East European Journal of Physics. **2.** 111-120 (2024)
DOI:10.26565/2312-4334-2024-2-09 ISSN 2312-4334

TRANSITION PROBABILITIES, OSCILLATOR AND LINE STRENGTHS IN Sc XIX

Muhammad Kaleem[a], Saba Javaid[b], Roohi Zafar[b], Zaheer Uddin[a]*
[a]Department of Physic, University of Karachi, Karachi, Pakistan
[b]Department of Physic, NED University of Engineering & Technology, Karachi, Pakistan
**Corresponding Author email: zuddin@uok.edu.pk*
Received February 6, 2024; revised March 27, 2024; accepted March 30, 2024

Scandium XIX ion is a member of the isoelectronic sequence of Li-like ions. Numerical coulomb approximation and quantum defect theory have been used to calculate energies, quantum defects & transition probabilities, oscillator, and line strengths of Sc XIX ion for the transitions ns → mp, np → ms, np → md, and nd → mp Rydberg series. The energies of Sc XIXX ions up to n = 5 are given in the NIST database and the literature. We used quantum defect theory and determined the energies and quantum defects up to n = 30. The energies and quantum defects of 125 levels are reported for the first time. Sc XIX ion's transition probabilities, oscillator, and line strengths were compared with the corresponding values in the NIST database of spectral lines. The NIST database contains data of only seventy-six spectral lines. Only six spectra lines have percent uncertainties of more than 10%. The results of the remaining seventy spectral lines agree well with the NIST values. Almost 1800 transition probabilities, oscillators, and line strengths are new.
Keywords: *Scandium; Li-like; Rydberg Level; Quantum Defect theory; Transition Probability; Oscillator strength; Line Strength*
PACS: 31.10, +z, 31.15.−p, 31.15.Ct, 31.90.+s, 32.30-r

INTRODUCTION

The knowledge of the composition of stars plays an important role in understanding the galaxies. Different stars have different compositions of elements, giving different physical and chemical properties to the stars. Scandium, Vanadium, and Yttrium are observed in galactical centers [1]. It is believed that atomic diffusion below the superficial convection region is the cause of abundance anomalies in AmFm stars. Scandium is a key element to understanding this cause of abundance, as it is one of the underabundant elements at the surface of AmFm stars [2]. The nucleosynthesis theory and the chemical evolution of the Galaxy of long-lived F and G stars can be understood by scandium abundance [3]. The hyperfine structure studies data were used to determine the Scandium abundance in Sun and Arcturus [4].

The calculation of the ionization potential of Sc XIX to Zn XXVIII by the R-matrix method was compared with the full core plus correlation method. The R-matrix method was also used to calculate the quantum defects of the series 1s2 nh [5]. An improved theoretical prediction of the g factor of Li-like ions was performed using QED corrections. The calculations were compared with three different methods, including QED, and the results were consistent [6]. With the help of full-core-plus-correlation, the energies of Li-like Sc XIX to Zn XXVIII ions were calculated for the series 1s2ng (n = 5 to 8). An effective nuclear charge formula was used to reduce the uncertainties, and first-order perturbation calculations were done to assess the mass and relativistic polarization effects [7]. The energies and fine structure intervals of 1s2l2l' for Li-like ions from Ar to U were calculated using the relativistic configuration interaction method. The calculations include QED corrections, nuclear recoil effect, and Breit interaction [8]. The g factor of Li-like ions was calculated, and the effect of nuclear recoil was evaluated for Z =3 -92; using Breit interaction, the recoil term for two electrons is calculated for low and middle Z ions [9]. The energy, electron impact excitation, and transition rates were calculated for an isoelectronic sequence of Li-like ions from 21 ≤ Z ≤ 28. The energy and transition probabilities were calculated using the General-Purpose Relativistic Atomic Structure Package (GPRASP) for the lowest 24 levels. The r-matrix method was used to calculate the excitation rates. The transition probabilities were used to calculate the lifetimes of the levels [10]. The spectra of the isoelectronic sequence of lithium are determined using the QED approach [11]. The full core plus correlation method is employed to determine the transition energies and the dipole oscillator strengths $1s^2$ $2s$–$1s^2$ np (2⩽ n⩽ 9) and $1s^2$ $2p$–$1s^2$ and (3⩽ n⩽ 9) of lithium-like Sc 18+ ion. The expectation values of spin-orbit and spin-other-orbit interaction operators were used to obtain the fine structure splittings of 1s 2np and 1s2nd (n≦9). The quantum defects of the above series, as a function of the principal quantum number n, are determined. The agreement between the values obtained from three alternative formulae is excellent [12].

Compared with quantum defects for high-Z ions, the energy level data recommendation by the screening constant is more effective and accurate. The quantum defect converges to a small value as Z increases, whereas the screening constant decreases monotonically. The dependency of the screening constant on Z is approximately. Z^3 for values of Z=10 to Z=40, and $Z^{3.5}$ for values of Z= 40 to Z=70, and Z^4 for $Z > 70$. The dependence of the screening constant on Z^3 could be explained in terms of the spin-orbit interaction of the hydrogenic wavefunction in the Coulomb potential [13]. By considering the differences between calculated ab initio values of the ionization potentials and the NIST-evaluated for Li through the Ar isoelectronic series, new ionization potentials are extracted for several light ions for Z=3 to Z=50. The relativistic multiconfiguration Dirac-Fock method has been applied to calculate the ionization energies' ab initio

Cite as: M. Kaleem, S. Javaid, R. Zafar, Z. Uddin, East Eur. J. Phys. 2, 111 (2024), https://doi.org/10.26565/2312-4334-2024-2-09

values [14]. Energies of lithium 1s 2s 2S and 1s2 2p2P isoelectronic sequence for values of Z up to Z=40 are calculated using a variational method. The oscillator strengths, finite nuclear mass effects, and the associated lifetimes for the transitions 1s2 2s2S→1s22p2P are determined for Z up to 20 [15]. The fine structure levels (n$\leq 12, l \leq 5$) for $Ca^{17+}, Sc^{18+}, Ti^{19+}, V^{20+}, Cr^{21+}$ and Mn^{22+} and the radiative transition probabilities between them are calculated in the multiconfiguration Dirac-Fock scheme [16].

THEORY

For non-relativistic calculations of energy and wavefunctions of Li atom and Li-like ions the Schrödinger equation in atomic unit in the following forms can be used.

$$H = \sum_{i-1}^{N}\left(-\frac{1}{2}\nabla_i^2 - \frac{Z}{r_i}\right) + \sum_{i>j}^{N}\frac{1}{r_{ij}} \qquad (1)$$

The Li atom and Li-like ions, however, can be treated as hydrogen-like if the electrons other than the valence shell electron, i.e., the electrons in 1s orbital together with the nucleus, are considered core, around which the valence electron revolves. In such case, the radial part of the Schrödinger equation becomes;

$$\frac{d^2R}{dr^2} + \frac{2}{r}\frac{dR}{dr} + 2\left(E + \frac{Z^*}{r_i} - \frac{l^*(l^*+1)}{r_i^2}\right) = 0, \qquad (2)$$

here $l^* = l - \delta_n$, $n^* = n - \delta_n$, δ_n is the quantum defect and is given as a function of n. The values of δ_n can be found using Quantum Defect Theory. The solution of equation (2) gives the radial wavefunction given by [17-18]

$$R = \left(\frac{2Z^*}{n^*}\right)^{l^*+\frac{3}{2}}\sqrt{\frac{(n^*-l^*-1)!}{2n^*\Gamma(n^*+l^*+1)}}\,\mathrm{x}\exp\left(-\frac{Z^*r}{n^*}\right) r^{\,l^*} L_{n^*-l^*-1}^{2l^*+1}\left(\frac{2Z^*r}{n^*}\right). \qquad (3)$$

The energy (E_n), corresponds to the principal quantum number' n', is given by the effective principal quantum number' n^* '.

$$E_n = I - \frac{RZ^2}{(n-\delta_n)^2}. \qquad (4)$$

The value of δ_n is found by

$$\delta_n = a_o + \frac{a_1}{(n-\delta_o)^2} + \frac{a_2}{(n-\delta_o)^4} + \frac{a_3}{(n-\delta_o)^6}. \qquad (5)$$

The coefficients a_o, a_o, a_o, and a_o are known as spectral coefficients; the values of these constants depend on the nature of the orbital, i.e., penetrating and non-penetrating orbitals and their orbital angular momentum. The values can be found with the help of Rydberg levels' first few known energies.

The transition probability (A_{fi}) of a transition between fine levels is given by

$$A_{fi} = 2.0261 \text{ x } 10^{-6}\,\frac{\left(E_f - E_i\right)^3}{2l_i+1}S, \qquad (6)$$

E_f and E_i are the energies of upper and lower states; S is dipole line strength and is found by

$$S_{LS} = \left[J_f, J_i, L_f, L_i\right]\left(\begin{Bmatrix} L_f & S & J_f \\ J_i & 1 & L_i \end{Bmatrix}\begin{Bmatrix} L_f & l_f & L_c \\ 1 & L_i & l_i \end{Bmatrix} P_{l_il_f}^{(1)}\right)^2. \qquad (7)$$

The terms in the bracket contain two 6J symbols and the matrix element.$P_{l_il_f}^{(1)}$, which is given by [19-20].

$$P_{l_il_f}^{(1)} = l_> < n_i, l_i|r|n_f, l_f > = l_> \int_o^\infty r^3 R_{n_il_i} R_{n_fl_f} dr. \qquad (8)$$

Numerical coulomb approximation is used to calculate the matrix element.

RESULTS AND DISCUSSION

This study was devoted to calculating energies, quantum defects, transition probabilities, oscillator, and line strengths Sc XIX ion of isoelectronic sequence of Li-like ions. The energies and quantum defects of ns, np, and nd series are given in tables 1-3. The energies are compared with the available data in NIST [21]and Aggarwal's work [10]. A good match between calculated and available energies was found. Table 1 gives the energies of the $1s^2ns$ ($^2S_{1/2}$), and $1s^2np$ ($^2P_{1/2}$) series, table 2 gives the energies of $1s^2np$ ($^2S_{3/2}$) and $1s^2nd$ ($^2D_{3/2}$) series, and table 3 gives the energies of $1s^2nd$ ($^2D_{5/2}$) series. In each table, 1-3, the first, second, and third columns give the principal quantum number, quantum defects, and energies determined in this work, the fourth column gives corresponding NIST values, and the last two columns show the energies from Aggarwal et al.'s work. Aggarwal et al. [10] calculations were based on the General-Purpose Relativistic Atomic Structure Package (GPRASP).

Four different series in spectral transition up to n = 20 were considered for calculating TP, OS, and LS of Sc XIX. This work presents eighteen hundred & sixty-two transitions in Rydberg ion Sc XIX, whose TP, OS, and LS are determined using numerical coulomb approximation and quantum defect theory. The results were compared with the NIST values for Sc XIX. Most of the results agree only six transitions differ significantly. Some of the results are shown in Table 5. (The complete results are available as a supplementary file on the Journal site.) There are eighteen columns; the first column gives the wavelength in Angstrom. Columns 2, 5, and 8 give the transition probabilities, oscillator, and line strengths calculated in this work, and columns 3, 6, and 9 give the corresponding values in the NIST database of spectral lines. Columns 4, 7, and 10 give the percent uncertainties between this work and NIST values. Columns 11 and 12 give the energies cm^{-1} of lower and upper levels, respectively. Columns 13, 14, and 15 show the configuration of the lower levels, term value, and angular momentum. The same for the upper level is given in columns 16-18. Most TP, OS, and LS are new and not found in the NIST data.

Table 1. The quantum defects and energies of $1s^2ns$ ($^2S_{1/2}$) and $1s^2np$ ($^2P_{1/2}$) up to n = 3 compared with NIST [21] and Aggarwal [10] results

n	QD	Energy (Rydberg)				n	QD	Energy (Rydberg)			
		This work	NIST [21]	GRASP1 [10]	GRASP2 [10]			This work	NIST [21]	GRASP1 [10]	GRASP2 [10]
2	0.149979	0.00000	0.00000	0	0	2	0.122049	2.79489	2.79489	2.80532	2.80715
3	0.201701	53.28798	53.28798	53.28735	53.25951	3	0.175645	54.04790	54.04790	54.0638	54.03701
4	0.253260	71.58441	71.58441	71.58356	71.54981	4	0.227392	71.89983	71.89983	71.90314	71.8698
5	0.304049	79.97183	79.97183	79.97088	79.93505	5	0.283215	80.10133	80.10133	80.1325	80.09689
6	0.338553	84.55576				6	0.321839	84.61518	84.49369		
7	0.361442	87.31243				7	0.347657	87.34287	87.26398		
8	0.377025	89.08862				8	0.365304	89.10572			
9	0.387991	90.29572				9	0.377754	90.30608			
10	0.395955	91.15158				10	0.386810	91.15826			
11	0.401899	91.77961				11	0.393577	91.78414			
12	0.406444	92.25370				12	0.398756	92.25690			
13	0.409993	92.62017				13	0.402802	92.62250			
14	0.412813	92.90918				14	0.406019	92.91094			
15	0.415090	93.14108				15	0.408617	93.14243			
16	0.416953	93.32995				16	0.410745	93.33102			
17	0.418498	93.48580				17	0.412508	93.48665			
18	0.419791	93.61588				18	0.413985	93.61657			
19	0.420885	93.72558				19	0.415235	93.72615			
20	0.421819	93.81893				20	0.416301	93.81940			
21	0.422621	93.89902				21	0.417218	93.89942			
22	0.423316	93.96826				22	0.418012	93.96860			
23	0.423922	94.02851				23	0.418705	94.02880			
24	0.424453	94.08127				24	0.419312	94.08152			
25	0.424921	94.12772				25	0.419847	94.12794			
26	0.425336	94.16884				26	0.420322	94.16903			
27	0.425706	94.20540				27	0.420744	94.20557			
28	0.426036	94.23807				28	0.421122	94.23822			
29	0.426333	94.26736				29	0.421461	94.26750			
30	0.426600	94.29374				30	0.421766	94.29386			

Table 2. The quantum defects and energies of $1s^2np$ ($^2P_{3/2}$) and $1s^2nd$ ($^2D_{3/2}$) up to n = 3 compared with NIST [21] and Aggarwal [10] results

n	QD	Energy (Rydberg)				n	QD	Energy (Rydberg)			
		This work	NIST [21]	GRASP1 [10]	GRASP2 [10]			NIST [21]	GRASP1 [10]	GRASP2 [10]	NIST [21]
2	0.117309	3.25691	3.25691	3.28673	3.26772	3	0.160635	54.47620	54.47620	54.50117	54.46362
3	0.170880	54.18459	54.18459	54.206	54.206	4	0.212962	72.07298	72.07298	72.0855	72.04777
4	0.227118	71.90314	71.90314	71.96299	71.96299	5	0.268387	80.19246	80.19246	80.22533	80.1875
5	0.263005	80.22533	80.22533	80.16309	80.16309	6	0.327832	84.59393	84.59393		
6	0.284901	84.74466	84.49369			7	0.374674	87.28304	87.28220		
7	0.298813	87.44921	87.26398			8	0.409372	89.04100	88.97718		
8	0.308083	89.18812				9	0.434988	90.24765			
9	0.314530	90.36930				10	0.454152	91.10862			
10	0.319178	91.20707				11	0.468743	91.74288			
11	0.322632	91.82228				12	0.480053	92.22280			
12	0.325265	92.28711				13	0.488970	92.59428			
13	0.327316	92.64675				14	0.496110	92.88747			
14	0.328944	92.93065				15	0.501906	93.12279			
15	0.330258	93.15865				16	0.506672	93.31446			
16	0.331332	93.34450				17	0.510633	93.47259			
17	0.332222	93.49797				18	0.513961	93.60456			
18	0.332967	93.62616				19	0.516781	93.71581			
19	0.333597	93.73433				20	0.519191	93.81046			
20	0.334134	93.82645				21	0.521267	93.89163			
21	0.334596	93.90553				22	0.523066	93.96178			
22	0.334996	93.97392				23	0.524636	94.02280			
23	0.335345	94.03347				24	0.526014	94.07621			
24	0.335651	94.08563				25	0.527230	94.12322			
25	0.335921	94.13158				26	0.528308	94.16482			
26	0.336160	94.17227				27	0.529268	94.20181			
27	0.336373	94.20847				28	0.530127	94.23483			
28	0.336563	94.24082				29	0.530898	94.26444			
29	0.336734	94.26984				30	0.531593	94.29109			
30	0.336887	94.29598									

Table 3. The quantum defects and energies of $1s^2nd$ ($^2D_{5/2}$) up to n = 3 compared with NIST [21] and Aggarwal [10] results

n	QD	Energy (Rydberg)				n	QD	Energy (Rydberg)			
		This work	NIST [21]	GRASP1 [10]	GRASP2 [10]			This work	NIST [21]	GRASP1 [10]	GRASP2 [10]
3	0.159346	54.51265	54.51265	54.54433	54.50651	17	0.50956	93.47275			
4	0.212198	72.08209	72.08209	72.10374	72.06586	18	0.51286	93.60469			
5	0.268387	80.19246	80.19246	80.23467	80.19676	19	0.51565	93.71593			
6	0.327832	84.59393	84.59393			20	0.51805	93.81056			
7	0.374496	87.28343	87.28220			21	0.52010	93.89172			
8	0.409006	89.04154	88.97718			22	0.52189	93.96186			
9	0.434462	90.24819				23	0.52345	94.02287			
10	0.453495	91.10911				24	0.52481	94.07627			
11	0.467982	91.74330				25	0.52602	94.12328			
12	0.479210	92.22316				26	0.52709	94.16487			
13	0.488060	92.59458				27	0.52804	94.20185			
14	0.495145	92.88772				28	0.52889	94.23487			
15	0.500897	93.12300				29	0.52966	94.26448			
16	0.505625	93.31464				30	0.53035	94.29113			

Lifetimes of Sc XIX Rydberg Levels

The lifetime of the ns, np, and nd & some f and g upper levels of the Rydberg series are also determined using the transition probabilities. All possible transitions from the level are considered to calculate the lifetime of an upper level; the lifetime is the reciprocal of the sum of all the transitions from the upper level, i.e.

$$\tau_j = \frac{1}{\sum_i A_{ji}}$$

One thousand eighteen hundred and sixty-two transition probabilities were used to calculate the lifetimes of ninety-six levels belonging to ns, np, and nd series up to n = 20. The lifetimes were compared with the work of Aggarwal et al. [10]. Out of twenty-one lifetimes, twenty lifetimes have percent uncertainties less than 0.1%. Only one lifetime differs significantly.

Table 4. The lifetimes of the ns, np, nd, some f, and g Rydberg levels of Sc XIX ion

Configuration	Lifetime (s)		Configuration	Lifetime (s)		Configuration	Lifetime (s)	
	This work	Aggarwal [10]		This work	Aggarwal [10]		This work	Aggarwal [10]
$1s^2$ 3s ($^2S_{1/2}$)	8.714E-13	8.86E-13	$1s^2$ 16p ($^2P_{1/2}$)	1.636E-10		$1s^2$ 11d ($^2D_{3/2}$)	4.248E-12	
$1s^2$ 4s ($^2S_{1/2}$)	1.301E-12	1.31E-12	$1s^2$ 17p ($^2P_{1/2}$)	1.860E-10		$1s^2$ 12d ($^2D_{3/2}$)	5.185E-12	
$1s^2$ 5s ($^2S_{1/2}$)	2.097E-12	2.07E-12	$1s^2$ 18p ($^2P_{1/2}$)	1.722E-10		$1s^2$ 13d ($^2D_{3/2}$)	6.227E-12	
$1s^2$ 6s ($^2S_{1/2}$)	3.654E-12		$1s^2$ 19p ($^2P_{1/2}$)	1.443E-10		$1s^2$ 14 ($^2D_{3/2}$)	7.391E-12	
$1s^2$ 7s ($^2S_{1/2}$)	6.683E-12		$1s^2$ 20p ($^2P_{1/2}$)	1.190E-10		$1s^2$ 15d ($^2D_{3/2}$)	8.695E-12	
$1s^2$ 8s ($^2S_{1/2}$)	1.287E-11		$1s^2$ 2p ($^2P_{3/2}$)	4.459E-10	4.46E-10	$1s^2$ 16d ($^2D_{3/2}$)	1.016E-11	
$1s^2$ 9s ($^2S_{1/2}$)	2.665E-11		$1s^2$ 3p ($^2P_{3/2}$)	3.454E-13	3.52E-13	$1s^2$ 17d ($^2D_{3/2}$)	1.179E-11	
$1s^2$ 10s ($^2S_{1/2}$)	6.079E-11		$1s^2$ 4p ($^2P_{3/2}$)	5.771E-13	5.93E-13	$1s^2$ 18d ($^2D_{3/2}$)	1.362E-11	
$1s^2$ 11s ($^2S_{1/2}$)	1.477E-10		$1s^2$ 5p ($^2P_{3/2}$)	1.021E-12	1.00E-12	$1s^2$ 19d ($^2D_{3/2}$)	1.565E-11	
$1s^2$ 12s ($^2S_{1/2}$)	2.667E-10		$1s^2$ 6p ($^2P_{3/2}$)	1.769E-12		$1s^2$ 20d ($^2D_{3/2}$)	1.788E-11	
$1s^2$ 13s ($^2S_{1/2}$)	2.256E-10		$1s^2$ 7p ($^2P_{3/2}$)	2.993E-12		$1s^2$ 3d ($^2D_{5/2}$)	1.135E-13	1.16E-13
$1s^2$ 14s ($^2S_{1/2}$)	1.438E-10		$1s^2$ 8p ($^2P_{3/2}$)	4.995E-12		$1s^2$ 4d ($^2D_{5/2}$)	2.642E-13	2.70E-13
$1s^2$ 15s ($^2S_{1/2}$)	9.876E-11		$1s^2$ 9p ($^2P_{3/2}$)	8.319E-12		$1s^2$ 5d ($^2D_{5/2}$)	5.113E-13	5.19E-13
$1s^2$ 16s ($^2S_{1/2}$)	7.566E-11		$1s^2$ 10p ($^2P_{3/2}$)	1.397E-11		$1s^2$ 6d ($^2D_{5/2}$)	8.823E-13	
$1s^2$ 17s ($^2S_{1/2}$)	6.331E-11		$1s^2$ 11p ($^2P_{3/2}$)	2.381E-11		$1s^2$ 7d ($^2D_{5/2}$)	1.378E-12	
$1s^2$ 18s ($^2S_{1/2}$)	5.671E-11		$1s^2$ 12p ($^2P_{3/2}$)	4.108E-11		$1s^2$ 8d ($^2D_{5/2}$)	1.976E-12	
$1s^2$ 19s ($^2S_{1/2}$)	5.362E-11		$1s^2$ 13p ($^2P_{3/2}$)	6.987E-11		$1s^2$ 9d ($^2D_{5/2}$)	2.660E-12	
$1s^2$ 20s ($^2S_{1/2}$)	5.303E-11		$1s^2$ 14 ($^2P_{3/2}$)	1.088E-10		$1s^2$ 10d ($^2D_{5/2}$)	3.422E-12	
$1s^2$ 2p ($^2P_{1/2}$)	7.107E-10	7.10E-10	$1s^2$ 15p ($^2P_{3/2}$)	1.389E-10		$1s^2$ 11d ($^2D_{5/2}$)	4.264E-12	
$1s^2$ 3p ($^2P_{1/2}$)	3.401E-13	3.44E-13	$1s^2$ 16p ($^2P_{3/2}$)	1.397E-10		$1s^2$ 12d ($^2D_{5/2}$)	5.195E-12	
$1s^2$ 4p ($^2P_{1/2}$)	5.768E-13	5.82E-13	$1s^2$ 17p ($^2P_{3/2}$)	1.213E-10		$1s^2$ 13d ($^2D_{5/2}$)	6.228E-12	
$1s^2$ 5p ($^2P_{1/2}$)	9.714E-13	9.87E-13	$1s^2$ 18p ($^2P_{3/2}$)	1.008E-10		$1s^2$ 14 ($^2D_{5/2}$)	7.381E-12	
$1s^2$ 6p ($^2P_{1/2}$)	1.606E-12		$1s^2$ 19p ($^2P_{3/2}$)	8.479E-11		$1s^2$ 15d ($^2D_{5/2}$)	8.673E-12	
$1s^2$ 7p ($^2P_{1/2}$)	2.590E-12		$1s^2$ 20p ($^2P_{3/2}$)	7.340E-11		$1s^2$ 16d ($^2D_{5/2}$)	1.012E-11	
$1s^2$ 8p ($^2P_{1/2}$)	4.097E-12		$1s^2$ 3d ($^2D_{3/2}$)	1.124E-13	1.16E-13	$1s^2$ 17d ($^2D_{5/2}$)	1.175E-11	
$1s^2$ 9p ($^2P_{1/2}$)	6.429E-12		$1s^2$ 4d ($^2D_{3/2}$)	2.613E-13	2.68E-13	$1s^2$ 18d ($^2D_{5/2}$)	1.358E-11	
$1s^2$ 10p ($^2P_{1/2}$)	1.011E-11		$1s^2$ 5d ($^2D_{3/2}$)	5.046E-13	5.14E-13	$1s^2$ 19d ($^2D_{5/2}$)	1.561E-11	
$1s^2$ 11p ($^2P_{1/2}$)	1.607E-11		$1s^2$ 6d ($^2D_{3/2}$)	8.721E-13		$1s^2$ 20d ($^2D_{5/2}$)	1.786E-11	
$1s^2$ 12p ($^2P_{1/2}$)	2.602E-11		$1s^2$ 7d ($^2D_{3/2}$)	1.364E-12		$1s^2$ 4f ($^2F_{5/2}$)	5.486E-13	5.54E-13
$1s^2$ 13p ($^2P_{1/2}$)	4.298E-11		$1s^2$ 8d ($^2D_{3/2}$)	1.959E-12		$1s^2$ 5f ($^2F_{5/2}$)	1.057E-12	1.07E-12
$1s^2$ 14 ($^2P_{1/2}$)	7.162E-11		$1s^2$ 9d ($^2D_{3/2}$)	2.641E-12		$1s^2$ 4f ($^2F_{7/2}$)	5.499E-13	5.55E-13
$1s^2$ 15p ($^2P_{1/2}$)	1.153E-10		$1s^2$ 10d ($^2D_{3/2}$)	3.403E-12		$1s^2$ 5g ($^2G_{9/2}$)	4.854E-13	1.80E-12

Table 5. The transition probabilities, oscillator, and line strengths in Sc XIX compared with NIST line data [21].

λ	Transition Probability (s^{-1})			Oscillator Strength			Line Strenght			Energy		Lower Level			Upper Level		
Å	This work	NIST	% Diff.	This work	NIST	% Diff.	This work	NIST	% Diff.	Lower Level	Upper level	Conf.	Term	J	Conf.	Term	J
10.4428	2.462E+11	2.530E+11	2.6911	0.003968	0.004136	4.0635	0.000271	0.0002844	4.6680	0	9576000	1s2.2s	2S	0.5	1s2.7p	2P	0.5
10.4428	2.462E+11	2.530E+11	2.6911	0.007936	0.008273	4.0751	0.000542	0.0005688	4.6680	0	9576000	1s2.2s	2S	1.5	1s2.7p	2P	0.5
10.5738	2.235E+11	2.400E+11	6.8762	0.007387	0.008046	8.1847	0.000511	0.0005601	8.7392	306700	9764000	1s2.2p	2P	1.5	1s2.8d	2P	0.5
10.6308	4.361E+10	4.600E+10	5.1865	0.000729	0.000779	6.4634	0.000101	0.000109	6.9908	357400	9764000	1s2.2p	2P	1.5	1s2.8d	2P	1.5
10.6308	2.617E+11	2.800E+11	6.5409	0.006558	0.007116	7.8436	0.000912	0.0009962	8.4099	357400	9764000	1s2.2p	2P	2.5	1s2.8d	2P	1.5
10.7852	4.002E+11	4.030E+11	0.6832	0.006884	0.007028	2.0550	0.000486	0.0004991	2.6519	0	9272000	1s2.2s	2S	0.5	1s2.6p	2P	0.5
10.7852	4.002E+11	4.030E+11	0.6832	0.013767	0.01406	2.0829	0.000972	0.0009981	2.6421	0	9272000	1s2.2s	2S	1.5	1s2.6p	2P	0.5
10.7860	3.688E+11	3.660E+11	0.7644	0.012687	0.01277	0.6474	0.000896	0.0009067	1.2264	306700	9578000	1s2.2p	2P	1.5	1s2.7d	2P	0.5
10.8453	7.208E+10	7.100E+10	1.5267	0.001254	0.00125	0.2935	0.000178	0.000179	0.5763	357400	9578000	1s2.2p	2P	1.5	1s2.7d	2P	1.5
10.8453	4.325E+11	4.310E+11	0.3489	0.011283	0.0114	1.0262	0.001602	0.001628	1.6146	357400	9578000	1s2.2p	2P	2.5	1s2.7d	2P	1.5
11.1404	5.956E+11	5.930E+11	0.4434	0.021868	0.02207	0.9144	0.001595	0.001619	1.5019	306700	9283000	1s2.2p	2P	1.5	1s2.6d	2P	0.5
11.2037	1.165E+11	1.200E+11	2.9472	0.002162	0.002258	4.2319	0.000317	0.0003332	4.8069	357400	9283000	1s2.2p	2P	1.5	1s2.6d	2P	1.5
11.2037	6.988E+11	7.010E+11	0.3167	0.019462	0.01979	1.6575	0.002855	0.002919	2.2045	357400	9283000	1s2.2p	2P	2.5	1s2.6d	2P	1.5
11.3766	6.772E+11	6.900E+11	1.8556	0.012967	0.01339	3.1579	0.000966	0.001003	3.7132	0	8790000	1s2.2s	2S	0.5	1s2.5p	2P	0.5
11.3766	6.772E+11	6.900E+11	1.8556	0.025934	0.02678	3.1579	0.001932	0.002006	3.7132	0	8790000	1s2.2s	2S	1.5	1s2.5p	2P	0.5
11.7740	1.109E+12	1.090E+12	1.7434	0.045508	0.0453	0.4588	0.003508	0.00351	0.0462	306700	8800000	1s2.2p	2P	1.5	1s2.5d	2P	0.5
11.8447	2.171E+11	2.200E+11	1.2970	0.004509	0.004627	2.5444	0.000699	0.0007218	3.0933	357400	8800000	1s2.2p	2P	1.5	1s2.5d	2P	1.5
11.8447	1.303E+12	1.290E+12	0.9984	0.040583	0.0407	0.2864	0.006295	0.00635	0.8621	357400	8800000	1s2.2p	2P	2.5	1s2.5d	2P	1.5
12.6743	1.303E+12	1.400E+12	6.9013	0.031013	0.034	8.7864	0.002575	0.0028	8.0458	0	7890000	1s2.2s	2S	0.5	1s2.4p	2P	0.5
13.1539	2.424E+12	2.200E+12	10.1755	0.124289	0.11	12.9899	0.010711	0.0099	8.1938	306700	7909000	1s2.2p	2P	1.5	1s2.4d	2P	0.5
13.2405	2.859E+12	2.800E+12	2.0958	0.111398	0.11	1.2707	0.019327	0.019	1.7234	357400	7910000	1s2.2p	2P	2.5	1s2.4d	2P	1.5
13.2422	4.757E+11	4.600E+11	3.4131	0.012361	0.01209	2.2451	0.002145	0.002109	1.7063	357400	7909000	1s2.2p	2P	1.5	1s2.4d	2P	1.5
16.8180	2.895E+12	2.850E+12	1.5678	0.243169	0.242	0.4830	0.026823	0.0268	0.0852	0	5946000	1s2.2s	2S	1.5	1s2.3p	2P	0.5
16.8606	2.940E+12	2.910E+12	1.0218	0.124105	0.124	0.0844	0.013724	0.0138	0.5495	0	5931000	1s2.2s	2S	0.5	1s2.3p	2P	0.5
17.6326	7.429E+12	7.210E+12	3.0365	0.686237	0.672	2.1186	0.079376	0.078	1.7646	306700	5978000	1s2.2p	2P	1.5	1s2.3d	2P	0.5
17.7790	8.809E+12	8.580E+12	2.6678	0.620496	0.61	1.7207	0.144741	0.143	1.2173	357400	5982000	1s2.2p	2P	2.5	1s2.3d	2P	1.5
17.7917	1.467E+12	1.400E+12	4.7761	0.068982	0.066	4.5185	0.016103	0.016	0.6419	357400	5978000	1s2.2p	2P	1.5	1s2.3d	2P	1.5
18.0203	3.680E+11	3.700E+11	0.5528	0.017753	0.018	1.3725	0.002099	0.0021	0.0581	306700	5856000	1s2.2p	2P	0.5	1s2.3s	2S	0.5
18.1864	7.548E+11	7.300E+11	3.3906	0.018546	0.018	3.0336	0.004426	0.0043	2.9224	357400	5856000	1s2.2p	2P	0.5	1s2.3s	2S	1.5
26.0892	8.274E+10	8.500E+10	2.6589	0.016772	0.0173	3.0495	0.002874	0.00298	3.5587	5931000	9764000	1s2.3p	2P	1.5	1s2.8d	2D	0.5
26.1917	1.633E+10	1.700E+10	3.9220	0.001669	0.00175	4.6546	0.000574	0.000603	4.7991	5946000	9764000	1s2.3p	2P	1.5	1s2.8d	2D	1.5
26.1917	9.800E+10	1.000E+11	2.0005	0.015017	0.01543	2.6773	0.005167	0.005321	2.9026	5946000	9764000	1s2.3p	2P	2.5	1s2.8d	2D	1.5
26.8817	7.786E+10	7.700E+10	1.1165	0.008380	0.00834	0.4739	0.001480	0.00148	0.0302	5856000	9576000	1s2.3s	2S	0.5	1s2.7p	2P	0.5
26.8817	7.786E+10	7.700E+10	1.1165	0.016759	0.0167	0.3535	0.002959	0.00295	0.3087	5856000	9576000	1s2.3s	2S	1.5	1s2.7p	2P	0.5
27.4198	1.302E+11	1.290E+11	0.9564	0.029169	0.02908	0.3047	0.005254	0.00525	0.0681	5931000	9578000	1s2.3p	2P	1.5	1s2.7d	2D	0.5
27.5330	2.577E+10	2.400E+10	7.3559	0.002909	0.00273	6.5676	0.001052	0.000989	6.4033	5946000	9578000	1s2.3p	2P	1.5	1s2.7d	2D	1.5
27.5330	1.546E+11	1.520E+11	1.7055	0.026184	0.02591	1.0562	0.009471	0.009395	0.8085	5946000	9578000	1s2.3p	2P	2.5	1s2.7d	2D	1.5
27.7932	6.851E+09	6.600E+09	3.8038	0.000394	0.00038	3.7249	0.000144	0.00014	2.8007	5978000	9576000	1s2.3d	2D	0.5	1s2.7p	2P	1.5

λ	Transition Probability (s^{-1})			Oscillator Strength			Line Strenght			Energy		Lower Level			Upper Level		
27.7932	6.851E+08	6.800E+08	0.7507	0.000079	0.000079	0.2141	0.000029	0.000029	0.7441	5978000	9576000	1s2.3d	2D	1.5	1s2.7p	2P	1.5
27.8242	6.219E+09	6.100E+09	1.9515	0.000478	0.00047	1.7284	0.000262	0.00026	0.8324	5982000	9576000	1s2.3d	2D	1.5	1s2.7p	2P	2.5
29.2740	1.295E+11	1.200E+11	7.9573	0.016541	0.01542	7.2700	0.003181	0.002972	7.0377	5856000	9272000	1s2.3s	2S	0.5	1s2.6p	2P	0.5
29.2740	1.295E+11	1.200E+11	7.9573	0.033082	0.03083	7.3048	0.006362	0.005943	7.0557	5856000	9272000	1s2.3s	2S	1.5	1s2.6p	2P	0.5
29.8329	2.110E+11	2.100E+11	0.4816	0.055967	0.05604	0.1309	0.010969	0.01101	0.3685	5931000	9283000	1s2.3p	2P	1.5	1s2.6d	2P	0.5
29.9670	4.179E+10	4.100E+10	1.9243	0.005592	0.00552	1.3025	0.002202	0.00218	1.0043	5946000	9283000	1s2.3p	2P	1.5	1s2.6d	2P	1.5
29.9670	2.507E+11	2.470E+11	1.5117	0.050327	0.04988	0.8963	0.019817	0.01968	0.6963	5946000	9283000	1s2.3p	2P	2.5	1s2.6d	2P	1.5
30.3582	1.425E+10	1.200E+10	18.7737	0.000979	0.000829	18.0604	0.000390	0.000331	17.9539	5978000	9272000	1s2.3d	2D	0.5	1s2.6p	2P	1.5
30.3582	1.425E+09	1.100E+09	29.5713	0.000196	0.00015	30.4961	0.000078	0.000061	28.0090	5978000	9272000	1s2.3d	2D	1.5	1s2.6p	2P	1.5
30.3951	1.292E+10	1.000E+10	29.1803	0.001186	0.000923	28.4542	0.000710	0.000554	28.2159	5982000	9272000	1s2.3d	2D	1.5	1s2.6p	2P	2.5
34.0832	2.112E+11	2.040E+11	3.5348	0.036579	0.03553	2.9532	0.008193	0.007973	2.7616	5856000	8790000	1s2.3s	2S	0.5	1s2.5p	2P	0.5
34.0832	2.112E+11	2.040E+11	3.5348	0.073159	0.07106	2.9532	0.016386	0.01595	2.7358	5856000	8790000	1s2.3s	2S	1.5	1s2.5p	2P	0.5
34.8554	3.805E+11	3.770E+11	0.9386	0.137862	0.1373	0.4090	0.031580	0.03152	0.1896	5931000	8800000	1s2.3p	2P	1.5	1s2.5d	2P	0.5
35.0385	7.558E+10	7.400E+10	2.1385	0.013836	0.0136	1.7322	0.006372	0.00628	1.4645	5946000	8800000	1s2.3p	2P	1.5	1s2.5d	2P	1.5
35.0385	4.535E+11	4.460E+11	1.6805	0.124520	0.1231	1.1537	0.057348	0.05681	0.9465	5946000	8800000	1s2.3p	2P	2.5	1s2.5d	2P	1.5
35.5619	2.320E+10	2.200E+10	5.4453	0.002187	0.00209	4.6529	0.001022	0.000977	4.6477	5978000	8790000	1s2.3d	2D	0.5	1s2.5p	2P	1.5
35.5619	2.320E+09	2.100E+09	10.4665	0.000437	0.0004	9.3622	0.000204	0.00019	7.6219	5978000	8790000	1s2.3d	2D	1.5	1s2.5p	2P	1.5
35.6125	2.106E+10	1.900E+10	10.8183	0.002655	0.00241	10.1471	0.001864	0.00169	10.2912	5982000	8790000	1s2.3d	2D	1.5	1s2.5p	2P	2.5
49.1642	3.808E+11	3.900E+11	2.3625	0.137382	0.1413	2.7730	0.044413	0.04575	2.9222	5856000	7890000	1s2.3s	2S	0.5	1s2.4p	2P	0.5
50.5561	7.725E+11	7.800E+11	0.9648	0.589444	0.5978	1.3977	0.195959	0.199	1.5281	5931000	7909000	1s2.3p	2P	1.5	1s2.4d	2P	0.5
50.9165	9.259E+11	9.000E+11	2.8782	0.537481	0.5247	2.4359	0.359919	0.3518	2.3078	5946000	7910000	1s2.3p	2P	2.5	1s2.4d	2P	1.5
50.9424	1.545E+11	1.500E+11	2.9701	0.059835	0.05836	2.5266	0.040088	0.03915	2.3960	5946000	7909000	1s2.3p	2P	1.5	1s2.4d	2P	1.5
52.3013	5.274E+10	5.100E+10	3.4029	0.010768	0.0105	2.5479	0.007407	0.0072	2.8710	5978000	7890000	1s2.3d	2D	0.5	1s2.4p	2P	1.5
53.3618	3.880E+10	3.850E+10	0.7720	0.032986	0.0329	0.2619	0.011576	0.0115	0.6567	7890000	9764000	1s2.4p	2P	1.5	1s2.8d	2D	0.5
59.2417	5.900E+10	5.850E+10	0.8513	0.061840	0.0616	0.3894	0.024095	0.024	0.3959	7890000	9578000	1s2.4p	2P	1.5	1s2.7d	2D	0.5
59.9880	7.862E+09	7.500E+09	4.8275	0.002112	0.002	5.6242	0.001667	0.0016	4.1849	7909000	9576000	1s2.4d	2D	0.5	1s2.7p	2P	1.5
59.9880	7.862E+08	7.700E+08	2.1048	0.000422	0.00042	0.5945	0.000333	0.00033	1.0278	7909000	9576000	1s2.4d	2D	1.5	1s2.7p	2P	1.5
60.0240	7.110E+09	6.800E+09	4.5575	0.002550	0.0024	6.2601	0.003020	0.0029	4.1518	7910000	9576000	1s2.4d	2D	1.5	1s2.7p	2P	2.5
71.7875	9.511E+10	9.120E+10	4.2900	0.146446	0.141	3.8626	0.069158	0.0666	3.8408	7890000	9283000	1s2.4p	2P	1.5	1s2.6d	2D	0.5
73.3676	1.667E+10	1.400E+10	19.0558	0.006702	0.00565	18.6147	0.006469	0.00546	18.4818	7909000	9272000	1s2.4d	2D	0.5	1s2.6p	2P	1.5
73.3676	1.667E+09	1.400E+09	19.0558	0.001340	0.0011	21.8497	0.001294	0.0011	17.6202	7909000	9272000	1s2.4d	2D	1.5	1s2.6p	2P	1.5
73.4214	1.506E+10	1.200E+10	25.5171	0.008087	0.00647	24.9871	0.011718	0.00938	24.9207	7910000	9272000	1s2.4d	2D	1.5	1s2.6p	2P	2.5
102.6694	2.150E+10			0.067742			0.045765			8790000	9764000	1s2.5p	2P	1.5	1s2.8d	2D	0.5
102.6694	4.300E+09			0.006774			0.009153			8790000	9764000	1s2.5p	2P	1.5	1s2.8d	2D	1.5
102.6694	2.580E+10			0.060968			0.082377			8790000	9764000	1s2.5p	2P	2.5	1s2.8d	2D	1.5
109.8901	1.603E+11	1.590E+11	0.8386	0.578840	0.5757	0.5454	0.418571	0.4165	0.4972	7890000	8800000	1s2.4p	2P	1.5	1s2.5d	2D	0.5
113.5074	2.899E+10	2.700E+10	7.3693	0.027917	0.0261	6.9609	0.041704	0.039	6.9338	7909000	8790000	1s2.4d	2D	0.5	1s2.5p	2P	1.5
113.5074	2.899E+09	2.700E+09	7.3693	0.005583	0.0052	7.3723	0.008341	0.0078	6.9338	7909000	8790000	1s2.4d	2D	1.5	1s2.5p	2P	1.5
113.6364	2.623E+10	2.400E+10	9.2737	0.033750	0.031	8.8711	0.075713	0.0695	8.9403	7910000	8790000	1s2.4d	2D	1.5	1s2.5p	2P	2.5
126.9036	3.142E+10			0.151301			0.126358			8790000	9578000	1s2.5p	2P	1.5	1s2.7d	2D	0.5
126.9036	6.284E+09			0.015130			0.025272			8790000	9578000	1s2.5p	2P	1.5	1s2.7d	2D	1.5

λ	Transition Probability (s^{-1})			Oscillator Strength			Line Strenght			Energy		Lower Level			Upper Level		
126.9036	3.770E+10			0.136171			0.227444			8790000	9578000	1s2.5p	2P	2.5	1s2.7d	2D	1.5
128.8660	7.548E+09			0.009370			0.015893			8800000	9576000	1s2.5d	2D	0.5	1s2.7p	2P	1.5
128.8660	7.548E+08			0.001874			0.003179			8800000	9576000	1s2.5d	2D	1.5	1s2.7p	2P	1.5
128.8660	6.793E+09			0.011244			0.028607			8800000	9576000	1s2.5d	2D	1.5	1s2.7p	2P	2.5
202.8398	4.853E+10			0.597228			0.797376			8790000	9283000	1s2.5p	2P	1.5	1s2.6d	2D	0.5
202.8398	9.705E+09			0.059723			0.159475			8790000	9283000	1s2.5p	2P	1.5	1s2.6d	2D	1.5
202.8398	5.823E+10			0.537505			1.435276			8790000	9283000	1s2.5p	2P	2.5	1s2.6d	2D	1.5
203.2520	1.288E+10			0.159199			0.212983			9272000	9764000	1s2.6p	2P	1.5	1s2.8d	2D	0.5
203.2520	2.577E+09			0.015920			0.042597			9272000	9764000	1s2.6p	2P	1.5	1s2.8d	2D	1.5
203.2520	1.546E+10			0.143279			0.383370			9272000	9764000	1s2.6p	2P	2.5	1s2.8d	2D	1.5
211.8644	1.669E+10			0.056031			0.156277			8800000	9272000	1s2.5d	2D	0.5	1s2.6p	2P	1.5
211.8644	1.669E+09			0.011206			0.031255			8800000	9272000	1s2.5d	2D	1.5	1s2.6p	2P	1.5
211.8644	1.502E+10			0.067238			0.281299			8800000	9272000	1s2.5d	2D	1.5	1s2.6p	2P	2.5
279.7985	2.242E+09	2.230E+09	0.5578	0.052522	0.0523	0.4246	0.096738	0.0964	0.3503	0	357400	1s2.2s	2S	1.5	1s2.2p	2P	0.5
326.0515	1.407E+09	1.390E+09	1.2256	0.022377	0.0222	0.7984	0.048030	0.0476	0.9041	0	306700	1s2.2s	2S	0.5	1s2.2p	2P	0.5
326.7974	1.682E+10			0.537425			1.156163			9272000	9578000	1s2.6p	2P	1.5	1s2.7d	2D	0.5
326.7974	3.364E+09			0.053742			0.231233			9272000	9578000	1s2.6p	2P	1.5	1s2.7d	2D	1.5
326.7974	2.018E+10			0.483682			2.081093			9272000	9578000	1s2.6p	2P	2.5	1s2.7d	2D	1.5
341.2969	6.925E+09			0.060340			0.271142			9283000	9576000	1s2.6d	2D	0.5	1s2.7p	2P	1.5
341.2969	6.925E+08			0.012068			0.054228			9283000	9576000	1s2.6d	2D	1.5	1s2.7p	2P	1.5
341.2969	6.233E+09			0.072408			0.488055			9283000	9576000	1s2.6d	2D	1.5	1s2.7p	2P	2.5
531.9149	8.743E+09			0.740213			2.592120			9576000	9764000	1s2.7p	2P	1.5	1s2.8d	2D	0.5
531.9149	1.749E+09			0.074021			0.518424			9576000	9764000	1s2.7p	2P	1.5	1s2.8d	2D	1.5
531.9149	1.049E+10			0.666191			4.665816			9576000	9764000	1s2.7p	2P	2.5	1s2.8d	2D	1.5
1111.1111	2.166E+08			0.080048			0.585590			5856000	5946000	1s2.3s	2S	1.5	1s2.3p	2P	0.5
1333.3333	1.248E+08			0.033193			0.291391			5856000	5931000	1s2.3s	2S	0.5	1s2.3p	2P	0.5
2127.6596	1.975E+07			0.026759			0.374856			5931000	5978000	1s2.3p	2P	1.5	1s2.3d	2D	0.5
2777.7778	1.065E+07			0.018450			0.674890			5946000	5982000	1s2.3p	2P	2.5	1s2.3d	2D	1.5
3125.0000	1.244E+06			0.001819			0.074843			5946000	5978000	1s2.3p	2P	1.5	1s2.3d	2D	1.5
5263.1579	5.564E+06			0.046129			1.598534			7890000	7909000	1s2.4p	2P	1.5	1s2.4d	2D	0.5
9090.9091	6.445E+06			0.159428			9.542886			9272000	9283000	1s2.6p	2P	1.5	1s2.6d	2D	0.5
9090.9091	1.289E+06			0.015943			1.908577			9272000	9283000	1s2.6p	2P	1.5	1s2.6d	2D	1.5
9090.9091	7.734E+06			0.143486			17.177195			9272000	9283000	1s2.6p	2P	2.5	1s2.6d	2D	1.5
10000.0000	2.213E+06			0.066227			4.360551			8790000	8800000	1s2.5p	2P	1.5	1s2.5d	2D	0.5
10000.0000	4.425E+05			0.006623			0.872110			8790000	8800000	1s2.5p	2P	1.5	1s2.5d	2D	1.5
10000.0000	2.655E+06			0.059604			7.848991			8790000	8800000	1s2.5p	2P	2.5	1s2.5d	2D	1.5
50000.0000	7.422E+04			0.055538			18.283910			9576000	9578000	1s2.7p	2P	1.5	1s2.7d	2D	0.5
50000.0000	1.484E+04			0.005554			3.656782			9576000	9578000	1s2.7p	2P	1.5	1s2.7d	2D	1.5
50000.0000	8.906E+04			0.049984			32.911038			9576000	9578000	1s2.7p	2P	2.5	1s2.7d	2D	1.5

CONCLUSION

Li-like isoelectronic ion Sc XIX has been studied for spectral line characteristics: energies, quantum defects, transition probability, oscillator, and line strengths. The following are the main points as concluding remarks.

1. The energies and quantum defects up to n = 30 are determined, and the available list of energies and quantum defects (up to n = 5) is extended.
2. The energies and quantum defects of five series $1s^2ns$ ($^2S_{1/2}$), $1s^2np$ ($^2P_{1/2}$), $1s^2np$ ($^2P_{3/2}$), $1s^2nd$ ($^2D_{3/2}$), and $1s^2nd$ ($^2D_{5/2}$) have been determined,
3. A comparison of energies with the NIST and Aggarwal et al.'s work shows good agreement results.
4. One thousand eighteen hundred and sixty-two spectral lines are investigated for calculating TP, OS, and LS of Sc XIX ion.
5. Seventy-six spectral lines were found in NIST line data for comparing the results.
6. Only six out of seventy-six lines have a percent error of more than 10%. Most of the results agree with the NIST values.
7. Almost eighteen hundred values of TP, OS, and LS are new.
8. Ninety-six Rydberg's level's lifetime was determined, and compared with the published work, only one value differs significantly.
9. The lifetimes of seventy-five levels are reported for the first time.

ORCID

Zaheer Uddin, https://orcid.org/0000-0002-8807-6186

REFERENCES

[1] B. Thorsbro, Atomic Data Needs in Astrophysics: The Galactic Center "Scandium Mystery", Atoms, **8**(1), 4. (2020). https://doi.org/10.3390/atoms8010004
[2] G. Alecian, F. LeBlanc, and G. Massacrier, "Scandium in AmFm stars in the light of new atomic data," Astronomy & Astrophysics, **554**, A89 (2013). https://doi.org/10.1051/0004-6361/201321156
[3] H.W. Zhang, T. Gehren, and G. Zhao, „A non-local thermodynamic equilibrum study of scandium in the Sun," Astronomy & Astrophysics, **481**(2), 489-497 (2008). https://doi.org/10.1051/0004-6361:20078910
[4] J.E. Lawler, C. Sneden, G. Nave, M.P. Wood, and J.J. Cowan, "Transition probabilities of Sc I and Sc II and Scandium abundances in the Sun, Arcturus, and HD 84937," The Astrophysical Journal Supplement Series, **241**(2), 21 (2019). https://doi.org/10.3847/1538-4365/ab08ef
[5] X. Liu, and J. Zhang, "Quantum defects of $1s^2nh$ configurations in Li-like system from Sc XIX to Zn XXVIII ion," Journal of the Korean Physical Society, **80**(12), 1107-1113 (2022). https://doi.org/10.1007/s40042-022-00465-3
[6] V.A. Yerokhin, C.H. Keitel, and Z. Harman, "Two-photon-exchange corrections to the g factor of Li-like ions," Physical Review A, **104**(2), 022814 (2021). https://doi.org/10.1103/PhysRevA.104.022814
[7] X. Liu, J.C. Zhang, and Z.W. Wang, "Theoretical calculation of ionization potentials and relativistic energies of high angular momentum 1s2ng states of Li-like ions," Results in Physics, **12**, 398-402 (2019). https://doi.org/10.1016/j.rinp.2018.11.087
[8] V.A. Yerokhin, and A. Surzhykov, "Energy levels of core-excited 1s2l2l′ states in lithium-like ions: Argon to uranium," Journal of Physical and Chemical Reference Data, **47**(2) (2018). https://doi.org/10.1063/1.5034574
[9] V.M. Shabaev, D.A. Glazov, A.V. Malyshev, and I.I. Tupitsyn, "Recoil effect on the g factor of Li-like ions," Physical Review Letters, **119**(26), 263001 (2017). https://doi.org/10.1103/PhysRevLett.119.263001
[10] K.M. Aggarwal, and F.P. Keenan, "Energy levels, radiative rates, and electron impact excitation rates for transitions in Li-like ions with 12≤ Z≤ 20," Atomic Data and Nuclear Data Tables, **99**(2), 156-248 (2013). https://doi.org/10.1016/j.adt.2012.03.001
[11] J. Sapirstein, and K.T. Cheng, "S-matrix calculations of energy levels of the lithium isoelectronic sequence," Physical Review A, **83**(1), 012504 (2011). https://doi.org/10.1103/PhysRevA.83.012504
[12] W. Zhi-Wen, Y. Di, H. Mu-Hong, H. Qiu-Ju, and L. Jin-Ying, "Transition energy and oscillator strength of Sc18+ ion," Chinese Physics, **14**(8), 1559 (2005). https://doi.org/10.1088/1009-1963/14/8/015
[13] T. Nishikawa, "Energy level data recommendation by screening constant," Journal of Quantitative Spectroscopy and Radiative Transfer, **67**(1), 43-54 (2000). https://doi.org/10.1016/S0022-4073(99)00192-2
[14] E. BiÉmont, Y. Frémat, and P. Quinet, "Ionization potentials of atoms and ions from lithium to tin (Z= 50)," Atomic Data and Nuclear Data Tables, **71**(1), 117-146 (1999). https://doi.org/10.1006/adnd.1998.0803
[15] Z.C. Yan, M. Tambasco, and G.W.F. Drake, "Energies and oscillator strengths for lithiumlike ions," Physical Review A, **57**(3), 1652 (1998). https://doi.org/10.1103/PhysRevA.57.1652
[16] Q.R. Zhu, S.F. Pan, and T.H. Zeng, "Energy levels, wavelengths, and radiative transition probabilities for the Li-like ions with 20≤ Z≤ 25," Atomic data and nuclear data tables, **52**(1), 109-141 (1992). https://doi.org/10.1016/0092-640X(92)90010-F
[17] M. Saeed, and Z. Uddin, "Lifetimes of Fine Levels of Li Atom for 20< n< 31 by Extended Ritz Formula," Canadian Journal of Physics, (January), (2023). https://doi.org/10.1139/cjp-2023-0220
[18] M. Saeed, S.U. Rehman, M.M. Khan, and Z. Uddin, "Computation of Characteristics of C IV Transitions," East European Journal of Physics, (2), 165-172 (2023). https://doi.org/10.26565/2312-4334-2023-2-16
[19] R. Siddique, R. Zafar, S. Raza, S.Z. Iqbal, and Z. Uddin, "Mean Lifetimes of ns, np, nd, & nf Levels of NV," East European Journal of Physics, (3), 424-429 (2023). https://doi.org/10.26565/2312-4334-2023-3-46
[20] R. Siddiq, M.N. Hameed, M.H. Zaheer, M.B. Khan, and Z. Uddin, "Rydberg energies and transition probabilities of Li I for np–ms (m≤ 5) transitions," Beni-Suef University Journal of Basic and Applied Sciences, **11**(1), 1-9 (2022). https://doi.org/10.1186/s43088-022-00224-0
[21] National Institute of Standards and Technology, 100 Bureau Drive Gaithersburg, MD 20899, 301-975-2000, USA, https://physics.nist.gov/PhysRefData/ASD/lines_form.html

ІМОВІРНОСТІ ПЕРЕХОДУ, ОСЦИЛЯТОР ТА ІНТЕНСИВНІСТЬ ЛІНІЙ У Sc XIX

Мухаммад Калім[a], Саба Джавайд[b], Рухі Зафар[b], Захір Уддін[a]
[a]*Фізичний факультет Університету Карачі, Карачі, Пакистан*
[b]*Кафедра фізики, Університет інженерії та технології NED, Карачі, Пакистан*

Іон скандію XIX є членом ізоелектронної послідовності Li-подібних іонів. Чисельне кулонівське наближення та квантовий дефект теорія була використана для розрахунку енергій, квантових дефектів і ймовірностей переходу, осцилятора та сили ліній іона Sc XIX для переходи ns → mp, np → ms, np → md і nd → mp ряд Рідберга. Енергії іонів Sc XIXX до n = 5 наведено в База даних NIST і література. Ми використали квантову теорію дефектів і визначили енергії та квантові дефекти до n = 30. енергії та квантових дефектів 125 рівнів повідомляється вперше. Імовірності переходу іона Sc XIX, осцилятор і лінія сили порівнювали з відповідними значеннями в базі даних спектральних ліній NIST. База даних NIST містить дані про лише сімдесят шість спектральних ліній. Лише шість спектральних ліній мають відсоткову невизначеність понад 10%. Результатів залишилося сімдесят спектральні лінії добре узгоджуються зі значеннями NIST. Майже 1800 ймовірностей переходів, осциляторів і інтенсивності ліній є новими.

Ключові слова: *скандій; Li-подібний; рівень Ридберга; квантова теорія дефектів; ймовірність переходу; сила осцилятора; інтенсивність лінії*