09-I	—
30I	3I3	2.I926	2.5I+I	2.30-I	2.I985	2.46+I	—
303	3II	2.I926	2.02-2	I.02-I	2.I985	2.49-2	—
II3	3II	2.I896	I.00+0	3.29-I	2.I954	I.02+0	—
3I3	3II	2.I902	2.25+I	I.54-I	2.I96I	2.25+I	—
323	3II	2.I936	7.80+0	2.07-I	2.I995	7.62+0	—
303	II3	2.I934	4.87+0	I.02-I	2.I993	4.77+0	—
II3	II3	2.I904	2.07+I	3.29-I	2.I962	2.07+I	—
3I3	II3	2.I9II	3.53+0	I.54-I	2.I969	3.46+0	—
323	II3	2.I944	I.36+0	2.07-I	2.2003	I.30+0	—
303	II3	2.I934	4.87+0	I.02-I	2.I993	4.77+0	—
II3	II3	2.I904	2.07+I	3.29-I	2.I962	2.07+I	—
3I3	II3	2.I9II	3.53+0	I.54-I	2.I969	3.46+0	—
323	II3	2.I944	I.36+0	2.07-I	2.2003	I.30+0	—
303	3I3	2.I926	2.86-I	I.02-I	2.I986	2.66-I	—
II3	3I3	2.I897	5.62+0	3.29-I	2.I955	5.52+0	—
3I3	3I3	2.I903	7.99+0	I.54-I	2.I962	7.99+0	—
323	3I3	2.I936	I.37+I	2.07-I	2.I996	I.35+I	—
303	3I5	2.I930	I.83+I	I.02-I	2.I990	I.80+I	—
II3	3I5	2.I90I	6.38 0	3.29-I	2.I959	6.30+0	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
				$1s\,2s\,(^1S)\,2p\,4p$ - $1s^2 2s\,4p$			
3I3	3I5	2.I907	8.57-I	I.54-I	2.I966	8.80-I	—
323	3I5	2.I940	I.2I-2	2.07-I	2.2000	9.99-3	—
3I5	II3	2.I849	6.I9-I	I.8I-I	2.I909	8.96-I	—
I25	II3	2.I840	7.84-I	9.48-I	2.I969	I.9I+0	—
325	II3	2.I934	8.68+0	7.23-I	2.I993	8.64+0	—
3I5	3I3	2.I84I	2.75-I	I.8I-I	2.I90I	2.5I-I	—
I25	3I3	2.I833	5.88-5	9.48-I	2.I96I	3.I5+I	—
325	3I3	2.I926	2.98+0	7.23-I	2.I986	2.80+0	—
3I5	3I5	2.I845	I.I8+0	I.8I-I	2.I905	I.68+0	—
I25	3I5	2.I837	8.73-5	9.48-I	2.I965	I.53+0	—
325	3I5	2.I930	I.26+I	7.23-I	2.I990	I.23+I	—
327	3I5	2.I845	I.28+0	3.65-I	2.I905	I.46+0	—
				$1s\,2s(^3S)2p(^2P)4p$ - $1s^2 2s\,4p$			
I0I	II3	2.I899	3.48+I	5.23-I	2.I957	3.48+I	—
30I	II3	2.I857	9.59-I	9.20-5	2.I9I7	9.62-I	—
I0I	3I3	2.I892	I.0I+0	5.23-I	2.I950	I.04+0	—
30I	3I3	2.I850	I.02+I	9.20-5	2.I909	I.08+I	—
303	3II	2.I840	I.02-I	I.88-I	2.I900	7.I4-2	—
II3	3II	2.I835	6.29-2	I.I6-I	2.I894	7.02-2	—
3I3	3II	2.I844	2.87-I	8.58-2	2.I904	3.38-I	—
323	3II	2.I85I	4.42+0	8.8I-I	2.I910	4.67+0	—
303	II3	2.I848	I.84+0	I.88-I	2.I908	2.I2+0	—
II3	II3	2.I843	2.45+0	I.I6-I	2.I903	2.92+0	—
3I3	II3	2.I852	I.I6+0	8.58-2	2.I9I2	7.66-I	—
323	II3	2.I859	2.03-I	8.8I-I	2.I9I8	I.77-I	—
303	3I3	2.I84I	9.75-I	I.88-I	2.I900	I.07+0	—
II3	3I3	2.I836	7.6I-5	I.I6-I	2.I895	2.5I-3	—
3I3	3I3	2.I845	5.42-3	8.58-2	2.I904	8.02-2	—
323	3I3	2.I85I	7.6I+0	8.8I-I	2.I9II	8.08+0	—
303	3I5	2.I845	3.07+0	I.88-I	2.I905	4.67+0	—
II3	3I5	2.I840	2.45-I	I.I6-I	2.I899	I.95-I	—

Appendix 3 (cont.)

sLJ	$s'L'J'$	GHRO λ	GHRO A	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
		$1s2s(^3S)2p(^2P)4p - 1s^2 2s\,4p$					
3I3	3I5	2.I849	6.90+0	8.58-2	2.I909	5.89+0	--
323	3I5	2.I855	6.42-I	8.8I-I	2.I9I5	6.I8-I	—
3I5	II3	2.I9I0	I.9I+0	7.77-I	2.I962	I.99+I	—
I25	II3	2.I904	2.0I+I	6.79-I	2.I900	9.79-I	—
325	II3	2.I855	4.I9+0	6.50-I	2.I9I4	4.07+0	--
3I5	3I3	2.I903	3.I4+I	7.77-I	2.I955	5.29-2	—
I25	3I3	2.I897	3.9I-2	6.79-I	2.I893	9.60-5	--
325	3I3	2.I847	I.30+0	6.50-I	2.I906	I.45+0	--
3I5	3I5	2.I907	I.70+0	7.77-I	2.I959	I.56+I	—
I25	3I5	2.I900	I.54+I	6.79-I	2.I897	9.I9-5	--
325	3I5	2.I85I	5.37+0	6.50-I	2.I9II	5.2I+0	--
327	3I5	2.I905	3.49+I	6.9I-I	2.I963	3.48+I	--
		$1s2s(^3S)2p(^4P)4p - 1s^2 2s\,4p$					
3II	II3	2.2062	4.86-I	2.05-3	2.2I20	4.93-I	—
52I	II3	2.2090	5.6I-4	I.84-4	2.2I48	4.I7-4	—
3II	3I3	2.2055	3.27-3	2.05-3	2.2II2	4.07-3	—
52I	3I3	2.2083	2.60-I	I.84-4	2.2I40	2.64-I	—
303	3II	2.20II	I.28-2	4.52-I	2.2068	I.39-2	--
3I3	3II	2.2064	I.I3-I	5.67-I	2.2I2I	I.I3-I	—
5I3	3II	2.2059	2.2I-I	I.I5-I	2.2II6	2.26-I	--
323	3II	2.2047	2.68-2	7.77-I	2.2I05	2.50-2	--
523	3II	2.2079	2.09-I	I.6I-2	2.2I37	2.I2-I	—
303	II3	2.20I9	2.24-2	4.52-I	2.2077	2.I5-2	--
3I3	II3	2.2072	4.79-4	5.67-I	2.2I30	4.64-4	--
5I3	II3	2.2067	9.48-3	I.I5-I	2.2I25	9.39-3	—
323	II3	2.2056	6.68-I	7.77-I	2.2II4	6.79-I	—
523	II3	2.2087	7.00-3	I.6I-2	2.2I45	6.87-3	—
303	3I3	2.20II	7.49-3	4.52-I	2.2069	8.52-3	—
3I3	3I3	2.2064	4.40-4	5.67-I	2.2I22	2.88-4	—
5I3	3I3	2.2059	3.09-I	I.I5-I	2.2II7	3.I2-I	—
323	3I3	2.2048	3.36-2	7.77-I	2.2I06	3.I5-2	—
523	3I3	2.2080	I.92-2	I.6I-2	2.2I37	I.99-2	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s2s(^3S)2p(^4P)4p - 1s^2 2s4p$					
303	3I5	2.20I5	I.39-I	4.52-I	2.2073	I.36-I	—
3I3	3I5	2.2068	I.46-I	5.67-I	2.2I26	I.47-I	—
5I3	3I5	2.2063	I.27-3	I.I5-I	2.2I2I	I.20-3	—
323	3I5	2.2052	2.46-2	7.77-I	2.2II0	2.49-2	—
523	3I5	2.2039	3.56-2	I.6I-2	2.2I42	3.59-2	—
505	II3	2.2037	2.35-3	4.43-2	2.2095	2.44-3	—
3I5	II3	2.2029	I.90-2	4.62-I	2.2086	I.94-2	—
5I5	II3	2.2072	2.4I-3	3.46-2	2.2I30	2.20-3	—
325	II3	2.2058	3.87-I	7.89-I	2.2II5	3.93-I	—
525	II3	2.208I	4.20-2	7.90-2	2.2I39	4.30-2	—
505	3I3	2.2029	I.I3-3	4.43-2	2.2087	I.22-3	—
3I5	3I3	2.202I	I.98-3	4.62-I	2.2978	2.47-3	—
5I5	3I3	2.2064	5.89-I	3.46-2	2.2I22	5.94-I	—
325	3I3	2.2050	9.I3-2	7.89-I	2.2I08	9.I5-2	—
525	3I3	2.2073	I.I5-I	7.90-2	2.2I3I	I.I8-I	—
505	3I5	2.2033	4.I0-3	4.43-2	2.209I	4.I6-3	—
3I5	3I5	2.2025	I.05-I	4.62-I	2.2083	I.06-I	—
5I5	3I5	2.2068	I.94-I	3.46-I	2.2I26	I.97-I	—
325	3I5	2.2054	I.82-I	7.89-I	2.2II2	I.82-I	—
525	3I5	2.2077	8.46-2	7.90-2	2.2I35	8.52-2	—
5I7	3I5	2.2032	I.25-2	I.48-I	2.2090	I.29-2	—
327	3I5	2.2020	I.76-3	I.34+0	2.2077	I.22-3	—
527	3I5	2.2064	6.05-I	I.44-I	2.2I2I	6.I5-I	—
		$1s2s(^1S)2p5p - 1s^2 2s5p$					
I0I	II3	2.I829	7.27-I	2.05-I	2.I89I	8.32-I	—
3II	II3	2.I925	6.83-I	I.4I-I	2.I985	6.83-I	—
I0I	3I3	2.I825	8.48-2	2.05-I	2.I887	I.32-I	—
3II	3I3	2.I92I	2.42+I	I.4I-I	2.I982	2.34+I	—
303	3II	2.I897	2.I9+I	2.66-I	2.I955	2.25+I	—
II3	3II	2.I894	I.04+0	I.72-I	2.I95I	9.88-I	—
3I3	3II	2.I92I	5.56-4	2.86-I	2.I98I	4.2I-4	—
323	3II	2.I925	8.06+0	3.79-I	2.I986	7.74+0	—

Appendix 3 (cont.)

SLJ	$S'L'J'$	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s2s(^1S)2p5p - 1s^22s5p$					
303	II3	2.I90I	3.89+0	2.66-I	2.I959	3.64+0	—
II3	II3	2.I898	2.I9+I	I.72-I	2.I955	2.27+I	—
3I3	II3	2.I925	4.38+0	2.86-I	2.I986	4.I8+0	—
323	II3	2.I929	I.22+0	3.79-I	2.I99I	I.I3+0	—
303	3I3	2.I898	8.03+0	2.66-I	2.I955	8.38+0	—
II3	3I3	2.I894	4.95+0	I.72-I	2.I952	4.77+0	—
3I3	3I3	2.I92I	2.79-I	2.86-I	2.I982	2.50-I	—
323	3I3	2.I926	I.45+I	3.79-I	2.I987	I.4I+I	—
303	3I5	2.I900	4.46-I	2.66-I	2.I957	4.67-I	—
II3	3I5	2.I896	5.96+0	I.72-I	2.I954	5.99+0	—
3I3	3I5	2.I923	I.95+I	2.86-I	2.I984	I.89+I	—
323	3I5	2.I928	I.27-2	3.79-I	2.I989	6.99-3	—
3I5	II3	2.I837	8.82-2	I.2I-I	2.I899	I.87-I	—
I25	II3	2.I90I	9.89-I	3.55-I	2.I959	I.I6+0	—
325	II3	2.I925	I.0I+I	3.99-I	2.I985	9.94+0	—
3I5	3I3	2.I833	6.94-I	I.2I-I	2.I896	7.26-I	—
I25	3I3	2.I898	3.23+I	3.55-I	2.I955	3.3I+I	—
325	3I3	2.I92I	I.6I+0	3.99-I	2.I982	I.48+0	—
3I5	3I5	2.I835	3.0I-I	I.2I-I	2.I898	5.07-I	—
I25	3I5	2.I900	I.08+0	3.55-I	2.I957	8.I4-I	—
325	3I5	2.I923	I.27+I	3.99-I	2.I984	I.22+I	—
327	3I5	2.I835	I.II+0	I.59-I	2.I897	I.28+0	—
		$1s2s(^3S)2p(^2P)5p - 1s^22s5p$					
I0I	II3	2.I896	3.34+I	2.63-I	2.I953	3.42+I	—
3II	II3	2.I845	6.40-I	I.06-3	2.I907	6.97-I	—
I0I	3I3	2.I892	I.39+0	2.63-I	2.I949	I.50+0	—
3II	3I3	2.I842	I.00+I	I.06-3	2.I903	I.I7+I	—
303	3II	2.I833	3.97-I	[illegible]	2.I895	3.75-I	—
II3	3II	2.I830	3.34-2	I.23-2	2.I892	3.99-2	—
3I3	3II	2.I839	2.55-I	4.5I-3	2.I900	3.32-I	—
323	3II	2.I842	3.80+0	3.98-I	2.I903	4.4I+0	—
303	II3	2.I837	4.22-I	I.97-2	2.I899	5.63-I	—

Appendix 3 (cont.)

SLJ	S'L'J'	GHRO λ	GHRO ..	GHRO Γ	HFRO λ	HFRO A	HFRO Γ
			$1s2s(^3S)2p(^2P)5p - 1s^22s5p$				
II3	II3	2.I834	I.27+0	I.23-2	2.I896	I.67+0	—
3I3	II3	2.I843	2.I8+0	4.5I-3	2.I904	2.25+0	—
323	II3	2.I846	I.62-I	3.98-I	2.I907	I.46-I	—
303	3I3	2.I833	5.32-I	I.97-2	2.I896	7.38-I	—
II3	3I3	2.I830	2.69-2	I.23-2	2.I893	6.00-3	—
3I3	3I3	2.I839	8.87-2	4.5I-3	2.I900	6.47-2	—
323	3I3	2.I843	7.I9+0	3.98-I	2.I904	8.25+0	—
303	3I5	2.I835	2.08-I	I.97-2	2.I898	5.47-I	—
II3	3I5	2.I832	2.54-I	I.23-2	2.I895	2.20-I	—
3I3	3I5	2.I84I	8.72+0	4.5I-3	2.I902	9.85+0	—
323	3I5	2.I845	6.I8-I	3.98-I	2.I906	6.95-I	—
3I5	II3	2.I898	I.89+I	3.43-I	2.I956	I.89+I	—
I25	II3	2.I833	8.I6-I	3.9I-I	2.I895	I.0I+0	—
325	II3	2.I844	4.63+0	2.47-I	2.I905	5.23+0	—
3I5	3I3	2.I895	I.74-3	3.43-I	2.I952	3.30-2	—
I25	3I3	2.I829	7.0I-3	3.9I-I	2.I89I	5.86-3	—
325	3I3	2.I840	7.34-I	2.47-I	2.I90I	8.83-I	—
3I5	3I5	2.I897	I.56+I	3.43-I	2.I954	I.64+I	—
I25	3I5	2.I83I	7.99-2	3.9I-I	2.I893	6.37-2	—
325	3I5	2.I842	5.7I+0	2.47-I	2.I903	6.46+0	—
327	3I5	2.I898	3.43+I	3.36-I	2.I956	3.50+I	—
			$1s2s(^3S)2p(^4P)5p - 1s^22s5p$				
3II	II3	2.2052	5.26-I	I.06-3	2.2II2	5.73-I	—
52I	II3	2.2072	3.22-3	I.27-4	2.2I34	2.94-3	—
3II	3I3	2.2048	6.45-3	I.06-3	2.2I09	5.85-3	—
52I	3I3	2.2068	2.I9-I	I.27-4	2.2I30	2.35-I	—
303	3II	2.20I2	4.80-3	I.43-I	2.207I	5.I8-3	—
3I3	3II	2.2059	3.46-2	3.6I-I	2.2I20	3.5I-2	—
5I3	3II	2.2050	3.06-I	5.07-3	2.2III	3.35-I	—
323	3II	2.2045	3.43-2	2.93-I	2.2I05	3.45-2	—
523	3II	2.2066	I.29-I	4.84-2	2.2I28	I.39-I	—
303	II3	2.20I6	4.66-3	I.43-I	2.2075	4.36-3	—

Appendix 3 (cont.)

sLJ	s'L'J'	GHRO			HFRO		
		λ	A	Γ	λ	A	Γ
		$1s2s(^3S)2p(^4P)5p - 1s^22s5p$					
3I3	II3	2.2063	3.86-3	3.6I-I	2.2I25	4.59-3	—
5I3	II3	2.2054	I.46-2	5.07-3	2.2II5	I.48-2	—
323	II3	2.2049	5.68-I	2.93-I	2.2I09	6.I6-I	—
523	II3	2.2070	9.92-3	4.84-2	2.2I32	I.03-2	—
303	3I3	2.20I2	3.42-3	I.43-I	2.207I	3.74-3	—
3I3	3I3	2.2060	I.53-2	3.6I-I	2.2I2I	I.64-2	—
5I3	3I3	2.205I	2.74-I	5.07-3	2.2II2	2.85-I	—
323	3I3	2.2045	5.06-3	2.93-I	2.2I06	5.00-3	—
523	3I3	2.2067	4.59-2	4.84-I	2.2I28	4.98-2	—
303	3I5	2.20I4	2.77-2	I.43-I	2.2073	2.82-2	—
3I3	3I5	2.2062	I.44-I	3.6I-I	2.2I23	I.54-I	—
5I3	3I5	2.2053	7.08-3	5.07-3	2.2II4	7.76-3	—
323	3I5	2.2047	5.5I-2	2.93-I	2.2I08	6.07-2	—
523	3I5	2.2069	3.03-2	4.84-I	2.2I30	3.I8-2	—
505	II3	2.2024	5.42-4	I.76-2	2.2084	5.I6-4	—
3I5	II3	2.2020	3.93-3	I.76-I	2.2079	4.I5-3	—
5I5	II3	2.2067	5.97-2	6.83-2	2.2I29	6.5I-2	—
325	II3	2.2050	3.65-I	3.99-I	2.2II0	3.94-I	—
525	II3	2.2057	2.25-4	9.I7-3	2.2II8	8.04-5	—
505	3I3	2.202I	5.I4-4	I.76-2	2.2080	5.29-4	—
3I5	3I3	2.20I6	9.42-4	I.76-I	2.2075	I.I7-3	—
5I5	3I3	2.2064	2.87-2	6.83-2	2.2I25	2.98-2	—
325	3I3	2.2046	4.2I-2	3.99-I	2.2I06	4.69-2	—
525	3I3	2.2053	6.0I-I	9.I7-3	2.2II4	6.5I-I	—
505	3I5	2.2023	I.43-3	I.76-2	2.2082	I.25-3	—
3I5	3I5	2.20I8	2.I2-2	I.76-I	2.2078	2.28-2	—
5I5	3I5	2.2066	I.I2-I	6.83-2	2.2I27	I.2I-I	—
325	3I5	2.2048	2.23-I	3.99-I	2.2I09	2.42-I	—
525	3I5	2.2055	9.I7-2	9.I7-3	2.2II6	9.79-2	—
5I7	3I5	2.2022	2.53-3	6.20-2	2.2082	2.90-3	—
327	3I6	2.20I6	I.47-9	6.II-I	2.2075	2.29-8	—
527	3I5	2.2052	6.07-I	9.75-2	2.2II3	6.59-I	—

Appendix 4. Wavelengths (Å) and electrical quadrupole transition probabilities (s^{-1}) in chromium ions

SLJ	$S'L'J'$	HFRO λ	HFRO A	SLJ	$S'L'J'$	HFRO λ	HFRO A
		$1s^2 2s^2 2p$				$1s^2 2s^2 2p^4$	
2I4	2I2	II96.0	3.79-I	3II	3I5	I679.0	2.09-I
		$1s^2 2s^2 2p^2$		I25	3II	I3I5.6	I.52-2
3I5	3II	I228.0	I.67-I	IOI	3I5	344.I4	I.9I+I
I25	3II	542.40	I.I5-2	IOI	I25	645.I2	7.82+I
IOI	3I5	395.59	6.60+I	3I3	3I5	I726.6	I.08-I
IOI	I25	667.30	5.36+I	I25	3I3	I287.8	2.09-2
3I5	3I3	27I2.2	5.I9-3	I25	3I5	737.63	2.2I+0
I25	3I3	7I5.3I	7.70-I				
I25	3I5	97I.53	9.80-I			$1s^2 2s^2 2p^5$	
				2I2	2I4	I437.9	4.23-I
		$1s^2 2s^2 2p^3$					
2I2	404	399.97	2.47+0				
2I4	2I2	2924.3	I.42-3				
2I2	224	836.33	8.07+0				
2I2	226	I034.4	2.22+0				
2I4	404	35I.84	5.65-2				
224	404	766.58	3.85-I				
2I4	224	650.34	7.90+0				
226	404	652.I3	I.2I+0				
2I4	226	764.I0	I.44+I				
226	224	4368.I	2.62-4				

Appendix 5. Wavelengths (Å) and magnetic dipole transition probabilities (s^{-1}) in chromium ions

SLJ	S'L'J'	HFRO λ	HFRO A	SLJ	S'L'J'	HFRO λ	HFRO A
		$1s^2 2s^2 2p$				$1s^2 2s\, 2p^2$	
2I4	2I2	II96.0	5.26+3	2I2	4I2	239.I2	2.34+4
		$1s^2 2s^2 2p^2$		202	2I2	II7I.0	5.69+3
3I3	3II	2244.0	I.5I+3	202	4I2	I98.57	I.70+2
IOI	3I3	345.24	7.04+4	2I4	2I2	963.73	5.0I+3
3I5	3I3	27I2.2	5.68+2	2I2	4I4	26I.4I	3.22+4
I25	3I3	7I5.3I	5.87+3	2I2	224	8I8.03	2.72+2
I25	3I5	97I.53	5.9I+3	2I4	4I2	I9I.58	I.33+3
		$1s^2 2s^2 2p^3$		4I4	4I2	2804.3	9.94+2
2I2	404	399.97	I.3I+4	224	4I2	337.88	I.54+3
2I4	2I2	2924.3	2.94+2	2I4	202	5444.4	2.66+I
2I2	224	836.33	4.I8+3	202	4I4	2I3.70	3.67+4
2I4	404	35I.84	I.99+4	202	224	48I.60	2.39+3
224	404	766.58	4.48+3	2I4	4I4	205.63	6.43+3
2I4	224	650.34	I.62+4	2I4	224	442.46	8.30+3
226	404	652.I3	2.50+2	224	4I4	384.I7	4.05+3
2I4	226	764.I0	5.60+3	2I4	4I6	224.48	I.2I+3
226	224	4368.I	I.09+2	2I4	226	467.I0	4.57+3
		$1s^2 2s^2 2p^4$		4I6	4I4	2449.4	I.08+3
3II	3I3	60892.	2.I3-I	226	4I4	367.34	5.23+3
IOI	3I3	429.8I	6.66+4	224	4I6	455.63	2.II+3
3I3	3I5	I726.6	4.07+3	226	224	8387.4	I.76+I
I25	3I3	I287.8	4.35+2	226	4I6	432.I6	I.33+4
I25	3I5	737.63	6.47+3			$1s^2 2s\, 2p^3$	
		$1s^2 2s^2 2p^5$		303	3II	547.79	2.34+3
2I2	2I4	I437.9	6.04+3	II3	3II	3I9.43	I.I6+3
		$1s^2 2s\, 2p$		3I3	3II	I6932.	3.30+0
II3	3II	278.I8	I.25+4	3II	323	870.94	6.99+3
3I3	3II	4202.5	2.39+2	II3	303	766.24	I.28+4
II3	3I3	297.90	7.52+3	303	3I3	566.II	I.08+3
II3	3I5	366.27	6.85+3	303	323	336.28	2.29+3
3I5	3I3	I595.9	3.27+3	II3	3I3	325.57	3.27+3

Appendix 5 (cont.)

SLJ	S'L'J'	HFRO		SLJ	S'L'J'	HFRO	
		λ	A			λ	A
		$1s^2 2s 2p^3$				$1s^2 2s 2p^4$	
II3	323	233.7I	8.3I+3	202	4I2	293.53	6.I3+3
3I3	323	828.33	7.68+3	2I2	2I4	I578.4	3.7I+3
303	505	I72.95	I.90+3	2I2	4I4	2I2.50	I.05+4
303	3I5	603.97	I.29+3	2I2	224	397.90	7.5I+3
I25	303	568I.I	5.24-2	2I4	4I2	256.58	I.33+3
303	325	335.46	6.40+3	4I2	4I4	57I2.2	2.33+2
II3	505	I4I.I0	7.58+I	224	4I2	495.6I	I.I2+3
II3	3I5	337.75	5.34+3	2I4	202	2038.5	I.70-2
II3	I25	885.70	5.78+0	202	4I4	279.I8	5.03+4
II3	325	233.3I	2.75-4	202	224	7I9.90	I.27+2
3I3	505	249.0[illegible]	2.07+4	2I4	4I4	245.55	5.67+2
3I5	3I3	9030.7	I.82+I	2I4	224	532.02	5.55+3
I25	3I3	5I4.8I	3.74+3	224	4I4	456.04	5.20+3
3I3	325	823.34	5.75+I	2I4	4I6	22I.32	7.39+3
323	505	356.07	2.I8-3	2I4	226	558.99	2.47+3
3I5	323	758.74	I.I2+3	4I4	4I6	2242.I	2.I3+3
I25	323	3I7.49	I.53+2	226	4I4	437.93	I.0I+3
323	325	I3652I	I.47-2	224	4I6	378.96	3.02+2
3I5	505	242.34	3.65+4	226	224	II028.	7.84+0
I25	505	I67.84	6.0I+2	226	4I6	366.37	I.30+4
325	505	357.0I	5.74+3			$1s^2 2s 2p^5$	
I25	3I5	545.93	8.34+3	II3	3II	4I4.I3	4.08-3
3I5	325	754.55	4.67-3	3II	3I3	3524.5	I.2I-3
I25	325	3I6.75	4.76-3	II3	3I3	370.58	4.20+3
327	505	336.40	2.02+2	II3	3I5	3I8.93	I.67+4
3I5	327	866.76	4.96+3	3I3	3I5	2268.2	I.85+3
I25	327	334.96	5.86-2			$1s 2p$	
327	325	5828.4	7.9I-I	II3	3II	396.59	I.59+4
				3I3	3II	4I29.6	2.4I+2
		$1s^2 2s 2p^4$		II3	3I3	438.72	8.3I+3
2I2	4I2	220.7I	8.0I+3	II3	3I5	705.04	3.53-3
2I2	202	889.59	7.50+3	3I5	3I3	II6I.5	8.I3+3