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Energies, and Transition Rates in Ga-like ions (Sn XX - I XXIII)

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ABSTRACT

Energy levels, wavelengths, transition probabilities, oscillator strengths, and line strengths were calculated for electric dipole $4s^24p$ - $4s4p^2$, $4s^24p$ - $4s^24d$, and $4s4p^2$ - $4p^3$ transitions of Gallium-like ions, Sn XX, Sb XXI, Te XXII, and I XXIII. The fully relativistic multiconfiguration Dirac-Fock method, taking into account both correlations within the n = 4 complex and the quantum electrodynamic effects, have been used in the calculations. The results were compared with the available experimental and other theoretical results.

1. Introduction

The spectra of highly ionized ions have a great interest in many fields of physics, such as plasma physics, astrophysics, and laser physics. The atomic data of Ga-like ions have been observed and calculated [1-30].

On the experimental side, the spectrum of Sn XX has been observed, and the spectral lines of $4s^24p$ - $4s^2ns$ and $4s^24p$ - $4s^2nd$ (n=5-7) have been reported by Khan [2]. Fournier *et al.* [11] measured the wavelengths for some transtions belonging to $4s^24p$-$4s4p^2$, and $4s^24p$-$4s4d^2$ transitions in the tokamak and the laser-produced plasma for Pr XXIX, Eu XXXIII, Gd XXXIV, Dy XXXVI, and Yb XL ions. The wavelengths of Xe XXIV have been observed in the extreme ultraviolet (EUV) wavelength range at the Berlin Electron Beam Ion Trap facility by Biedermann *et al.* [13], and the experimental wavelengths were compared with the HULLAC code results.

On the theoretical side, for Ga-like ions with $Z \le 92$, the theoretical energy level values of $4s^24p$ $^2P_{3/2}^o$ state have been calculated using semiempirical (SE) and Dirac-Fock (DF) methods by Curtis [7], using the multiconfiguration Dirac Fock (MCDF) method by Ali [12], and using the relativistic many-body perturbation theory by Safronova *et al.* [15]. For I XXIII, the energy levels of $4s^24p$ $^2P^o$, $4s4p^2$ ($^4P^e$, $^2D^e$, $^2P^e$, $^2S^e$) terms have been calculated using the GRASP2K program [20], and wavelengths results were reported [20-21].

The atomic data for some ions in Ga-like ions, Ge II–Rb VII [22], Pt XLVIII [24], W XLIV [25, 30], Ag XVII [26], Xe XXIV–Pr XXIX [27], Nd XXX–Tb XXXV [28], Kr VI-Xe XXIV [29] are presented.

In this paper, the energy levels, wavelengths, transition probabilities, oscillator strengths, and line strengths of electric dipole (E1) transitions among the fine-structure levels of terms belonging to the $4s^24p$, $4s4p^2$, $4s^24d$, and $4p^3$ configurations are calculated for Ga-like ions from Sn XX to I XXIII, and the calculations have been performed using the multiconfiguration Dirac-Fock (MCDF) method.

2. Calculations

The present calculations were preformed using the multiconfiguration Dirac-Fock (MCDF) method with the multiconfiguration Dirac-Fock and General Matrix Elements (MCDFGME) program [31]. This program is used to calculate a number of atomic quatitites, such as energy levels, transition rates, photoionization cross sections, and hyperfine structure constants, taking into account the relativistic Breit-interactions (BI) and quantum electrodynamics (QED), vacuum polarization and self-energy, contributions.

The wavelengths, transition probabilities, oscillator strengths, and line strengths for the $4s^24p$ - $4s4p^2$, $4s^24p$ - $4s^24d$, and $4s4p^2$ - $4p^3$ electric dipole transitions were calculated for Sn XX, Sb XXI, Te XXII, and I XXIII, using MCDF method.

Most odd and even configurations with the n = 4 complex were included in the calculations. These configurations are $4s^24p$, $4p^3$, $4s4p4d$, $4p4d^2$, $4s^24f$, $4s4d4f$, $4p^24f$, $4d^24f$ and $4s4p^2$, $4s^24d$, $4s4d^2$, $4p^24d$, $4s4p4f$, $4p4d4f$, $4d^3$ for odd and even parities, respectively.

3. Results and Discussion

3.1. Energy Levels

The MCDF energy level values for the $4s^24p$, $4s4p^2$, $4s^24d$, and $4p^3$ configurations for Ga-like Sn XX – I XXIII were listed in Table 1, where each level was presented in both the *LS*-coupling and the *jj*-coupling schemes.

Table 1: MCDF energy levels (in cm^{-1}) for the $4s^24p$, $4s4p^2$, $4s^24d$, and $4p^3$ configurations for Ga-like ions with Z=50-53.

Index	Configuration	LSJ	JJ	Sn XX	Sb XXI	Te XXII	I XXIII
1	$4s^2\,4p$	$^2P_{1/2}^o$	$4s^24p^*$	0	0	0	0
2	$4s^2\,4p$	$^2P_{3/2}^o$	$4s^24p$	87,825	98,964	111,108	124,317
3	$4s\,4p^2$	$^4P_{1/2}^e$	$4s4p^{*2}$	328,307	345,892	363,650	381,582
4	$4s\,4p^2$	$^4P_{3/2}^e$	$4s4p^*4p$	380,110	405,793	432,600	460,607
5	$4s\,4p^2$	$^4P_{5/2}^e$	$4s4p^*4p$	408,975	436,685	465,494	495,475
6	$4s\,4p^2$	$^2D_{3/2}^e$	$4s4p^*4p$	462,433	492,964	522,242	553,917
7	$4s\,4p^2$	$^2P_{1/2}^e$	$4s4p^*4p$	502,390	531,108	560,893	591,833
8	$4s\,4p^2$	$^2D_{5/2}^e$	$4s4p^2$	499,093	536,554	574,184	615,028
9	$4s\,4p^2$	$^2S_{1/2}^e$	$4s4p^2$	588,891	628,751	670,702	714,889
10	$4s\,4p^2$	$^2P_{3/2}^e$	$4s4p^2$	598,757	638,581	680,406	724,359
11	$4s^2\,4d$	$^2D_{3/2}^e$	$4s^24d^*$	720,294	760,253	801,254	843,393
12	$4s^2\,4d$	$^2D_{5/2}^e$	$4s^24d$	735,274	777,267	820,471	864,976
13	$4p^3$	$^4S_{3/2}^o$	$4p^{*2}4p$	842,694	889,465	937,391	986,571
14	$4p^3$	$^2D_{3/2}^o$	$4p^*4p^2$	910,964	968,029	998,140	1,057,713
15	$4p^3$	$^2D_{5/2}^o$	$4p^*4p^2$	888,669	992,478	1,001,399	1,061,050
16	$4p^3$	$^2P_{1/2}^o$	$4p^*4p^2$	945,434	1,025,953	1,062,679	1,124,782
17	$4p^3$	$^2P_{3/2}^o$	$4p^3$	1,001,697	1,103,932	1,136,270	1,222,964

It showed that the present MCDF energy levels were in an excellent agreement with the other theoretical results, where the agreement was within ~0.07% with DF [7] results, and was within 0.6% with [7, 12, 15] results (Table 2).

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Table 2. Comparison between MCDF and other theoretical $4s^24p\ ^2P_{3/2}$ in Ga-like ions with Z=50-53.

Ion	MCDF	SE [7]	DF [7]	[12]	RMBPT [15]
Sn XX	87,825	88,356	87,850	88,411	88,357
Sb XXI	98,964	99,492	99,007	99,593	99,545
Te XXII	111,108	111,614	111,169	111,779	111,738
I XXIII	124,317	124,783	124,396	125,030	124,999

3.2. Wavelengths, Transition Probabilities, and Oscillator Strengths

Tables 3 and 4 present wavelengths λ (in Å), transition probabilities A in length gauge (in sec^{-1}), oscillator strengths *f* (dimensionless), and line strengths S (in a. u.) for electric dipole $4s^24p$ - $4s4p^2$, $4s^24p$ - $4s^24d$, and $4s4p^2$ - $4p^3$ transitions for Sn XX, Sb XXI, Te XXII, and I XXIII.

For strong transitions ($f \geq 0.01$), the difference between transitions probabilities in the Babushkin (length) and the Coulomb (velocity) gauges is within ~10%, except for $4s4p^2$-$4p^3$ ($^2D_{3/2}{}^e$ – $^4S_{3/2}{}^o$, $^2P_{1/2}{}^e$ – $^2P_{3/2}{}^o$, and $^2P_{1/2}{}^e$ – $^4S_{3/2}{}^o$) transitions for all ions, and for Sn XX, and Sb XXI, there are several transitions have difference greater than 25%, these transitions are $4s4p^2$-$4p^3$ ($^4P_{1/2}{}^e$ – $^2D_{3/2}{}^o$, $^2P_{1/2}{}^e$ – $^2D_{3/2}{}^o$, $^2P_{3/2}{}^e$ – $^2D_{5/2}{}^o$, and $^2S_{1/2}{}^e$ – $^2D_{3/2}{}^o$).

Table A presents comparison between the present MCDF wavelengths with the available experimental and other theoretical results for I XXIII [20, 21].

Table A: Comparison between MCDF, experimental, and other theoretical wavelengths (in Å) of I XXIII ion.

Index	Transition	MCDF	Experimental [20]	GRASP2K [21]
1	$4s^24p\ ^2P_{1/2}{}^o$ - $4s4p^2\ ^4P_{1/2}{}^e$	263.89	267.7 ± 0.10	264.1
2	$4s^24p\ ^2P_{3/2}{}^o$ - $4s4p^2\ ^4P_{5/2}{}^e$	271.33	270.0 ± 0.10	271.8
3	$4s^24p\ ^2P_{3/2}{}^o$ - $4s4p^2\ ^4P_{3/2}{}^e$	299.70	296.3 ± 0.15	299.4

A comparison showed that the present MCDF wavelengths were in an excellent agreement with the available theoretical [21] and experimental [20] results, where the agreement was within ~ 1% -1.4 %.

Table 3: MCDF wavelengths λ (in Å), transition probabilities A (in sec^{-1}), oscillator strengths *f*, and line strengths S (in a. u.) for Sn XX, and Sb XXI.

Configuration	i	j	Sn XX				Sb XXI			
			λ	A	f	S	λ	A	f	S
4s24p - 4s4p2	2P1/2o	4P1/2e	306.42	1.66E+09	2.34E-02	4.72E-02	290.93	2.07E+09	2.63E-02	5.04E-02
	2P1/2o	4P3/2e	264.41	3.70E+07	7.76E-04	1.35E-03	247.73	4.71E+07	8.67E-04	1.41E-03
	2P1/2o	2D3/2e	217.11	2.08E+10	2.94E-01	4.20E-01	203.69	2.39E+10	2.97E-01	3.98E-01
	2P1/2o	2P1/2e	199.83	8.15E+10	4.88E-01	6.42E-01	189.06	8.99E+10	4.82E-01	6.00E-01
	2P1/2o	2S1/2e	170.36	6.15E+09	2.68E-02	3.00E-02	159.58	5.99E+09	2.29E-02	2.40E-02
	2P1/2o	2P3/2e	167.54	2.13E+10	1.79E-01	1.97E-01	157.11	2.40E+10	1.77E-01	1.84E-01
	2P3/2o	4P1/2e	419.32	9.09E+07	1.20E-03	6.62E-03	408.63	9.38E+07	1.17E-03	6.32E-03
	2P3/2o	4P3/2e	344.44	1.85E+08	3.29E-03	1.49E-02	328.23	2.21E+08	3.56E-03	1.54E-02
	2P3/2o	4P5/2e	313.27	1.45E+09	3.20E-02	1.32E-01	297.99	1.74E+09	3.48E-02	1.37E-01
	2P3/2o	2D3/2e	268.29	6.03E+08	6.50E-03	2.30E-02	255.15	9.01E+08	8.79E-03	2.95E-02
	2P3/2o	2P1/2e	242.39	2.77E+09	1.22E-02	3.89E-02	232.60	3.39E+09	1.37E-02	4.21E-02
	2P3/2o	2D5/2e	244.24	7.01E+09	9.41E-02	3.03E-01	229.59	7.45E+09	8.83E-02	2.67E-01
	2P3/2o	2S1/2e	200.35	5.99E+10	1.80E-01	4.75E-01	189.52	6.53E+10	1.76E-01	4.39E-01
	2P3/2o	2P3/2e	196.46	9.56E+10	5.53E-01	1.43E+00	186.05	1.04E+11	5.40E-01	1.32E+00
4s24p - 4s24d	2P1/2o	2D3/2e	138.87	1.61E+11	9.33E-01	8.53E-01	131.57	1.75E+11	9.09E-01	7.88E-01
	2P3/2o	2D3/2e	158.17	3.48E+10	1.31E-01	2.72E-01	151.28	3.88E+10	1.33E-01	2.65E-01
	2P3/2o	2D5/2e	154.49	1.52E+11	8.16E-01	1.66E+00	147.47	1.63E+11	7.96E-01	1.55E+00
4s4p2 - 4p3	4P1/2e	4S3/2o	195.16	2.42E+10	2.76E-01	3.55E-01	184.71	2.72E+10	2.78E-01	3.38E-01
	4P1/2e	2D3/2o	172.2	2.11E+09	1.88E-02	2.13E-02	161.30	2.31E+09	1.80E-02	1.91E-02
	4P1/2e	2P1/2o	162.51	4.79E+08	1.90E-03	2.03E-03	147.51	1.33E+09	4.35E-03	4.22E-03
	4P1/2e	2P3/2o	148.84	4.39E+09	2.92E-02	2.86E-02	132.28	3.53E+07	1.85E-04	1.61E-04
	4P3/2e	4S3/2o	217.13	1.66E+10	1.18E-01	3.36E-01	207.71	1.66E+10	1.07E-01	2.93E-01
	4P3/2e	2D3/2o	189.09	2.44E+10	1.31E-01	3.26E-01	178.56	2.87E+10	1.37E-01	3.23E-01
	4P3/2e	2D5/2o	197.27	8.37E+07	7.33E-04	1.90E-03	171.09	1.96E+08	1.29E-03	2.91E-03
	4P3/2e	2P1/2o	177.46	5.40E+08	1.27E-03	2.98E-03	161.82	4.24E+08	8.32E-04	1.77E-03
	4P3/2e	2P3/2o	161.29	2.82E+09	1.10E-02	2.33E-02	143.68	9.13E+08	2.82E-03	5.34E-03
	4P5/2e	4S3/2o	231.66	3.17E+10	1.70E-01	7.78E-01	221.97	3.32E+10	1.63E-01	7.16E-01
	4P5/2e	2D3/2o	200.01	5.20E+09	2.08E-02	8.21E-02	188.99	5.73E+09	2.04E-02	7.63E-02
	4P5/2e	2D5/2o	209.19	6.79E+09	4.45E-02	1.84E-01	180.65	2.11E+10	1.03E-01	3.68E-01
	4P5/2e	2P3/2o	169.17	9.41E+07	2.69E-04	8.99E-04	150.35	3.56E+08	8.04E-04	2.39E-03
	2D3/2e	4S3/2o	264.44	4.23E+09	4.44E-02	1.55E-01	253.70	4.89E+09	4.72E-02	1.58E-01
	2D3/2e	2D3/2o	223.99	1.24E+10	9.29E-02	2.74E-01	211.52	1.29E+10	8.67E-02	2.41E-01
	2D3/2e	2D5/2o	235.57	4.22E+09	5.26E-02	1.63E-01	201.12	1.83E+10	1.66E-01	4.40E-01
	2D3/2e	2P1/2o	207.85	4.37E+10	1.42E-01	3.88E-01	188.42	5.60E+10	1.49E-01	3.70E-01
	2D3/2e	2P3/2o	186.02	5.68E+09	2.95E-02	7.21E-02	164.27	1.24E+10	5.03E-02	1.09E-01
	2D5/2e	4S3/2o	292.86	5.60E+07	4.80E-04	2.78E-03	285.27	7.51E+07	6.11E-04	3.44E-03
	2D5/2e	2D3/2o	244.05	1.46E+10	8.68E-02	4.18E-01	233.03	1.60E+10	8.70E-02	4.01E-01
	2D5/2e	2D5/2o	257.86	1.10E+10	1.09E-01	5.57E-01	220.46	2.64E+10	1.92E-01	8.37E-01
	2D5/2e	2P3/2o	199.64	2.44E+10	9.71E-02	3.83E-01	176.96	2.16E+10	6.75E-02	2.36E-01
	2P1/2e	4S3/2o	295.57	5.47E+09	1.43E-01	2.79E-01	280.77	6.40E+09	1.51E-01	2.80E-01
	2P1/2e	2D3/2o	245.93	2.41E+10	4.38E-01	7.08E-01	230.01	2.74E+10	4.34E-01	6.57E-01
	2P1/2e	2P1/2o	226.61	3.30E+09	2.54E-02	3.79E-02	202.96	8.42E+09	5.20E-02	6.95E-02
	2P1/2e	2P3/2o	200.9	4.83E+09	5.84E-02	7.73E-02	175.21	3.01E+09	2.77E-02	3.20E-02
	2S1/2e	4S3/2o	397.2	1.66E+08	7.84E-03	2.05E-02	386.91	1.57E+08	7.06E-03	1.80E-02
	2S1/2e	2D3/2o	312.44	1.12E+09	3.28E-02	6.76E-02	296.69	1.01E+09	2.66E-02	5.19E-02
	2S1/2e	2P1/2o	281.91	1.29E+10	1.53E-01	2.85E-01	253.16	2.79E+10	2.68E-01	4.48E-01
	2S1/2e	2P3/2o	243.19	3.00E+09	5.33E-02	8.53E-02	211.40	1.41E+10	1.90E-01	2.64E-01
	2P3/2e	4S3/2o	413.42	3.11E+08	7.97E-03	4.34E-02	402.24	3.09E+08	7.49E-03	3.97E-02
	2P3/2e	2D3/2o	322.39	4.72E+08	7.35E-03	3.12E-02	305.62	5.25E+08	7.35E-03	2.96E-02
	2P3/2e	2D5/2o	346.94	3.55E+09	9.61E-02	9.61E-02	284.37	1.53E+10	2.78E-01	1.04E+00
	2P3/2e	2P1/2o	289.99	8.76E+08	5.52E-03	5.52E-03	259.63	3.33E+09	1.68E-02	5.76E-02
	2P3/2e	2P3/2o	249.18	1.76E+10	1.64E-01	5.36E-01	215.90	5.94E+10	4.15E-01	1.18E+00

Table 4: MCDF wavelengths λ (in Å), transition probabilities A (in sec^{-1}), oscillator strengths *f*, and line strengths S (in a. u.) for Te XXII, and I XXIII.

Configuration	i	j	Te XXII				I XXIII			
			□	A	*f*	S	□	A	*f*	S
$4s^24p - 4s4p^2$	$^{2}P_{1/2}^{o}$	$^{4}P_{1/2}^{e}$	276.81	2.55E+09	2.93E-02	5.34E-02	263.89	3.10E+09	3.24E-02	5.63E-02
	$^{2}P_{1/2}^{o}$	$^{4}P_{3/2}^{e}$	232.42	5.94E+07	9.62E-04	1.47E-03	218.33	7.43E+07	1.06E-03	1.53E-03
	$^{2}P_{1/2}^{o}$	$^{2}D_{3/2}^{e}$	192.31	2.76E+10	3.06E-01	3.87E-01	181.35	3.16E+10	3.12E-01	3.72E-01
	$^{2}P_{1/2}^{o}$	$^{2}P_{1/2}^{e}$	179.05	9.89E+10	4.75E-01	5.60E-01	169.72	1.09E+11	4.69E-01	5.24E-01
	$^{2}P_{1/2}^{o}$	$^{2}S_{1/2}^{e}$	149.62	5.86E+09	1.97E-02	1.94E-02	140.39	5.74E+09	1.69E-02	1.57E-02
	$^{2}P_{1/2}^{o}$	$^{2}P_{3/2}^{e}$	147.47	2.72E+10	1.78E-01	1.72E-01	138.53	3.12E+10	1.80E-01	1.64E-01
	$^{2}P_{3/2}^{o}$	$^{4}P_{1/2}^{e}$	399.83	9.50E+07	1.14E-03	5.99E-03	392.78	9.44E+07	1.09E-03	5.65E-03
	$^{2}P_{3/2}^{o}$	$^{4}P_{3/2}^{e}$	313.38	2.61E+08	3.84E-03	1.58E-02	299.70	3.05E+08	4.11E-03	1.62E-02
	$^{2}P_{3/2}^{o}$	$^{4}P_{5/2}^{e}$	284.07	2.06E+09	3.75E-02	1.40E-01	271.33	2.41E+09	3.99E-02	1.43E-01
	$^{2}P_{3/2}^{o}$	$^{2}D_{3/2}^{e}$	244.59	1.13E+09	1.01E-02	3.27E-02	234.15	1.47E+09	1.21E-02	3.73E-02
	$^{2}P_{3/2}^{o}$	$^{2}P_{1/2}^{e}$	223.54	4.06E+09	1.52E-02	4.47E-02	215.13	4.78E+09	1.66E-02	4.69E-02
	$^{2}P_{3/2}^{o}$	$^{2}D_{5/2}^{e}$	217.00	8.02E+09	8.50E-02	2.43E-01	204.82	8.53E+09	8.05E-02	2.17E-01
	$^{2}P_{3/2}^{o}$	$^{2}S_{1/2}^{e}$	179.46	7.12E+10	1.72E-01	4.06E-01	170.08	7.76E+10	1.68E-01	3.77E-01
	$^{2}P_{3/2}^{o}$	$^{2}P_{3/2}^{e}$	176.38	1.13E+11	5.26E-01	1.22E+00	167.37	1.22E+11	5.12E-01	1.13E+00
$4s^24p - 4s^24d$	$^{2}P_{1/2}^{o}$	$^{2}D_{3/2}^{e}$	124.84	1.90E+11	8.86E-01	7.28E-01	118.61	2.04E+11	8.63E-01	6.74E-01
	$^{2}P_{3/2}^{o}$	$^{2}D_{3/2}^{e}$	144.96	4.33E+10	1.36E-01	2.61E-01	139.13	4.87E+10	1.41E-01	2.59E-01
	$^{2}P_{3/2}^{o}$	$^{2}D_{5/2}^{e}$	141.01	1.74E+11	7.78E-01	1.44E+00	135.06	1.86E+11	7.61E-01	1.35E+00
$4s4p^2 - 4p^3$	$^{4}P_{1/2}^{e}$	$^{4}S_{3/2}^{o}$	175.03	3.06E+10	2.81E-01	3.24E-01	166.02	3.45E+10	2.85E-01	3.12E-01
	$^{4}P_{1/2}^{e}$	$^{2}D_{3/2}^{o}$	158.15	1.34E+10	1.01E-01	1.05E-01	148.42	1.50E+10	9.90E-02	9.68E-02
	$^{4}P_{1/2}^{e}$	$^{2}P_{1/2}^{o}$	143.50	5.71E+08	1.76E-03	1.67E-03	134.99	6.05E+08	1.65E-03	1.47E-03
	$^{4}P_{1/2}^{e}$	$^{2}P_{3/2}^{o}$	129.72	2.02E+10	1.02E-01	8.70E-02	119.05	5.46E+10	2.32E-01	1.82E-01
	$^{4}P_{3/2}^{e}$	$^{4}S_{3/2}^{o}$	199.07	1.65E+10	9.82E-02	2.58E-01	191.11	1.65E+10	9.03E-02	2.27E-01
	$^{4}P_{3/2}^{e}$	$^{2}D_{3/2}^{o}$	177.52	3.50E+10	1.66E-01	3.87E-01	168.16	3.88E+10	1.64E-01	3.64E-01
	$^{4}P_{3/2}^{e}$	$^{2}D_{5/2}^{o}$	176.43	1.32E+08	9.23E-04	2.15E-03	167.15	1.64E+08	1.03E-03	2.27E-03
	$^{4}P_{3/2}^{e}$	$^{2}P_{1/2}^{o}$	159.27	7.82E+08	1.49E-03	3.12E-03	151.12	9.32E+08	1.60E-03	3.18E-03
	$^{4}P_{3/2}^{e}$	$^{2}P_{3/2}^{o}$	142.47	1.24E+09	3.78E-03	7.09E-03	131.42	3.03E+10	7.85E-02	1.36E-01
	$^{4}P_{5/2}^{e}$	$^{4}S_{3/2}^{o}$	213.03	3.46E+10	1.57E-01	6.61E-01	204.77	3.62E+10	1.52E-01	6.13E-01
	$^{4}P_{5/2}^{e}$	$^{2}D_{3/2}^{o}$	188.53	1.77E+10	6.27E-02	2.34E-01	178.64	1.86E+10	5.94E-02	2.09E-01
	$^{4}P_{5/2}^{e}$	$^{2}D_{5/2}^{o}$	187.31	9.62E+09	5.06E-02	1.87E-01	177.50	1.12E+10	5.27E-02	1.85E-01
	$^{4}P_{5/2}^{e}$	$^{2}P_{3/2}^{o}$	149.48	8.17E+07	1.82E-04	5.39E-04	137.74	1.76E+09	3.34E-03	9.09E-03
	$^{2}D_{3/2}^{e}$	$^{4}S_{3/2}^{o}$	242.37	5.72E+09	5.04E-02	1.61E-01	232.64	6.49E+09	5.27E-02	1.61E-01
	$^{2}D_{3/2}^{e}$	$^{2}D_{3/2}^{o}$	211.15	3.63E+09	2.43E-02	6.75E-02	199.49	3.68E+09	2.19E-02	5.76E-02
	$^{2}D_{3/2}^{e}$	$^{2}D_{5/2}^{o}$	209.61	5.56E+09	5.49E-02	1.52E-01	198.08	6.28E+09	5.54E-02	1.44E-01
	$^{2}D_{3/2}^{e}$	$^{2}P_{1/2}^{o}$	185.83	5.44E+10	1.41E-01	3.44E-01	175.96	6.05E+10	1.40E-01	3.25E-01
	$^{2}D_{3/2}^{e}$	$^{2}P_{3/2}^{o}$	163.36	3.33E+09	1.33E-02	2.87E-02	149.81	1.61E+10	5.41E-02	1.07E-01
	$^{2}D_{5/2}^{e}$	$^{4}S_{3/2}^{o}$	277.31	6.06E+07	4.66E-04	2.55E-03	271.23	5.91E+07	4.34E-04	2.33E-03
	$^{2}D_{5/2}^{e}$	$^{2}D_{3/2}^{o}$	237.19	9.60E+09	5.40E-02	2.53E-01	227.21	1.07E+10	5.50E-02	2.47E-01
	$^{2}D_{5/2}^{e}$	$^{2}D_{5/2}^{o}$	235.25	1.18E+10	9.80E-02	4.56E-01	225.38	1.21E+10	9.25E-02	4.12E-01
	$^{2}D_{5/2}^{e}$	$^{2}P_{3/2}^{o}$	178.52	2.73E+10	8.70E-02	3.07E-01	164.92	2.51E+10	6.82E-02	2.22E-01
	$^{2}P_{1/2}^{e}$	$^{4}S_{3/2}^{o}$	267.32	7.34E+09	1.57E-01	2.77E-01	255.05	8.27E+09	1.61E-01	2.71E-01
	$^{2}P_{1/2}^{e}$	$^{2}D_{3/2}^{o}$	229.84	6.04E+09	9.57E-02	1.45E-01	215.74	6.94E+09	9.68E-02	1.37E-01
	$^{2}P_{1/2}^{e}$	$^{2}P_{1/2}^{o}$	200.15	5.17E+09	3.10E-02	4.09E-02	188.48	6.33E+09	3.37E-02	4.18E-02
	$^{2}P_{1/2}^{e}$	$^{2}P_{3/2}^{o}$	174.32	6.58E+09	5.99E-02	6.88E-02	158.79	8.04E+08	6.08E-03	6.35E-03
	$^{2}S_{1/2}^{e}$	$^{4}S_{3/2}^{o}$	378.50	1.46E+08	6.28E-03	1.57E-02	371.81	1.34E+08	5.53E-03	1.36E-02
	$^{2}S_{1/2}^{e}$	$^{2}D_{3/2}^{o}$	307.50	1.87E+08	5.29E-03	1.07E-02	293.79	1.69E+08	4.38E-03	8.46E-03
	$^{2}S_{1/2}^{e}$	$^{2}P_{1/2}^{o}$	256.58	1.47E+10	1.46E-01	2.46E-01	245.44	1.57E+10	1.42E-01	2.29E-01
	$^{2}S_{1/2}^{e}$	$^{2}P_{3/2}^{o}$	215.62	3.63E+09	5.05E-02	7.18E-02	197.39	2.58E+09	3.01E-02	3.91E-02
	$^{2}P_{3/2}^{e}$	$^{4}S_{3/2}^{o}$	392.98	3.01E+08	6.98E-03	3.61E-02	385.45	2.90E+08	6.46E-03	3.28E-02
	$^{2}P_{3/2}^{e}$	$^{2}D_{3/2}^{o}$	316.98	8.14E+08	1.23E-02	5.12E-02	302.24	8.96E+08	1.23E-02	4.88E-02
	$^{2}P_{3/2}^{e}$	$^{2}D_{5/2}^{o}$	313.53	4.09E+09	9.03E-02	3.73E-01	299.01	4.35E+09	8.74E-02	3.44E-01
	$^{2}P_{3/2}^{e}$	$^{2}P_{1/2}^{o}$	263.15	7.88E+08	4.09E-03	1.42E-02	251.31	7.38E+08	3.49E-03	1.16E-02
	$^{2}P_{3/2}^{e}$	$^{2}P_{3/2}^{o}$	220.25	1.94E+10	1.41E-01	4.09E-01	201.17	1.85E+10	1.12E-01	2.97E-01

4. Conclusions

In the present work, the energy levels, wavelengths, transition probabilities, oscillator strengths, and line strengths for electric dipole (E1) $4s^24p - 4s4p^2$, $4s^24p - 4s^24d$, and $4s4p^2 - 4p^3$ transitions for Sn XX, Sb XXI, Te XXII, and I XXIII were calculated using the multiconfiguration Dirac-Fock (MCDF) method. The correlations within the n=4 complex and the quantum electrodynamic (QED) effects were taken into account in the calcuations. The calculated MCDF energy levels and wavelengths were compared with the available experimental and other theoretical results, and the comparison showed an excellent agreement.

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