COLLISION STRENGTHS AND LINE STRENGTHS FOR TRANSITIONS FROM THE $1s^23\ell$ LEVELS TO THE $1s2\ell'3\ell''$ LEVELS IN LI-LIKE IONS*

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It is well known that radiation from the levels of the $1s2\ell2\ell'$ and $1s2\ell3\ell'$ configurations of Li-like ions form satellites of spectral lines from He-like ions that are of high interest for plasma diagnostic purposes. Recently Sampson et al (1984) have made calculations of the collision strengths for innershell excitation to these upper levels from the $1s^22s$ and $1s^22p$ levels for a large number of Li-like ions using a Coulomb-Born-exchange method. Here we consider the alternative mechanism for populating the $1s2\ell3\ell'$ levels by collisional excitation from the $1s^23s$, $1s^23p$ and $1s^23d$ levels. Although the populations of the $1s^23\ell$ levels are lower than those of the $1s^22\ell$ levels, this is at least partially compensated for by the fact that the collision strengths for the $1s^23\ell$ - $1s2\ell'3\ell''$ transitions are considerably larger on the average than those for the $1s^22\ell$ - $1s2\ell'3\ell''$ transitions. The method of calculation is the same as that used by Sampson et al (1984), where all possible configuration mixing, parentage mixing and intermediate coupling type mixing among the states in a complex (the states having the same n values, parity and J values) was included. Also the present application is sufficiently simple that after summation over J values for the initial level the results for the collision strength Ω can be expressed in a simple manner in terms of the Z scaled hydrogenic collision strengths $Z^2\Omega_H$ and $Z^2\Omega_H^e$ analogous to Eqs (8)-(15) of Sampson et al (1984). The appropriate formulae and the numerical results for both excitation to upper fine structure levels and to upper energy terms for 19 Li-like ions have been submitted for publication to Atomic Data and Nuclear Data Tables. Here we give only the pertinent formula and sample numerical results for transitions between energy terms in Li-like iron. This formula is

$$\Omega[1s^23\ell\ {}^2L-(1s2\ell_a\ {}^{2S''+1}L'')3\ell''\ {}^{2S'+1}L'] = \frac{1}{(Z-\sigma)^2}A(1s-2\ell')Z^2\Omega_H(1s-2\ell') + \frac{1}{(Z-\sigma^e)^2}A^e(1s-2\ell')Z^2\Omega_H^e(1s-2\ell'),$$

where due to configuration mixing neither ℓ need equal ℓ'' nor ℓ_a need equal ℓ'. The recommended values for σ and σ^e are zero for transitions involving 1s-2s and are -0.5 and 0.3, respectively, for transitions involving 1s-2p. Numerical values for the coefficients A and A^e for Li-like iron are given in Tables I-III. Values for $Z^2\Omega_H$ and $Z^2\Omega_H^e$ for impact electron energies up to 15 times threshold are given in Golden et al (1981) and Clark et al (1982) and are repeated in Table IV for convenience. Finally we note that the line strengths S for transitions involving 1s-2p are obtained by multiplying the corresponding value for A(1s-2p) by the scaled hydrogenic line strength 1.665 and dividing by $(Z-\sigma)^2$.

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TABLES

TABLE I. Values for the Coefficients A (Upper Entries) and A^e (Lower Entries) for Determining Ω for Innershell Excitation from $1s^2 3s\,^2S$

Transitions Involving 1s-2s			Transitions Involving 1s-2p		
Upper Level	ΔE (Z^2Ryd)	A(Upper) A^e(Lower)	Upper Level	ΔE (Z^2Ryd)	A(Upper) A^e(Lower)
$(1s2s\,^3S)3s\,^4S$	7.206(-1)	0.0	$(1s2s\,^3S)3p\,^4P$	7.227(-1)	5.718(-3)
		1.928(0)			1.384(-2)
$(1s2s\,^3S)3s\,^2S$	7.220(-1)	1.413(-3)	$(1s2s\,^3S)3p\,^2P$	7.231(-1)	7.128(-2)
		9.481(-1)			9.883(-2)
$(1s2s\,^1S)3s\,^2S$	7.244(-1)	3.755(0)	$(1s2s\,^1S)3p\,^2P$	7.262(-1)	5.168(-2)
		-2.816(0)			1.367(-1)
$(1s2s\,^3S)3d\,^4D$	7.243(-1)	3.667(-3)	$(1s2p\,^3P)3s\,^4P$	7.256(-1)	1.479(-1)
		-2.690(-3)			1.726(0)
$(1s2s\,^3S)3d\,^2D$	7.251(-1)	0.0	$(1s2p\,^3P)3s\,^2P$	7.274(-1)	1.928(-1)
		3.539(-5)			5.557(-1)
$(1s2s\,^1S)3d\,^2D$	7.280(-1)	0.0	$(1s2p\,^1P)3s\,^2P$	7.291(-1)	3.266(0)
		2.783(-4)			-2.380(0)
$(1s2p\,^3P)3p\,^4D$	7.270(-1)	6.479(-3)	$(1s2p\,^3P)3d\,^4F$	7.283(-1)	1.040(-3)
		-1.600(-3)			-5.515(-4)
$(1s2p\,^3P)3p\,^2D$	7.287(-1)	0.0	$(1s2p\,^3P)3d\,^2F$	7.298(-1)	0.0
		8.160(-3)			1.219(-2)
$(1s2p\,^1P)3p\,^2D$	7.308(-1)	0.0	$(1s2p\,^1P)3d\,^2F$	7.326(-1)	0.0
		7.721(-5)			1.429(-5)
$(1s2p\,^3P)3p\,^4P$	7.281(-1)	6.391(-2)	$(1s2p\,^3P)3d\,^4D$	7.295(-1)	1.033(-2)
		-3.283(-2)			-1.785(-3)
$(1s2p\,^3P)3p\,^2P$	7.281(-1)	5.217(-3)	$(1s2p\,^3P)3d\,^2D$	7.282(-1)	1.236(-1)
		2.437(-2)			-7.960(-2)
$(1s2p\,^1P)3p\,^2P$	7.311(-1)	3.749(-2)	$(1s2p\,^1P)3d\,^2D$	7.322(-1)	4.233(-3)
		-2.466(-2)			-2.919(-3)

TABLE I - continued

$(1s2p\,^3P)3p\,^4S$	7.266(-1)	0.0 3.035(-2)	$(1s2p\,^3P)3d\,^4P$	7.302(-1)	3.464(-3) 8.374(-3)
$(1s2p\,^3P)3p\,^2S$	7.298(-1)	8.281(-3) 1.676(-2)	$(1s2p\,^3P)3d\,^2P$	7.308(-1)	1.115(-1) -8.028(-2)
$(1s2p\,^1P)3p\,^2S$	7.319(-1)	1.187(-1) -7.816(-2)	$(1s2p\,^1P)3d\,^2P$	7.330(-1)	1.074(-2) -6.277(-3)

TABLE II. Values for the Coefficients A(Upper Entries) and A^e(Lower Entries) for Determining Ω for Innershell Excitation from $1s^2 3p\,^2P$

Transitions Involving 1s-2p			Transitions Involving 1s-2s		
Upper Level	ΔE (Z^2Ryd)	A(Upper) A^e(Lower)	Upper Level	ΔE (Z^2Ryd)	A(Upper) A^e(Lower)
$(1s2s\,^3S)3s\,^4S$	7.186(-1)	4.693(-4) 2.358(-2)	$(1s2s\,^3S)3p\,^4P$	7.207(-1)	9.995(-3) 5.835(0)
$(1s2s\,^3S)3s\,^2S$	7.200(-1)	3.598(-4) 1.648(-2)	$(1s2s\,^3S)3p\,^2P$	7.212(-1)	1.420(-1) 2.307(0)
$(1s2s\,^1S)3s\,^2S$	7.224(-1)	6.888(-2) -4.902(-2)	$(1s2s\,^1S)3p\,^2P$	7.242(-1)	8.760(0) -6.401(0)
$(1s2s\,^3S)3d\,^4D$	7.223(-1)	1.158(-2) 1.654(-1)	$(1s2p\,^3P)3s\,^4P$	7.236(-1)	1.130(-1) 1.326(-1)
$(1s2s\,^3S)3d\,^2D$	7.231(-1)	7.456(-3) 7.611(-2)	$(1s2p\,^3P)3s\,^2P$	7.254(-1)	2.293(0) -1.561(0)
$(1s2s\,^1S)3d\,^2D$	7.260(-1)	2.322(-1) 1.867(-2)	$(1s2p\,^1P)3s\,^2P$	7.272(-1)	3.796(-1) -2.471(-1)
$(1s2p\,^3P)3p\,^4D$	7.250(-1)	4.463(-1) 2.696(0)	$(1s2p\,^3P)3d\,^4F$	7.264(-1)	9.162(-3) -5.712(-3)
$(1s2p\,^3P)3p\,^2D$	7.268(-1)	4.094(-1) 1.194(0)	$(1s2p\,^3P)3d\,^2F$	7.278(-1)	0.0 2.395(-2)
$(1s2p\,^1P)3p\,^2D$	7.288(-1)	5.688(0) -4.107(0)	$(1s2p\,^1P)3d\,^2F$	7.306(-1)	0.0 7.540(-5)
$(1s2p\,^3P)3p\,^4P$	7.261(-1)	1.214(-1) 1.719(0)	$(1s2p\,^3P)3d\,^4D$	7.275(-1)	2.559(-2) 3.481(-3)
$(1s2p\,^3P)3p\,^2P$	7.262(-1)	2.350(-1) 7.475(-1)	$(1s2p\,^3P)3d\,^2D$	7.262(-1)	2.414(-2) 1.168(-2)
$(1s2p\,^1P)3p\,^2P$	7.291(-1)	3.246(0) -2.257(0)	$(1s2p\,^1P)3d\,^2D$	7.302(-1)	7.441(-3) -3.112(-3)
$(1s2p\,^3P)3p\,^4S$	7.246(-1)	1.117(-1) 5.334(-1)	$(1s2p\,^3P)3d\,^4P$	7.283(-1)	2.026(-3) 4.823(-2)
$(1s2p\,^3P)3p\,^2S$	7.278(-1)	4.920(-1) -1.670(-1)	$(1s2p\,^3P)3d\,^2P$	7.289(-1)	4.622(-2) -4.702(-3)
$(1s2p\,^1P)3p\,^2S$	7.299(-1)	9.294(-1) -6.095(-1)	$(1s2p\,^1P)3d\,^2P$	7.310(-1)	1.880(-1) -1.395(-1)

TABLE III. Values for the Coefficients A(Upper Entries) and A^e(Lower Entries) for Determining Ω for Innershell Excitation from $1s^2 3d\,^2D$

Transitions Involving 1s-2s			Transitions Involving 1s-2p		
Upper Level	ΔE (Z^2Ryd)	A(Upper) A^e(Lower)	Upper Level	ΔE (Z^2Ryd)	A(Upper) A^e(Lower)
$(1s2s\,{}^3S)3s\,{}^4S$	7.176(-1)	4.234(-8)	$(1s2s\,{}^3S)3p\,{}^4P$	7.197(-1)	8.342(-4)
		9.408(-8)			3.138(-2)
$(1s2s\,{}^3S)3s\,{}^2S$	7.190(-1)	0.0	$(1s2s\,{}^3S)3p\,{}^2P$	7.201(-1)	1.077(-3)
		7.965(-7)			1.249(-2)
$(1s2s\,{}^1S)3s\,{}^2S$	7.214(-1)	0.0	$(1s2s\,{}^1S)3p\,{}^2P$	7.232(-1)	7.964(-2)
		1.584(-3)			-5.438(-2)
$(1s2s\,{}^3S)3d\,{}^4D$	7.213(-1)	5.605(-3)	$(1s2p\,{}^3P)3s\,{}^4P$	7.226(-1)	4.293(-3)
		9.462(0)			3.993(-2)
$(1s2s\,{}^3S)3d\,{}^2D$	7.221(-1)	4.113(-1)	$(1s2p\,{}^3P)3s\,{}^2P$	7.244(-1)	2.463(-3)
		4.338(0)			4.990(-3)
$(1s2s\,{}^1S)3d\,{}^2D$	7.250(-1)	1.676(1)	$(1s2p\,{}^1P)3s\,{}^2P$	7.261(-1)	2.311(-2)
		-1.251(1)			4.721(-2)
$(1s2p\,{}^3P)3p\,{}^4D$	7.240(-1)	1.963(-1)	$(1s2p\,{}^3P)3d\,{}^4F$	7.253(-1)	5.318(-1)
		3.723(-1)			4.133(0)
$(1s2p\,{}^3P)3p\,{}^2D$	7.257(-1)	5.587(-2)	$(1s2p\,{}^3P)3d\,{}^2F$	7.268(-1)	1.558(0)
		1.249(-1)			7.549(-1)
$(1s2p\,{}^1P)3p\,{}^2D$	7.278(-1)	9.582(-1)	$(1s2p\,{}^1P)3d\,{}^2F$	7.296(-1)	7.089(0)
		-6.991(-1)			-4.756(0)
$(1s2p\,{}^3P)3p\,{}^4P$	7.251(-1)	1.546(0)	$(1s2p\,{}^3P)3d\,{}^4D$	7.265(-1)	4.263(-1)
		-1.097(0)			2.889(0)
$(1s2p\,{}^3P)3p\,{}^2P$	7.251(-1)	9.008(-4)	$(1s2p\,{}^3P)3d\,{}^2D$	7.252(-1)	3.452(-1)
		2.181(-2)			1.266(0)
$(1s2p\,{}^1P)3p\,{}^2P$	7.281(-1)	5.593(-2)	$(1s2p\,{}^1P)3d\,{}^2D$	7.292(-1)	6.019(0)
		-3.643(-2)			-4.355(0)
$(1s2p\,{}^3P)3p\,{}^4S$	7.236(-1)	9.072(-3)	$(1s2p\,{}^3P)3d\,{}^4P$	7.272(-1)	1.033(-1)
		2.532(-2)			1.868(0)
$(1s2p\,{}^3P)3p\,{}^2S$	7.268(-1)	0.0	$(1s2p\,{}^3P)3d\,{}^2P$	7.278(-1)	3.227(-1)
		1.612(-4)			6.322(-1)
$(1s2p\,{}^1P)3p\,{}^2S$	7.289(-1)	0.0	$(1s2p\,{}^1P)3d\,{}^2P$	7.300(-1)	3.493(0)
		2.890(-6)			-2.514(0)

TABLE IV. Values for $Z^2\Omega_H$ and $Z^2\Omega_H^e$ as a Function of Impact Electron Energy ε in Threshold Units

ε	$Z^2\Omega_H$(1s-2s)	$Z^2\Omega_H^e$(1s-2s)	$Z^2\Omega_H$(1s-2p)	$Z^2\Omega_H^e$(1s-2p)
1.0	3.614(-1)	1.554(-1)	1.478(0)	8.770(-1)
1.2	3.674(-1)	1.276(-1)	1.599(0)	6.651(-1)
1.5	3.747(-1)	9.804(-2)	1.827(0)	4.634(-1)
1.9	3.824(-1)	7.236(-2)	2.147(0)	3.082(-1)
2.5	3.912(-1)	4.945(-2)	2.595(0)	1.866(-1)
4.0	4.051(-1)	2.427(-2)	3.494(0)	7.494(-2)
6.0	4.152(-1)	1.250(-2)	4.355(0)	3.294(-2)
10.0	4.250(-1)	5.154(-3)	5.548(0)	1.145(-2)
15.0	4.307(-1)	2.472(-3)	6.550(0)	4.936(-3)