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Energies and Electric Dipole Transitions for Sodium-like Gold

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Abstract: We have reported energies and electric dipole transition parameters such as transition probabilities, oscillator strengths, line strengths and wavelengths for Na like gold (Au^{68+} , $Z=79$) using AUTOSTRUCTURE atomic code. Calculations include Breit and QED contributions besides correlation effects. A few of the results have been compared with available theoretical and experimental results in the literature. Our atomic structure data for sodium-like gold are in good agreement with others. Also we have presented new results for electric dipole transitions in sodium like gold.

Key words: Energies, correlation effects, Breit and QED contributions, electric dipole transitions

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1. Introduction

Gold has been a significant element which plays important roles in magnetic fusion and high energy density (HED) plasmas [1]. Accurate atomic structure and spectral data of highly ionized gold (Au , $Z=79$) ions are needed, in particular, in plasma science, fusion reaction, biomedical applications, high-energy astrophysics and other scientific research fields [2]. Na like ions which only a valence electron outside the last closed shell is the simplest system for atomic calculations such as transition rates. The investigation of highly charged ions (HCI) is of great importance in many fields of science and technology such as atomic physics, plasma

physics, laser physics, and astrophysics [3]. Because of the relativistic and quantum electrodynamical (QED) effects are strongly dependent on the nuclear charge Z , highly charged heavy ions are suitable for investigations of high-order quantum electrodynamics (QED) effects [4].

Although there are a lot of papers about Na-like ions, only a few works have considered the properties of Na-like Au^{68+} . Theodosiou and Curtis [5] calculated 3p and 3d lifetimes in the sodium isoelectronic sequence for $Z=11-54, 74, 79, 90$, and 92. QED contributions to the 3s-3p transitions in highly charged Na-like ions were determined by Seely and Wagner [6]. Kim et al. [7] presented resonance transition energies of Li-, Na-, and Cu-like ions. Relativistic multireference many-body perturbation theory calculations on $\text{Au}^{64+} - \text{Au}^{69+}$ ions were reported by Vilkas et al. [8]. Brown et al. [9] investigated the $2p_{3/2}-3d_{5/2}$ line emission of $\text{Au}^{53+}-\text{Au}^{69+}$ for diagnosing high energy density plasmas. Ralchenko et al. [10] presented the first measurements and detailed analysis of extreme ultraviolet (EUV) spectra of highly charged tungsten ions and also measured the EUV spectra for Hf, Ta and Au. A direct observation of the D-line doublet of Na-like ions with $Z \geq 72$ was reported by Gillaspay et al [11]. Beiersdorfer et al. [1] studied ionization balance of high- Z ions. A comprehensive study of transition energies of the D lines in Na-like ions was presented by Gillaspay et al. [12]. Sapirstein and Cheng [13] performed the S -matrix calculations of energy levels of sodium like ions.

The aim of this work is to perform calculations of energy levels and radiative properties, such as wavelengths, oscillator strengths, line strengths, and transition decay probabilities (or rates) for electric dipole (E1) transitions in Na-like Au (Au^{68+} , $Z=79$). The calculations have been obtained using atomic structure code (AUTOSTRUCTURE) within the frame work of the

Breit-Pauli distorted wave approach [14] developed by Badnell. Also we have here investigated QED (self-energy and vacuum polarization) and Breit interaction (magnetic interaction between the electrons and retardation effects of the electron-electron interaction) contributions. We had made a similar study for Mg-like Au (Au^{67+}) [15]. The ground state configuration of Na like gold is $1s^2 2s^2 2p^6 3s$. In this work, we have studied with three different configuration sets for calculations according to valence–valence correlation, core–valence correlation and core-core correlation within the frame work of configuration interaction expansion. In the calculations, we have taken into account the configurations of nl ($n=3-7$ and $l=0-6$) including one electron excitation from valence to other high subshells for valence-valence correlation(VV); nl ($n=3-7$ and $l=0-6$), $2p^5 3l 3l'$ ($l, l'=0-2$) and $2p^5 3d 4l$ ($l=0-3$) including one electron excitations from 2p subshell to other high subshells for core-valence correlation(CV), and nl ($n=3-7$ and $l=0-6$), $2p^5 3l 3l'$ ($l, l'=0-2$), $2p^5 3d 4l$ ($l=0-3$), $2s 2p^6 3l 3l'$ ($l, l'=0,1$) and $2p^4 3s^2 3p$, $2p^4 3s 3p^2$, $2p^4 3p^3$, $2p^4 3p^2 3d$, $2p^4 3d^3$, $2p^4 3d^2 4s$ including two electron excitations from 2p subshell to other high subshells for core-core correlation (CC).

2. Calculation method

The details of the theory on AUTOSTRUCTURE code which is based on SUPERSTRUCTURE can be found in [14, 16-20]. We outline it in the present work briefly. This code is a general program for the calculation of atomic properties such as energies, radiative and autoionization rates and photoionization cross sections using non-relativistic or semi-relativistic wave functions. In this code, the configuration set is chosen optionally and added new configuration to improve accuracy (a configuration interaction (CI) expansion). The CI expansion is related to the choice of radial functions. Each (nl) radial function is calculated in Thomas-Fermi or Slater-Type-Orbital potential model. The Hamiltonian in any coupling model (LS, IC or ICR) is diagonalized to obtain eigenvalues and eigenvectors with

which to construct the rates. In addition, AUTOSTRUCTURE code uses non-relativistic or kappa-averaged relativistic wave functions and the full Breit interaction in Pauli approximation. This code also includes quantum electrodynamics (QED) contributions. For an ion with N electrons, a set of configurations

$$c = \prod_{nl} (nl)^{q_{nl}}, \quad \sum_i q_i = N \quad (1)$$

defines a trial solution $\Psi(\gamma)$ to a suitable Hamiltonian H in the multiconfigurational sum form

$$\Psi(\gamma | \mathbf{x}_1, \dots, \mathbf{x}_N) = \sum_k a_k \Phi_k(c_k(\gamma) | \mathbf{x}_1, \dots, \mathbf{x}_N) \quad (2)$$

where γ denotes configuration and coupling scheme. In intermediate coupling (IC) wave functions can be written as

$$\Psi = \Psi(\Gamma SLJM_J | \mathbf{x}_1, \dots, \mathbf{x}_N) \quad (3)$$

which are eigenvectors to the Breit-Pauli matrix $\langle k | H_{BP} | k' \rangle$ with eigenvalues E_k .

Quantum electrodynamics (QED) contributions include vacuum polarization and self-energy contributions to level energies. The finite-nucleus effect is taken into account by assuming an extended Fermi distribution for the nucleus. Both of Breit and QED contributions are treated as perturbation. Orbitals are fixed, but the mixing coefficients are calculated by diagonalizing the modified Hamiltonian. The correlation effects are taken into account by CI (configuration interaction) method. The correlation contribution should be separated for three parts: correlation of core electrons, correlation between core and valence electrons, and correlation of two valence electrons.

For transitions, this code computes Einstein coefficients and associated quantities for multipole transitions of low multipolarity (for electric dipole, E1, radiation). Generally,

electric multipole transitions exist in both of LS coupling and intermediate coupling (or jj-coupling). As intermediate coupling wave functions contain admixtures of order α^2 , radiative operators must also be expanded up to Breit contributions order. In the long wavelength low intensity approximation the transition probability (or rate) for spontaneous emission from the upper level to the lower level is given by

$$A_{i' \rightarrow i} = 2.6774 \times 10^9 \frac{(E_i - E_{i'})^3}{g_{i'}} \cdot S(i, i') \quad (4)$$

where, $g_{i'}$ is statistical weighted of the upper level, E_i and $E_{i'}$ are energies of the levels i and i' , respectively. The electric dipole line strengths $S(i, i')$ is defined by

$$S(i, i') = \left| \langle i' \| R^{[k]} \| i \rangle \right|^2 \quad (5)$$

where $R^{[k]}$ is a transition operator and describes each multipole and k is 1 for electric dipole radiation.

The oscillator strength may refer to transition either in absorption or emission. In absorption, the oscillator strength is

$$f_{ii'} = \frac{1}{g_{i'}} \cdot \frac{E_i - E_{i'}}{3} \cdot S(i, i') \quad , \quad E_{i'} < E_i \quad (6)$$

A similar expression applies to emission oscillator strength where i' and i are changed. In this case, oscillator strength is negative. The weighted oscillator strength, or gf -value, is an important property. This property is completely symmetrical (except for sign) between two levels and is given by

$$gf_{ii'} = g_i \cdot f_{ii'} \quad (7)$$

The intensity of the special line is proportional to the line strength and also to the gf value.

3. Results and Discussion

We have calculated the energies and radiative parameters such as wavelengths, λ (in Å) weighted oscillator strengths, gf , line strengths S (in au) and transition probabilities (or rates), A (in s^{-1}) for electric dipole (E1) transitions in Na-like Au (Au^{68+} , $Z=79$) using atomic structure code (AUTOSTRUCTURE) developed by Badnell [14]. We have considered nl ($n=3-7$ and $l=0-6$) configurations for valence-valence correlation and nl ($n=3-7$ and $l=0-6$), $2p^5 3l3l'$ ($l, l'=0-2$), $2p^5 3d4l$ ($l=0-3$) configurations for core-valence correlation and nl ($n=3-7$ and $l=0-6$), $2p^5 3l3l'$ ($l, l'=0-2$), $2p^5 3d4l$ ($l=0-3$), $2s2p^6 3l3l'$ ($l, l'=0,1$) and $2p^4 3s^2 3p$, $2p^4 3s3p^2$, $2p^4 3p^3$, $2p^4 3p^2 3d$, $2p^4 3d^3$, $2p^4 3d^2 4s$ for core-core correlation. QED and Breit interaction contributions have been considered according to Breit-Pauli approach [14, 16-20]. In the tables, the superscript "o" denotes only odd-parity levels and we omitted the core $1s^2 2s^2 2p^6$. Also the number in brackets in the tables represents the power of 10.

In Table 1 we have listed the energy levels and compared with other available works in [7, 8, 12, 13, 21]. Also, the correlation effects (valence-valence, core-valence and core-core) and Breit and QED contributions on energy levels have been exhibited in this table. We have obtained 45 energy levels from valence-valence correlation, 514 energy levels from core-valence correlation and 1547 energy levels from core-core correlation. Here we have only listed the levels of nl ($n=3-7$, $l=0-6$). There are a few data for Na like gold in the literature for comparing. For this reason, we have calculated the atomic structure properties such as energies and radiative parameters for this ion using the MCHF (multiconfiguration Hartree-Fock) atomic structure code [22, 23] developed by Fischer for comparing some levels from AUTOSTRUCTURE results and presented in Table 1. The MCHF atomic structure code has been widely used in literature. This code also includes Breit-Pauli relativistic corrections and

correlation effects as in AUTOSTRUCTURE code. In Table, we have only reported the MCHF results obtained according to core-core correlation. In MCHF calculation, we have taken into the configurations of nl ($n=3-6$ and $l=0-3$), $2p^5 3s 3p$, $2p^5 3s 4s$, $2p^5 3s 4p$, $2p^5 3s 5s$, $2p^5 3s 5p$, $2p^5 3d^2$, $2p^5 3d 4s$, $2p^4 3s^2 3p$, $2p^4 3s 3p^2$, $2p^4 3s^2 3d$, $2p^4 3s^2 4s$, and $2p^4 3s^2 4p$. In MCHF calculation, the core $1s^2 2s^2$ is fixed. This set of configurations gives 333 levels. In Table 1, the values with superscript “*” have been obtained CV and CC correlation calculations include the configurations excitations from the closed shell $2s$. We added $2s 2p^5 3p^3$ in CV calculation and $2s 2p^5 3s^2 3p$, $2p^6 3s 3p^2$ and $2p^6 3s^2 3p$ in CC correlation calculations. It is seen that these values do not change much according to CV and CC correlation calculations include only excitations from the closed subshell $2p$. When Table 1 has been investigated, the results obtained from CV and CC correlations (and plus Breit and QED contributions) are in agreement with other works. In addition, we have calculated $\left(\frac{E_{our}-E_{other}}{E_{other}}\right) \times 100$, the differences in per cent, for the accuracy of our AUTOSTRUCTURE and MCHF results and reported in Table 2. It is seen from this table that only the differences from VV (valence correlation), and plus Breit and QED contributions, in AUTOSTRUCTURE and MCHF calculations for $3p^2 P_{1/2}$ are somewhat poor. Other results are in agreement. Here we have calculated these differences in per cent (%) according to [8]. Table 3 lists other high energy levels from AUTOSTRUCTURE and MCHF calculations.

The best agreement has been obtained from CV+Breit+QED calculation for energies. Therefore we have calculated the electric dipole transition parameters between these energy levels and presented in tables. Table 4 lists the wavelengths, weighted oscillator strengths, line strengths and transition rates (or probabilities) for possible electric dipole (E1) transitions among $3l$ ($l=0-2$) levels obtained from CV+Breit+QED calculation using AUTOSTRUCTURE code and CC+Breit calculations using the MCHF code. We could only

find comparing values for these transitions in literature. These transition parameters are in agreement with other works. Table 5 only includes the transitions obtained from AUTOSTRUCTURE and MCHF calculations for comparing with each other. In this table the transition parameters obtained from AUTOSTRUCTURE and MCHF except $4p\ ^2P_{1/2, 3/2}-4s\ ^2S_{1/2}$, $5p\ ^2P_{1/2, 3/2}-5s\ ^2S_{1/2}$ and $6p\ ^2P_{1/2, 3/2}-6s\ ^2S_{1/2, 3/2}$ transitions are in agreement with each other. We didn't explain for this case. The transition results obtained are too much. For this reason, we have here presented just a part of the results. MCHF results are somewhat restricted because of the configuration limit of code. Hence other transitions obtained from AUTOSTRUCTURE code for Na-like gold have been presented in Table 6. The oscillator strengths (*gf-values*) presented in Table 5 and Table 6 are in length form. The *gf-values* either length or velocity form has given as supplementary material (Table S1).

4. Conclusion

In this work we tried to make a systematic AUTOSTRUCTURE study of the energies, weighted oscillator strengths, line strengths, wavelengths and transition probabilities for the electric dipole transitions in sodium like gold have been presented. Energy levels and transition parameters for sodium like gold (Au^{68+}) are only available for a limited number in the literature. Therefore we have made the calculations using the MCHF atomic structure code for reliable of AUTOSTRUCTURE results for this ion. We find that the agreement is good. That is the results obtained from AUTOSTRUCTURE code have been supported by using relativistic multiconfiguration Hartree-Fock calculations. Hence we have here report new data from both of these atomic structure codes. Reliable atomic data in the study of astrophysical problems are needed. In addition, the correlation and relativistic effects are important for atomic calculations. Thus, we have to consider these effects for highly charged ions of heavy elements. Of course our results need other works including computational and

experimental works for comparing. We hope that the results reported in this paper will be useful in the interpretation of the atomic spectra of Na-like gold (Au^{68+}).

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Table 1. Energies (cm⁻¹) of $3l$ ($l=0-2$) levels for Na-like gold (Au⁶⁸⁺). Here we omitted $1s^22s^22p^6$. **A:** Valence-valence correlation (VV), **B:** VV+Breit+QED, **C:** Core-valence correlation (CV), **D:** CV+Breit+QED, **E:** Core-core correlation (CC), **F:** CC+Breit+QED. The results with superscript “*” include the configurations excited from 2s for CV+Breit+QED and CC+Breit+QED

Levels		This Work						Other Works	
		AUTOSTRUCTURE							MCHF
		A	B	C	D	E	F		
3s	$^2S_{1/2}$	0	0	0	0	0	0	0	0 ^{a,b,c,d,e}
3p	$^2P^o_{1/2}$	1175954	1145951	1433967	1401520 1394226*	1439181	1406732 1404454*	1670161	1428506 ^a 1428326 ^b 1428702 ^c 1428564 ^d 1429101 ^e
3p	$^2P^o_{3/2}$	5491097	5455982	5580176	5546229 5536183*	5582401	5548463 5546379*	5485638	5542749 ^a 5542881 ^b 5543006 ^c 5548584 ^d 5543326 ^e
3d	$^2D_{3/2}$	7207647	7160502	6952287	6905174 6893401*	6950370	6903228 6903841*	7052357	7179829 ^a
3d	$^2D_{5/2}$	8190953	8143272	7917892	7870315 7858372*	7915791	7868185 7868811*	8049964	8106367 ^a

^a Ref. 8, ^b Ref. 13, ^c Ref. 12, ^d Ref 21, ^e Ref 7.

Table 2. Differences in per cent (%) between our results obtained AUTOSTRUCTURE and MCHF calculations for $3l$ ($l=0-2$) levels for Na-like gold (Au⁶⁸⁺), and Ref. 8 in Table 1. The results with superscript “*” also include the configurations excited from 2s for CV+Breit+QED and CC+Breit+QED. Here we omitted $1s^22s^22p^6$. **A:** Valence-valence correlation (VV), **B:** VV+Breit+QED, **C:** Core-valence correlation (CV), **D:** CV+Breit+QED, **E:** Core-core correlation (CC), **F:** CC+Breit+QED.

Levels		AUTOSTRUCTURE					MCHF
		A	B	C	D	E	F
3s	² S _{1/2}	0	0	0	0	0	0
3p	² P _{1/2}	17.67	19.77	0.38	1.88 2.39*	0.74	1.52 1.68*
3p	² P _{3/2}	0.93	1.56	0.67	0.06 0.11*	0.71	0.10 0.06*
3d	² D _{3/2}	0.38	0.26	3.16	3.82 3.98*	3.19	3.85 3.84*
3d	² D _{5/2}	1.04	0.45	2.32	2.91 3.05*	2.35	2.93 2.93*

Table 3. Energies (cm^{-1}) of nl ($n=4-7$, $l=0-6$) levels for Na-like gold (Au^{68+}). Here we omitted $1s^2 2s^2 2p^6$. **A:** Valence-valence correlation (VV), **B:** VV+Breit+QED, **C:** Core-valence correlation (CV), **D:** CV+Breit+QED, **E:** Core-core correlation (CC), **F:** CC+Breit+QED.

Levels		AUTOSTRUCTURE						MCHF
		A	B	C	D	E	F	
4s	$^2S_{1/2}$	30840613	30811453	31704090	31674995	31711352	31682240	32102206
4p	$^2P^o_{1/2}$	31408852	31367052	32270112	32228402	32279883	32238192	31861564
4p	$^2P^o_{3/2}$	33117573	33074930	33980018	33937424	33989798	33947223	33196286
4d	$^2D_{3/2}$	33751964	33704093	34615916	34568120	34625804	34578029	33708464
4d	$^2D_{5/2}$	34171923	34123843	35035958	34987946	35045845	34997853	34148096
4f	$^2F^o_{5/2}$	34493517	34445283	35357306	35309152	35367197	35319063	34637548
4f	$^2F^o_{7/2}$	34674374	34626119	35538186	35490008	35548077	35499920	34826952
5s	$^2S_{1/2}$	44539293	44500470	45403526	45364771	45413386	45374652	45293256
5p	$^2P^o_{1/2}$	44847827	44802603	45711627	45666479	45721467	45676338	45149476
5p	$^2P^o_{3/2}$	45693118	45647821	46556943	46511707	46566772	46521556	45805188
5d	$^2D_{3/2}$	45994531	45946492	46858975	46811009	46868865	46820919	46006984
5d	$^2D_{5/2}$	46210339	46162196	47074779	47026706	47084667	47036615	46252772
5f	$^2F^o_{5/2}$	46368677	46320469	47232877	47184744	47242768	47194655	46548040
5f	$^2F^o_{7/2}$	46461995	46413771	47326215	47278064	47336106	47287975	46656708
5g	$^2G_{7/2}$	46482016	46433859	47346523	47298441	47356414	47308352	-
5g	$^2G_{9/2}$	46536397	46488240	47400901	47352818	47410792	47362729	-
6s	$^2S_{1/2}$	51786740	51743836	52651152	52608318	52661023	52618209	52256700
6p	$^2P^o_{1/2}$	51974835	51928242	52839110	52792590	52848973	52802473	52212756
6p	$^2P^o_{3/2}$	52451813	52405354	53315989	53269596	53325839	53279466	52652380
6d	$^2D_{3/2}$	52615941	52567844	53480476	53432452	53490366	53442362	52761352
6d	$^2D_{5/2}$	52740910	52692754	53605435	53557351	53615324	53567260	52971048
6f	$^2F^o_{5/2}$	52830296	52782107	53694670	53646554	53704561	53656466	53198100
6f	$^2F^o_{7/2}$	52884495	52836295	53748879	53700751	53758770	53710662	53298660
6g	$^2G_{7/2}$	52897453	52849296	53762029	53713946	53771921	53723857	-
6g	$^2G_{9/2}$	52928985	52880827	53793559	53745474	53803450	53755385	-
6h	$^2H^o_{9/2}$	52929359	52881204	53794011	53745928	53803902	53755839	-
6h	$^2H^o_{11/2}$	52950210	52902054	53814862	53766779	53824753	53776690	-
7s	$^2S_{1/2}$	56076421	56031506	56940918	56896074	56950794	56905971	-
7p	$^2P^o_{1/2}$	56203673	56156415	57068129	57020944	57078004	57030839	-
7p	$^2P^o_{3/2}$	56497683	56450661	57362006	57315051	57371866	57324931	-
7d	$^2D_{3/2}$	56593174	56545051	57457752	57409702	57467642	57419612	-
7d	$^2D_{5/2}$	56671848	56623690	57536414	57488327	57546304	57498237	-
7f	$^2F^o_{5/2}$	56726960	56678784	57591432	57543327	57601323	57553239	-
7f	$^2F^o_{7/2}$	56761150	56712964	57625623	57577510	57635515	57587421	-
7g	$^2G_{7/2}$	56769744	56721588	57634352	57586268	57644243	57596179	-
7g	$^2G_{9/2}$	56789610	56741453	57654215	57606130	57664106	57616042	-
7h	$^2H^o_{9/2}$	56789941	56741785	57654593	57606510	57664484	57616421	-
7i	$^2I_{11/2}$	56802973	56754817	57667625	57619542	57677516	57629453	-
7h	$^2H^o_{11/2}$	56803084	56754929	57667737	57619653	57677628	57629564	-
7i	$^2I_{13/2}$	56812320	56764165	57676972	57628889	57686863	57638800	-

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Table 4. Transition probabilities, A_r (s^{-1}), weighted oscillator strengths, (gf), wavelengths, λ ($\text{\AA}$), and line strengths, $S(\text{au})$, for electric dipole (E1) transitions in Na-like gold (Au^{68+} , $Z=79$). Numbers in square brackets represent powers of 10. Again we omitted the core $1s^22s^22p^6$. The results obtained from CV+Breit+QED calculation using AUTOSTRUCTURE code and CC+Breit calculation using the MCHF code are given here.

Levels				$A_r(s^{-1})$			gf			$\lambda(\text{\AA})$			$S(\text{au})$		
Upper		Lower		AUTOSTRUCTURE	MCHF	Other works	AUTOSTRUCTURE	MCHF	Other works	AUTOSTRUCTURE	MCHF	Other works	AUTOSTRUCTURE	MCHF	Other works
3p	$^2P^o_{1/2}$	3s	$^2S_{1/2}$	4.829[10]	8.394[10]	4.95[10] ^f	0.0737	0.0902	0.0650 ^g	71.3511	59.87	69.991 ^a 70.025 ^a 69.99 ^b 70.030 ^b 69.974 ^c 69.973 ^d 69.994 ^e 69.96 ^f 70.009 ^f	1.73[-02]	1.77[-02]	-
3p	$^2P^o_{3/2}$	3s	$^2S_{1/2}$	3.181[12]	3.187[12]	-	0.6202	0.6352	0.6317 ^g	18.0303	18.23	18.066 ^a 18.030 ^a 18.040 ^c 18.032 ^d 18.0408 ^e	3.68[-02]	3.81[-02]	-
3d	$^2D_{3/2}$	3p	$^2P^o_{1/2}$	2.223[12]	1.900[12]	-	0.4402	0.3933	0.4535 ^g	18.1697	18.58	-	2.63[-02]	2.40[-02]	-
3d	$^2D_{3/2}$	3p	$^2P^o_{3/2}$	6.545[09]	9.757[09]	-	0.0213	0.0238	0.0255 ^g	73.5865	63.83	-	5.14[-03]	5.01[-03]	-
3d	$^2D_{5/2}$	3p	$^2P^o_{3/2}$	2.039[11]	2.673[11]	-	0.3396	0.3657	0.3798 ^g	43.0277	39.00	-	4.81[-02]	4.69[-02]	-

^a Ref. 11, ^b Ref. 10, ^c Ref. 7, ^d Ref. 6, ^e Ref. 12, ^f Ref. 8, ^g Ref. 5.

Table 5. Transition probabilities, A_r (s^{-1}), weighted oscillator strengths, (gf), wavelengths, λ ($\text{\AA}$), and line strengths, $S(\text{au})$, for electric dipole (E1) transitions in Na-like gold (Au^{68+} , $Z=79$) obtained from AUTOSTRUCTURE and MCHF codes in this work. Numbers in square brackets represent powers of 10.

Levels				$A_r(s^{-1})$		gf		$\lambda(\text{\AA})$		$S(\text{au})$	
Upper		Lower		AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF
4s	$2S_{1/2}$	3p	$2P^o_{1/2}$	2.272[13]	1.182[13]	0.0743	0.0382	3.3032	3.29	8.08[-04]	4.14[-04]
4s	$2S_{1/2}$	3p	$2P^o_{3/2}$	8.047[13]	4.964[13]	0.3534	0.2100	3.8272	3.76	4.45[-03]	2.59[-03]
4p	$2P^o_{1/2}$	3s	$2S_{1/2}$	8.544[13]	1.057[14]	0.2466	0.3122	3.1029	3.14	2.51[-03]	3.22[-03]
4p	$2P^o_{1/2}$	3d	$2D_{3/2}$	2.455[13]	2.483[13]	0.1148	0.1209	3.9489	4.03	1.49[-03]	1.60[-03]
4p	$2P^o_{1/2}$	4s	$2S_{1/2}$	1.065[10]	9.139[08]	0.1042	0.0473	180.6990	415.71	6.20[-02]	6.48[-02]
4p	$2P^o_{3/2}$	3s	$2S_{1/2}$	4.972[13]	7.468[13]	0.2589	0.4064	2.9466	3.01	2.51[-03]	4.03[-03]
4p	$2P^o_{3/2}$	3d	$2D_{3/2}$	1.281[12]	1.312[12]	0.0105	0.0115	3.6993	3.82	1.28[-04]	1.45[-04]
4p	$2P^o_{3/2}$	3d	$2D_{5/2}$	1.455[13]	1.482[13]	0.1284	0.1405	3.8363	3.98	1.62[-03]	1.84[-03]
4p	$2P^o_{3/2}$	4s	$2S_{1/2}$	7.542[11]	8.966[10]	0.8836	0.4491	44.2003	91.39	1.28[-01]	1.35[-01]
4d	$2D_{3/2}$	3p	$2P^o_{1/2}$	1.327[14]	1.339[14]	0.7234	0.7827	3.0151	3.12	7.18[-03]	8.04[-03]
4d	$2D_{3/2}$	3p	$2P^o_{3/2}$	3.067[13]	2.852[13]	0.2183	0.2147	3.4457	3.54	2.47[-03]	2.50[-03]
4d	$2D_{3/2}$	4p	$2P^o_{1/2}$	7.376[11]	3.591[11]	0.8080	0.6315	42.7402	54.15	1.13[-01]	1.12[-01]
4d	$2D_{3/2}$	4p	$2P^o_{3/2}$	2.876[09]	1.519[09]	0.0434	0.0347	158.5548	195.28	2.26[-02]	2.23[-02]
4d	$2D_{5/2}$	3p	$2P^o_{3/2}$	1.755[14]	1.629 [14]	1.8210	1.7842	3.3965	3.49	2.03[-02]	2.04[-02]
4d	$2D_{5/2}$	4p	$2P^o_{3/2}$	8.183[10]	6.015[10]	0.6670	0.5973	95.1907	105.07	2.09[-01]	2.06[-01]
4f	$2F^o_{5/2}$	3d	$2D_{3/2}$	3.460[14]	3.225[14]	3.8580	3.8132	3.5206	3.63	4.47[-02]	4.55[-02]
4f	$2F^o_{5/2}$	3d	$2D_{5/2}$	2.375[13]	2.203[13]	0.2838	0.2803	3.6445	3.76	3.40[-03]	3.47[-03]
4f	$2F^o_{5/2}$	4d	$2D_{3/2}$	1.749[10]	3.414[10]	0.2865	0.3557	134.9470	107.62	1.27[-01]	1.26[-01]
4f	$2F^o_{5/2}$	4d	$2D_{5/2}$	9.999[07]	3.505[08]	0.0087	0.0131	311.3269	204.27	8.93[-03]	8.85[-03]
4f	$2F^o_{7/2}$	3d	$2D_{5/2}$	3.602[14]	3.341[14]	5.6630	5.5901	3.6206	3.73	6.74[-02]	6.87[-02]
4f	$2F^o_{7/2}$	4d	$2D_{5/2}$	5.835[09]	1.433[10]	0.2776	0.3729	199.1784	147.29	1.82[-01]	1.80[-01]
5s	$2S_{1/2}$	3p	$2P^o_{1/2}$	7.999[12]	1.727[12]	0.0124	0.0027	2.2746	2.29	9.30[-05]	2.05[-05]
5s	$2S_{1/2}$	3p	$2P^o_{3/2}$	3.858[13]	1.867[13]	0.0730	0.0353	2.5114	2.51	6.03[-04]	2.92[-04]
5s	$2S_{1/2}$	4p	$2P^o_{1/2}$	7.351[12]	3.990[12]	0.1277	0.0663	7.6125	7.45	3.20[-03]	1.62[-03]
5s	$2S_{1/2}$	4p	$2P^o_{3/2}$	2.434[13]	1.521[13]	0.5589	0.3116	8.7509	8.27	1.61[-02]	0.84[-02]
5p	$2P^o_{1/2}$	3s	$2S_{1/2}$	4.288[13]	4.493[13]	0.0617	0.0660	2.1898	2.21	4.44[-04]	4.81[-04]
5p	$2P^o_{1/2}$	3d	$2D_{3/2}$	9.991[12]	1.074 [13]	0.0199	0.0221	2.5799	2.62	1.69[-04]	1.91[-04]
5p	$2P^o_{1/2}$	4s	$2S_{1/2}$	1.711[13]	2.106[13]	0.2620	0.3710	7.1472	7.66	6.16[-03]	9.36[-03]
5p	$2P^o_{1/2}$	4d	$2D_{3/2}$	1.038[13]	1.080[13]	0.2527	0.2475	9.0103	8.74	7.49[-03]	7.12[-03]
5p	$2P^o_{1/2}$	5s	$2S_{1/2}$	4.505[09]	4.973[08]	0.1484	0.0722	331.4468	695.95	1.61[-01]	1.65[-01]
5p	$2P^o_{3/2}$	3s	$2S_{1/2}$	3.169[13]	3.928[13]	0.0879	0.1122	2.1500	2.18	6.22[-04]	8.06[-04]
5p	$2P^o_{3/2}$	3d	$2D_{3/2}$	4.224[11]	5.792[11]	0.0016	0.0023	2.5248	2.58	1.30[-05]	1.96[-05]
5p	$2P^o_{3/2}$	3d	$2D_{5/2}$	5.885[12]	7.664[12]	0.0236	0.0322	2.5879	2.65	2.01[-04]	2.81[-04]
5p	$2P^o_{3/2}$	4s	$2S_{1/2}$	9.443[12]	1.535[13]	0.2572	0.4902	6.7400	7.30	0.57[-02]	1.17[-02]
5p	$2P^o_{3/2}$	4d	$2D_{3/2}$	5.631[11]	6.833[11]	0.0237	0.0280	8.3727	8.27	6.52[-04]	7.62[-04]
5p	$2P^o_{3/2}$	4d	$2D_{5/2}$	6.338[12]	7.661[12]	0.2862	0.3381	8.6777	8.58	8.17[-03]	9.54[-03]
5p	$2P^o_{3/2}$	5s	$2S_{1/2}$	2.513[11]	2.323[10]	1.1450	0.5314	87.1888	195.30	3.28[-01]	3.41[-01]
5d	$2D_{3/2}$	3p	$2P^o_{1/2}$	6.913[13]	7.349[13]	0.2011	0.2241	2.2022	2.26	1.45[-03]	1.66[-03]

Table 5 (continued)

Levels				Ar(s ⁻¹)		<i>gf</i>		$\lambda(\text{\AA})$		S(au)	
Upper		Lower		AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF
5d	² D _{3/2}	3p	² P _{3/2} ^o	1.492[13]	1.451[13]	0.0525	0.0530	2.4234	2.47	4.19[-04]	4.30[-04]
5d	² D _{3/2}	4p	² P _{1/2} ^o	2.123[13]	2.284[13]	0.5987	0.6845	6.8575	7.07	1.35[-02]	1.59[-02]
5d	² D _{3/2}	4p	² P _{3/2} ^o	5.889[12]	5.714[12]	0.2131	0.2088	7.7678	7.81	5.44[-03]	5.36[-03]
5d	² D _{3/2}	4f	² F _{5/2} ^o	1.823[12]	2.169[12]	0.0827	0.1006	8.6942	8.80	2.36[-03]	2.91[-03]
5d	² D _{3/2}	5p	² P _{1/2} ^o	2.387[11]	9.829[10]	1.0930	0.8018	87.3721	116.63	3.14[-01]	3.07[-01]
5d	² D _{3/2}	5p	² P _{3/2} ^o	8.488[08]	2.552[08]	0.0568	0.0376	334.1107	495.76	6.25[-02]	6.14[-02]
5d	² D _{5/2}	3p	² P _{3/2} ^o	9.110[13]	8.892[13]	0.4762	0.4813	2.4108	2.45	3.78[-03]	3.88[-03]
5d	² D _{5/2}	4p	² P _{3/2} ^o	3.278[13]	3.160[13]	1.7210	1.6676	7.6398	7.66	4.32[-02]	4.20[-02]
5d	² D _{5/2}	4f	² F _{5/2} ^o	6.800[10]	8.075[10]	0.0045	0.0053	8.5342	8.61	1.25[-04]	1.52[-04]
5d	² D _{5/2}	4f	² F _{7/2} ^o	1.558[12]	1.826[12]	0.1053	0.1258	8.6680	8.75	3.00[-03]	3.62[-03]
5d	² D _{5/2}	5p	² P _{3/2} ^o	2.641[10]	1.708[10]	0.8957	0.7672	194.1751	223.47	5.72[-01]	5.64[-01]
5f	² F _{5/2} ^o	3d	² D _{3/2}	1.161[14]	1.190[14]	0.6440	0.6865	2.4826	2.53	5.26[-03]	5.72[-03]
5f	² F _{5/2} ^o	3d	² D _{5/2}	7.703[12]	7.797[12]	0.0448	0.0473	2.5436	2.60	3.75[-04]	4.04[-04]
5f	² F _{5/2} ^o	4d	² D _{3/2}	5.471[13]	5.858[13]	3.0920	3.1966	7.9261	7.79	8.06[-02]	8.19[-02]
5f	² F _{5/2} ^o	4d	² D _{5/2}	3.943[12]	4.222[12]	0.2384	0.2470	8.1989	8.06	6.43[-03]	6.55[-03]
5f	² F _{5/2} ^o	5d	² D _{3/2}	7.988[09]	2.383[10]	0.5144	0.7321	267.5695	184.79	4.53[-01]	4.45[-01]
5f	² F _{5/2} ^o	5d	² D _{5/2}	4.252[07]	2.737[08]	0.0153	0.0282	632.7607	338.57	3.18[-02]	3.14[-02]
5f	² F _{7/2} ^o	3d	² D _{5/2}	1.207[14]	1.222[14]	0.9323	0.9838	2.5376	2.59	7.78[-03]	8.39[-03]
5f	² F _{7/2} ^o	4d	² D _{5/2}	5.864[13]	6.264[13]	4.6570	4.8022	8.1366	7.99	1.24[-01]	1.26[-01]
5f	² F _{7/2} ^o	5d	² D _{5/2}	2.599[09]	1.069[10]	0.4934	0.7859	397.8393	247.51	6.46[-01]	6.40[-01]
6s	² S _{1/2}	3p	² P _{1/2} ^o	2.323[12]	3.625[12]	0.0027	0.0042	1.9529	1.98	1.70[-05]	2.76[-05]
6s	² S _{1/2}	3p	² P _{3/2} ^o	2.471[13]	4.656[12]	0.0335	0.0063	2.1249	2.14	2.34[-04]	4.49[-05]
6s	² S _{1/2}	4p	² P _{1/2} ^o	3.150[12]	1.092[12]	0.0227	0.0078	4.9068	4.90	3.67[-04]	1.27[-04]
6s	² S _{1/2}	4p	² P _{3/2} ^o	1.341[13]	9.908[12]	0.1154	0.0817	5.3559	5.25	2.03[-03]	1.41[-03]
6s	² S _{1/2}	5p	² P _{1/2} ^o	2.987[12]	1.630[12]	0.1859	0.0967	14.4054	14.07	8.81[-03]	4.48[-03]
6s	² S _{1/2}	5p	² P _{3/2} ^o	9.675[12]	6.846[12]	0.7805	0.4932	16.4026	15.50	4.21[-02]	2.51[-02]
6p	² P _{1/2} ^o	3s	² S _{1/2}	2.326[13]	1.393[13]	0.0250	0.0153	1.8942	1.92	1.56[-04]	0.96[-04]
6p	² P _{1/2} ^o	3d	² D _{3/2}	4.215[12]	6.244[12]	0.0060	0.0091	2.1792	2.21	4.30[-05]	6.69[-05]
6p	² P _{1/2} ^o	4s	² S _{1/2}	1.004[13]	9.887[12]	0.0675	0.0733	4.7354	4.97	1.05[-03]	1.20[-03]
6p	² P _{1/2} ^o	4d	² D _{3/2}	4.427[12]	6.925[12]	0.0400	0.0606	5.4871	5.40	0.72[-03]	1.07[-03]
6p	² P _{1/2} ^o	5s	² S _{1/2}	5.204[12]	7.823[12]	0.2828	0.4899	13.4629	14.45	1.25[-02]	2.33[-02]
6p	² P _{1/2} ^o	5d	² D _{3/2}	4.783[12]	6.561[12]	0.4009	0.5108	16.7180	16.11	2.20[-02]	2.70[-02]
6p	² P _{1/2} ^o	6s	² S _{1/2}	2.221[09]	2.810[07]	0.1962	0.0438	542.6779	2280.15	3.50[-01]	3.28[-01]
6p	² P _{3/2} ^o	3s	² S _{1/2}	2.065[13]	1.443[13]	0.0436	0.0312	1.8772	1.90	2.70[-04]	1.95[-04]
6p	² P _{3/2} ^o	3d	² D _{3/2}	1.724[11]	3.852[11]	0.0005	0.0011	2.1568	2.19	3.00[-06]	8.02[-06]
6p	² P _{3/2} ^o	3d	² D _{5/2}	3.568[12]	8.619[12]	0.0104	0.0259	2.2027	2.24	0.75[-04]	1.91[-04]
6p	² P _{3/2} ^o	4s	² S _{1/2}	7.176[12]	9.138[12]	0.0923	0.1297	4.6308	4.87	1.40[-03]	2.07[-03]
6p	² P _{3/2} ^o	4d	² D _{3/2}	2.639[11]	5.514[11]	0.0045	0.0092	5.3472	5.28	0.80[-04]	1.60[-04]
6p	² P _{3/2} ^o	4d	² D _{5/2}	3.435[12]	7.533[12]	0.0616	0.1319	5.4700	5.40	1.11[-03]	2.34[-03]

Table 5 (continued)

Levels			Ar(s ⁻¹)		<i>gf</i>		$\lambda(\text{\AA})$		S(au)	
Upper	Lower		AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF	AUTOSTRUCTURE	MCHF
6p	² P _{3/2} ^o	5s ² S _{1/2}	2.805[12]	6.140[12]	0.2692	0.6798	12.6505	13.59	1.12[-02]	3.04[-02]
6p	² P _{3/2} ^o	5d ² D _{3/2}	2.794[11]	4.915[11]	0.0402	0.0667	15.4833	15.05	2.04[-03]	3.30[-03]
6p	² P _{3/2} ^o	5d ² D _{5/2}	3.121[12]	5.683[12]	0.4803	0.8322	16.0182	15.63	2.53[-02]	4.28[-02]
6p	² P _{3/2} ^o	6s ² S _{1/2}	1.023[11]	2.011[10]	1.4030	0.7699	151.2224	252.67	6.98[-01]	6.40[-01]
6d	² D _{3/2}	3p ² P _{1/2} ^o	3.451[13]	3.671[13]	0.0764	0.0843	1.9219	1.96	4.84[-04]	5.43[-04]
6d	² D _{3/2}	3p ² P _{3/2} ^o	8.632[12]	9.517[12]	0.0226	0.0255	2.0883	2.12	1.55[-04]	1.77[-04]
6d	² D _{3/2}	4p ² P _{1/2} ^o	1.319[13]	1.786[13]	0.1759	0.2453	4.7161	4.78	2.73[-03]	3.86[-03]
6d	² D _{3/2}	4p ² P _{3/2} ^o	3.575[12]	4.626[12]	0.0564	0.0724	5.1295	5.11	0.95[-03]	1.21[-03]
6d	² D _{3/2}	4f ² F _{5/2} ^o	7.198[11]	2.836[12]	0.0131	0.0517	5.5178	5.52	2.39[-04]	9.40[-04]
6d	² D _{3/2}	5p ² P _{1/2} ^o	5.598[12]	7.094[12]	0.5567	0.7342	12.8767	13.14	2.35[-02]	3.17[-02]
6d	² D _{3/2}	5p ² P _{3/2} ^o	1.748[12]	2.008[12]	0.2188	0.2489	14.4493	14.38	1.04[-02]	1.17[-02]
6d	² D _{3/2}	5f ² F _{5/2} ^o	1.335[12]	2.752[12]	0.2051	0.4276	16.0059	16.09	1.08[-02]	2.26[-02]
6d	² D _{3/2}	6p ² P _{1/2} ^o	9.238[10]	4.941[10]	1.3530	0.9849	156.2836	182.31	6.96[-01]	5.91[-01]
6d	² D _{3/2}	6p ² P _{3/2} ^o	3.019[08]	7.342[07]	0.0683	0.0371	614.0399	918.40	1.37[-01]	1.12[-01]
6d	² D _{5/2}	3p ² P _{3/2} ^o	5.531[13]	6.526[13]	0.2159	0.2603	2.0829	2.11	1.48[-03]	1.80[-03]
6d	² D _{5/2}	4p ² P _{3/2} ^o	2.129[13]	2.895[13]	0.4974	0.6661	5.0969	5.06	0.83[-02]	1.10[-02]
6d	² D _{5/2}	4f ² F _{5/2} ^o	2.726[10]	1.233[11]	0.0007	0.0033	5.4800	5.45	1.30[-05]	5.92[-05]
6d	² D _{5/2}	4f ² F _{7/2} ^o	7.078[11]	3.031[12]	0.0195	0.0828	5.5348	5.51	0.35[-03]	1.50[-03]
6d	² D _{5/2}	5p ² P _{3/2} ^o	9.621[12]	1.135[13]	1.7430	1.9899	14.1932	13.96	8.14[-02]	9.14[-02]
6d	² D _{5/2}	5f ² F _{5/2} ^o	5.121[10]	1.140[11]	0.0113	0.0248	15.6922	15.57	0.58[-03]	1.27[-03]
6d	² D _{5/2}	5f ² F _{7/2} ^o	1.169[12]	2.617[12]	0.2666	0.5905	15.9254	15.84	1.39[-02]	3.07[-02]
6d	² D _{5/2}	6p ² P _{3/2} ^o	1.010[10]	1.088[10]	1.0970	0.9643	347.5185	313.89	1.25	0.99
6f	² F _{5/2} ^o	3d ² D _{3/2}	5.426[13]	8.436[13]	0.2234	0.3563	2.1394	2.17	1.57[-03]	2.54[-03]
6f	² F _{5/2} ^o	3d ² D _{5/2}	3.619[12]	5.637[12]	0.0155	0.0248	2.1845	2.21	1.12[-04]	1.81[-04]
6f	² F _{5/2} ^o	4d ² D _{3/2}	2.872[13]	4.519[13]	0.7097	1.0702	5.2415	5.13	1.22[-02]	1.80[-02]
6f	² F _{5/2} ^o	4d ² D _{5/2}	2.010[12]	3.182[12]	0.0519	0.0788	5.3595	5.25	0.91[-03]	1.36[-03]
6f	² F _{5/2} ^o	5d ² D _{3/2}	1.459[13]	2.065[13]	2.8080	3.5921	14.6294	13.91	1.35[-01]	1.64[-01]
6f	² F _{5/2} ^o	5d ² D _{5/2}	1.089[12]	1.558[12]	0.2235	0.2905	15.1061	14.40	1.11[-02]	1.37[-02]
6f	² F _{5/2} ^o	5g ² G _{7/2}	3.024[11]	-	0.0675	-	15.7527	-	3.50[-03]	-
6f	² F _{5/2} ^o	6d ² D _{3/2}	3.647[09]	2.277[10]	0.7157	1.0733	467.0665	228.92	1.10	0.80
6f	² F _{5/2} ^o	6d ² D _{5/2}	1.860[07]	2.203[08]	0.0210	0.0384	1121.0295	440.26	7.75[-02]	5.56[-02]
6f	² F _{7/2} ^o	3d ² D _{5/2}	5.810[13]	9.305[13]	0.3317	0.5450	2.1820	2.21	2.38[-03]	3.96[-03]
6f	² F _{7/2} ^o	4d ² D _{5/2}	3.088[13]	5.017[13]	1.0580	1.6409	5.3439	5.22	1.86[-02]	2.82[-02]
6f	² F _{7/2} ^o	5d ² D _{5/2}	1.604[13]	2.335[13]	4.3190	5.6426	14.9834	14.19	2.13[-01]	2.63[-01]
6f	² F _{7/2} ^o	5g ² G _{7/2}	7.385[09]	-	0.0022	-	15.6194	-	1.11[-04]	-
6f	² F _{7/2} ^o	5g ² G _{9/2}	2.871[11]	-	0.0854	-	15.7532	-	4.43[-03]	-
6f	² F _{7/2} ^o	6d ² D _{5/2}	1.168[09]	9.876[09]	0.6814	1.1030	697.3475	305.15	1.56	1.10

Table 6. Transition probabilities, $\text{Ar}(\text{s}^{-1})$, weighted oscillator strengths, (gf), wavelengths, λ ($\text{\AA}$), and line strengths, $S(\text{au})$, for electric dipole (E1) transitions in Na-like gold (Au^{68+}) calculated by AUTOSTRUCTURE. Numbers in square brackets represent powers of 10.

Levels				Ar(s ⁻¹)	gf	λ(Å)	S(au)
Upper		Lower					
5g	² G _{7/2}	4f	² F _{5/2} ^o	9.458[13]	7.8910	8.3408	2.16[-01]
5g	² G _{7/2}	4f	² F _{7/2} ^o	3.421[12]	0.2943	8.4685	8.20[-03]
5g	² G _{7/2}	5f	² F _{5/2} ^o	1.354[08]	0.1256	879.5267	3.63[-01]
5g	² G _{7/2}	5f	² F _{7/2} ^o	2.854[04]	0.0008	4907.3980	1.33[-02]
5g	² G _{9/2}	4f	² F _{7/2} ^o	9.676[13]	10.3100	8.4297	2.86[-01]
5g	² G _{9/2}	5f	² F _{7/2} ^o	3.990[07]	0.1070	1337.7205	4.71[-01]
6g	² G _{7/2}	4f	² F _{5/2} ^o	3.091[13]	1.0950	5.4334	1.95[-02]
6g	² G _{7/2}	4f	² F _{7/2} ^o	1.092[12]	0.0395	5.4873	7.13[-04]
6g	² G _{7/2}	5f	² F _{5/2} ^o	2.433[13]	6.8460	15.3158	3.45[-01]
6g	² G _{7/2}	5f	² F _{7/2} ^o	8.977[11]	0.2599	15.5379	1.32[-02]
6g	² G _{7/2}	6f	² F _{5/2} ^o	9.026[07]	0.2384	1483.8732	1.16
6g	² G _{7/2}	6f	² F _{7/2} ^o	2.484[04]	0.0017	7578.9710	4.27[-02]
6g	² G _{9/2}	4f	² F _{7/2} ^o	3.159[13]	1.4210	5.4778	2.56[-02]
6g	² G _{9/2}	5f	² F _{7/2} ^o	2.515[13]	9.0160	15.4621	4.58[-01]
6g	² G _{9/2}	6f	² F _{7/2} ^o	2.729[07]	0.2045	2235.9966	1.50
6h	² H _{9/2} ^o	5g	² G _{7/2}	3.678[13]	13.2700	15.5099	6.77[-01]
6h	² H _{9/2} ^o	5g	² G _{9/2}	8.236[11]	0.3021	15.6418	1.55[-02]
6h	² H _{9/2} ^o	6f	² G _{7/2} ^o	5.502[06]	0.0806	3126.7245	8.30[-01]
6h	² H _{9/2} ^o	6f	² G _{9/2} ^o	3.547[01]	0.0000	220280.5362	1.87[-02]
6h	² H _{11/2} ^o	5g	² G _{9/2}	3.736[13]	16.3400	15.5910	8.38[-01]
6h	² H _{11/2} ^o	6f	² G _{9/2} ^o	1.661[06]	0.0658	4693.8116	1.01
7s	² S _{1/2}	3p	² P _{1/2} ^o	8.662[09]	0.0000	1.8020	0.00
7s	² S _{1/2}	3p	² P _{3/2} ^o	2.169[13]	0.0247	1.9474	1.58[-04]
7s	² S _{1/2}	4p	² P _{1/2} ^o	8.933[11]	0.0044	4.0539	0.59[-04]
7s	² S _{1/2}	4p	² P _{3/2} ^o	1.001[13]	0.0570	4.3557	8.17[-04]
7s	² S _{1/2}	5p	² P _{1/2} ^o	1.272[12]	0.0303	8.9050	8.87[-04]
7s	² S _{1/2}	5p	² P _{3/2} ^o	6.079[12]	0.1690	9.6299	5.35[-03]
7s	² S _{1/2}	6p	² P _{1/2} ^o	1.335[12]	0.2378	24.3695	1.90[-02]
7s	² S _{1/2}	6p	² P _{3/2} ^o	4.530[12]	1.0330	27.5750	9.37[-02]
7p	² P _{1/2} ^o	3s	² S _{1/2}	1.338[13]	0.0123	1.7537	0.71[-04]
7p	² P _{1/2} ^o	3d	² D _{3/2}	1.410[12]	0.0017	1.9954	0.11[-04]
7p	² P _{1/2} ^o	4s	² S _{1/2}	5.869[12]	0.0274	3.9454	3.56[-04]
7p	² P _{1/2} ^o	4d	² D _{3/2}	1.850[12]	0.0110	4.4538	1.61[-04]
7p	² P _{1/2} ^o	5s	² S _{1/2}	3.248[12]	0.0717	8.5791	2.02[-03]
7p	² P _{1/2} ^o	5d	² D _{3/2}	2.105[12]	0.0606	9.7944	1.95[-03]
7p	² P _{1/2} ^o	6s	² S _{1/2}	1.928[12]	0.2969	22.6622	2.21[-02]
7p	² P _{1/2} ^o	6d	² D _{3/2}	2.300[12]	0.5355	27.8669	4.91[-02]

Table 6 (continued)

Levels				Ar(s ⁻¹)	gf	λ(Å)	S(au)
Upper		Lower					
7p	2p ^o _{1/2}	7s	2S _{1/2}	1.338[09]	0.2572	800.8308	6.78[-01]
7p	2p ^o _{3/2}	3s	2S _{1/2}	1.517[13]	0.0277	1.7447	1.59[-04]
7p	2p ^o _{3/2}	3d	2D _{3/2}	4.668[10]	0.0001	1.9837	1.00[-06]
7p	2p ^o _{3/2}	3d	2D _{5/2}	3.140[12]	0.0077	2.0225	5.10[-05]
7p	2p ^o _{3/2}	4s	2S _{1/2}	5.475[12]	0.0499	3.9001	6.41[-04]
7p	2p ^o _{3/2}	4d	2D _{3/2}	1.236[11]	0.0014	4.3962	2.10[-05]
7p	2p ^o _{3/2}	4d	2D _{5/2}	2.551[12]	0.0307	4.4789	4.52[-04]
7p	2p ^o _{3/2}	5s	2S _{1/2}	2.453[12]	0.1030	8.3680	2.83[-03]
7p	2p ^o _{3/2}	5d	2D _{3/2}	1.459[11]	0.0079	9.5201	2.49[-04]
7p	2p ^o _{3/2}	5d	2D _{5/2}	2.022[12]	0.1145	9.7197	3.66[-03]
7p	2p ^o _{3/2}	6s	2S _{1/2}	1.087[12]	0.2942	21.2462	2.05[-02]
7p	2p ^o _{3/2}	6d	2D _{3/2}	1.462[11]	0.0582	25.7559	4.93[-03]
7p	2p ^o _{3/2}	6d	2D _{5/2}	1.683[12]	0.7149	26.6120	6.26[-02]
7p	2p ^o _{3/2}	7s	2S _{1/2}	4.830[10]	1.6500	238.6766	1.29
7d	2D _{3/2}	3p	2p ^o _{1/2}	1.137[13]	0.0217	1.7855	1.28[-04]
7d	2D _{3/2}	3p	2p ^o _{3/2}	6.424[12]	0.0143	1.9281	0.91[-04]
7d	2D _{3/2}	4p	2p ^o _{1/2}	5.970[12]	0.0565	3.9712	7.38[-04]
7d	2D _{3/2}	4p	2p ^o _{3/2}	2.539[12]	0.0276	4.2603	3.88[-04]
7d	2D _{3/2}	4f	2F ^o _{5/2}	2.953[11]	0.0036	4.5248	5.40[-05]
7d	2D _{3/2}	5p	2p ^o _{1/2}	3.354[12]	0.1459	8.5155	4.08[-03]
7d	2D _{3/2}	5p	2p ^o _{3/2}	1.248[12]	0.0630	9.1760	1.90[-03]
7d	2D _{3/2}	5f	2F ^o _{5/2}	5.777[11]	0.0331	9.7800	1.06[-03]
7d	2D _{3/2}	6p	2p ^o _{1/2}	1.813[12]	0.5101	21.6586	3.63[-02]
7d	2D _{3/2}	6p	2p ^o _{3/2}	6.707[11]	0.2346	24.1540	1.86[-02]
7d	2D _{3/2}	6f	2F ^o _{5/2}	8.157[11]	0.3454	26.5735	3.02[-02]
7d	2D _{3/2}	7p	2p ^o _{1/2}	4.097[10]	1.6260	257.2297	1.37
7d	2D _{3/2}	7p	2p ^o _{3/2}	1.128[08]	0.0755	1056.5146	2.62[-01]
7d	2D _{5/2}	3p	2p ^o _{3/2}	4.372[13]	0.1458	1.9252	9.24[-04]
7d	2D _{5/2}	4p	2p ^o _{3/2}	1.625[13]	0.2636	4.2461	3.68[-03]
7d	2D _{5/2}	4f	2F ^o _{5/2}	1.136[10]	0.0002	4.5087	3.00[-06]
7d	2D _{5/2}	4f	2F ^o _{7/2}	4.546[11]	0.0084	4.5458	1.26[-04]
7d	2D _{5/2}	5p	2p ^o _{3/2}	7.529[12]	0.5621	9.1103	1.68[-02]
7d	2D _{5/2}	5f	2F ^o _{5/2}	2.300[10]	0.0019	9.7054	6.20[-05]
7d	2D _{5/2}	5f	2F ^o _{7/2}	6.334[11]	0.0547	9.7941	1.76[-03]
7d	2D _{5/2}	6p	2p ^o _{3/2}	3.740[12]	1.8900	23.7038	1.47[-01]
7d	2D _{5/2}	6f	2F ^o _{5/2}	3.222[10]	0.0196	26.0296	1.68[-03]
7d	2D _{5/2}	6f	2F ^o _{7/2}	7.536[11]	0.4725	26.4021	4.10[-02]
7d	2D _{5/2}	7p	2p ^o _{3/2}	4.117[09]	1.2330	577.1130	2.34
7f	2F ^o _{5/2}	3d	2D _{3/2}	2.860[13]	0.1003	1.9748	6.52[-04]

Table 6 (continued)

Levels				Ar(s ⁻¹)	gf	λ(Å)	S(au)
Upper	Lower						
7f	² F _{5/2} ^o	3d	² D _{5/2}	2.084[12]	0.0076	2.0132	5.00[-05]
7f	² F _{5/2} ^o	4d	² D _{3/2}	1.607[13]	0.2738	4.3525	3.92[-03]
7f	² F _{5/2} ^o	4d	² D _{5/2}	1.175[12]	0.0208	4.4335	3.03[-04]
7f	² F _{5/2} ^o	5d	² D _{3/2}	9.026[12]	0.7048	9.3177	2.16[-02]
7f	² F _{5/2} ^o	5d	² D _{5/2}	6.730[11]	0.0547	9.5088	1.71[-03]
7f	² F _{5/2} ^o	5g	² G _{7/2}	1.105[11]	0.0095	9.7610	3.04[-04]
7f	² F _{5/2} ^o	6d	² D _{3/2}	5.001[12]	2.6620	24.3257	2.13[-01]
7f	² F _{5/2} ^o	6d	² D _{5/2}	3.869[11]	0.2190	25.0880	1.80[-02]
7f	² F _{5/2} ^o	6f	² G _{7/2} ^o	2.852[11]	0.1749	26.1139	1.50[-02]
7f	² F _{5/2} ^o	7d	² D _{3/2}	1.801[09]	0.9075	748.3597	2.23
7f	² F _{5/2} ^o	7d	² D _{5/2}	8.801[06]	0.0262	1818.1775	1.56[-01]
7f	² F _{7/2} ^o	3d	² D _{5/2}	3.446[13]	0.1673	2.0118	1.10[-03]
7f	² F _{7/2} ^o	4d	² D _{5/2}	1.865[13]	0.4384	4.4268	6.39[-03]
7f	² F _{7/2} ^o	5d	² D _{5/2}	1.033[13]	1.1130	9.4780	3.47[-02]
7f	² F _{7/2} ^o	5g	² G _{7/2}	2.719[09]	0.0003	9.7285	1.00[-05]
7f	² F _{7/2} ^o	5g	² G _{9/2}	1.300[11]	0.0149	9.7802	4.80[-04]
7f	² F _{7/2} ^o	6d	² D _{5/2}	5.705[12]	4.2340	24.8746	3.46[-01]
7f	² F _{7/2} ^o	6f	² G _{7/2} ^o	7.084[09]	0.0057	25.8828	4.85[-04]
7f	² F _{7/2} ^o	6f	² G _{9/2} ^o	2.830[11]	0.2311	26.0958	1.98[-02]
7f	² F _{7/2} ^o	7d	² D _{5/2}	5.614[08]	0.8465	1121.2936	3.12
7g	² G _{7/2}	4f	² F _{5/2} ^o	1.441[13]	0.3482	4.4889	5.14[-03]
7g	² G _{7/2}	4f	² F _{7/2} ^o	5.105[11]	0.0125	4.5257	1.87[-04]
7g	² G _{7/2}	5f	² F _{5/2} ^o	1.219[13]	1.3510	9.6140	4.27[-02]
7g	² G _{7/2}	5f	² F _{7/2} ^o	4.436[11]	0.0501	9.7010	1.59[-03]
7g	² G _{7/2}	6f	² F _{5/2} ^o	8.160[12]	6.3050	25.3826	5.26[-01]
7g	² G _{7/2}	6f	² F _{7/2} ^o	3.058[11]	0.2429	25.7366	2.05[-02]
7g	² G _{7/2}	6h	² H _{9/2} ^o	8.023[10]	0.0652	26.0394	5.59[-03]
7g	² G _{7/2}	7f	² F _{5/2} ^o	5.269[07]	0.3427	2328.8073	2.62
7g	² G _{7/2}	7f	² F _{7/2} ^o	1.637[04]	0.0026	11418.3133	9.62[-02]
7g	² G _{9/2}	4f	² F _{7/2} ^o	1.507[13]	0.4619	4.5216	6.87[-03]
7g	² G _{9/2}	5f	² F _{7/2} ^o	1.275[13]	1.7920	9.6824	5.71[-03]
7g	² G _{9/2}	6f	² F _{7/2} ^o	8.553[12]	8.4070	25.6057	7.08[-01]
7g	² G _{9/2}	6h	² H _{9/2} ^o	1.349[09]	0.0014	25.9054	1.16[-04]
7g	² G _{9/2}	6h	² H _{11/2} ^o	8.170[10]	0.0831	26.0461	7.12[-03]
7g	² G _{9/2}	7f	² F _{7/2} ^o	1.599[07]	0.2926	3493.9871	3.36
7h	² H _{9/2} ^o	5g	² G _{7/2}	1.140[13]	1.6090	9.7011	5.13[-02]
7h	² H _{9/2} ^o	5g	² G _{9/2}	2.517[11]	0.0359	9.7526	1.15[-03]
7h	² H _{9/2} ^o	6f	² G _{7/2} ^o	1.185[13]	11.7200	25.6900	9.91[-01]
7h	² H _{9/2} ^o	6f	² G _{9/2} ^o	2.681[11]	0.2696	25.8998	2.29[-02]

Table 6 (continued)

Levels				Ar(s ⁻¹)	gf	λ(Å)	S(au)
Upper		Lower					
7h	² H _{9/2} ^o	7g	² G _{7/2}	4.156[06]	0.1521	4940.2810	2.47
7h	² H _{9/2} ^o	7g	² G _{9/2}	6.152[-01]	0.0001	263833.6375	5.57[-02]
7i	² I _{11/2}	6h	² H _{9/2} ^o	1.662[13]	19.9300	25.8157	1.69
7i	² I _{11/2}	6h	² H _{11/2} ^o	2.531[11]	0.3068	25.9554	2.62[-02]
7i	² I _{11/2}	7h	² H _{9/2} ^o	6.145[05]	0.0651	7673.3036	1.64
7h	² H _{11/2} ^o	5g	² G _{9/2}	1.163[13]	1.9850	9.7401	6.36[-02]
7h	² H _{11/2} ^o	6f	² G _{9/2} ^o	1.212[13]	14.5300	25.8119	1.23
7h	² H _{11/2} ^o	7g	² G _{9/2}	1.257[06]	0.1237	7394.9982	3.01
7i	² I _{13/2}	6h	² H _{11/2} ^o	1.683[13]	23.6800	25.8926	2.01
7i	² I _{13/2}	7h	² H _{11/2} ^o	2.207[05]	0.0543	10827.6336	1.93