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LIFETIMES AND FLUORESCENCE YIELDS OF THREE-ELECTRON IONS

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ABSTRACT

Theoretical total rates of the various levels for the $1s\ 2p^2$, $1s\ 2s^2$ and $1s\ 2s\ 2p$ configurations are presented for atomic numbers 7, 8, 10, 16 and 26. The line fluorescence yields for these cases are also listed.

INTRODUCTION

The theoretical investigations of few-electron ions are important for the diagnostic applications to plasmas and solar flares. Similarly such calculations are also relevant to the recent experimental spectral measurements in ion-atom collisions and the measurements of lifetimes.

Satellite lines situated on the long-wavelength side of helium-like resonance lines were first reported from laboratory spark sources by Edlén and Tyrén (1939). Parkinson (1972), Grineva et al., (1972), and Acton et al., (1972) published the experimental observations on the solar spectra. Grineva et al., (1973) have now reported a new reduction of the iron XXV spectra and associated satellites, which are emitted during solar flares. Peacock et al. (1973) and Feldman et al., (1974) published the spectra from the laser-produced plasmas. Nagel (1974) discussed x-ray diagnostics of laser-compressed plasmas. Golt et al., (1974) have published a spectrum using a low inductance spark in iron.

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The theory determining the wavelength and intensity of the lines for the helium-like ions and ions with the $1s\ 2p^2$, $1s\ 2s^2$ and $1s\ 2s\ 2p$ configurations is given by Gabriel and collaborators (1969a, 1969, 1972), and by Gabriel (1972). Recently Bhalla, Gabriel and Presnyakov (1975) published the theoretical results on the dielectronic satellite spectra for highly-charged helium-like ions. These calculations removed the most notable discrepancy reported previously for the satellite intensities (Feldman *et al.*, 1974).

Sellin (1973) has published an extensive review on the lifetimes of the $4p^0\ 5/2$ autoionizing states of ions in the Li isoelectronic sequence. Calculations of Cheng *et al.*, (1974) are in reasonable agreement with the experimental data. More recently Betz *et al.*, (1974, 1975) have reported a new technique for measuring short lifetimes $\approx 10^{-14}$ sec. Calculations of lifetimes for few-electron systems are, therefore, needed. Similarly, the line fluorescence yields, (Bhalla 1975), defined as the ratio of the radiative rate for the line and the total rate for the level, are essential in the analysis of x-ray spectral measurements relevant to the heavy ion-atom collisions. Richard (1975) and Macdonald (1975) have recently reviewed this subject.

We present in this paper the lifetimes of all the levels of the $1s\ 2p^2$, $1s\ 2s^2$ and $1s2s2p$ configurations and the line fluorescence yields for $Z = 7, 8, 10, 16$ and 26 .

THEORY AND NUMERICAL RESULTS

The calculations were performed in the intermediate coupling scheme and the configuration interaction between the $1s\ 2s^2\ ^2S$ and $1s\ 2p^2\ ^2S$ terms were included. The theoretical expressions for the autoionization rates in the L-S coupling are given below in atomic units ($1\ a.u. = 2.419 \cdot 10^{-17}$ sec).

$$\begin{aligned}
 A_a(1s^2\epsilon s\ ^3S - 1s\ 2s^2\ ^2S) &= 2\pi [-R^0(1s, \epsilon s, 2s, 2s)]^2 \\
 A_a(1s^2\epsilon s\ ^2S - 1s\ 2p^2\ ^2S) &= \frac{2\pi}{3} [-R^1(1s, \epsilon s, 2p, 2p)]^2 \\
 A_a(1s^2\epsilon d\ ^2D - 1s\ 2p^2\ ^2D) &= \frac{2\pi}{15} [-R^1(1s, \epsilon d, 2p, 2p)]^2 \\
 A_a(1s^2\epsilon p\ ^2P - 1s\ 2p(^3P)2s\ ^2P) &= 3\pi [-R^0(1s, \epsilon p, 2s, 2p)]^2 \\
 A_a(1s^2\epsilon p\ ^2P - 1s\ 2p(^1P)2s\ ^2P) &= 4\pi \left[\frac{1}{3} R^1(1s, \epsilon p, 2p, 2s) \right. \\
 &\quad \left. - \frac{1}{2} R^0(1s, \epsilon p, 2s, 2p) \right]^2
 \end{aligned}$$

The relative phases of the amplitudes are contained in the brackets. The continuum electron of orbital angular momentum ℓ is designated by $\epsilon\ell$. The generalized Slater integrals involve three discrete-states and one continuum state wavefunctions. The detailed atomic model, Hartree-Fock-Slater with the HVDO exchange approximation, is described by Bhalla (1975).

The Hartree-Fock program of Froese-Fischer (1969) was used to obtain the total energies of the various terms and the values of the spin-orbit parameters. The appropriate matrices for various values of the total angular momentum were diagonalized to obtain the eigenvectors and eigen values. The procedure of the adjustment of the calculated energies is discussed by Gabriel (1972). All the appropriate radiative rates, A_r , and the autoionization-rates were, then, calculated.

Table I contains the notation used for designating the individual lines considered in this paper. The wavelengths of the satellite lines are given by Gabriel (1972), Vainstein and Safronova (1972) and Goldsmith (1974).

The total rate, Γ_i , for a level (αJ_i) is

$$\Gamma_i = \sum A_n + \sum A_a$$

where $\sum$ denotes a sum over all transitions. The line fluorescence yield, $\omega(\alpha J_i \rightarrow \alpha' J_f)$ is given by

$$\omega(\alpha J_i \rightarrow \alpha' J_f) = A_n(\alpha J_i \rightarrow \alpha' J_f) / \Gamma_i$$

Table II contains the total rates (in 10^{13} /sec) and the line fluorescence yields for $Z = 7, 8, 10, 16$ and 26 . We have also listed for the sake of completeness these quantities for the v' transition, (Cheng *et al.*, 1974).

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Table I Key Letter System for Individual Lines

Array	Multiplet	Line	Key Letter
$1s^2 2p - 1s 2p^2$	$2_P^0 - 2_P$	$1\frac{1}{2} - 1\frac{1}{2}$	a
		$\frac{1}{2} - 1\frac{1}{2}$	b
		$1\frac{1}{2} - \frac{1}{2}$	c
		$\frac{1}{2} - \frac{1}{2}$	d
	$2_P^0 - 4_P$	$1\frac{1}{2} - 2\frac{1}{2}$	e
		$1\frac{1}{2} - 1\frac{1}{2}$	f
		$\frac{1}{2} - 1\frac{1}{2}$	g
		$1\frac{1}{2} - \frac{1}{2}$	h
		$\frac{1}{2} - \frac{1}{2}$	i
	$2_P^0 - 2_D$	$1\frac{1}{2} - 2\frac{1}{2}$	j
		$\frac{1}{2} - 1\frac{1}{2}$	k
		$1\frac{1}{2} - 1\frac{1}{2}$	l
	$2_P^0 - 2_S$	$1\frac{1}{2} - \frac{1}{2}$	m
		$\frac{1}{2} - \frac{1}{2}$	n
$1s^2 2p - 1s 2s^2$	$2_P^0 - 2_S$	$1\frac{1}{2} - \frac{1}{2}$	o
		$\frac{1}{2} - \frac{1}{2}$	p
$1s^2 2s - 1s 2p 2s$	$2_S - (1_P) 2_P^0$	$\frac{1}{2} - 1\frac{1}{2}$	q
		$\frac{1}{2} - \frac{1}{2}$	r
	$2_S - (3_P) 2_P^0$	$\frac{1}{2} - 1\frac{1}{2}$	s
		$\frac{1}{2} - \frac{1}{2}$	t
	$2_S - 4_P^0$	$\frac{1}{2} - 1\frac{1}{2}$	u
		$\frac{1}{2} - \frac{1}{2}$	v
		$\frac{1}{2} - 2\frac{1}{2}$	v'

Table II Total rates, Γ , and Line Fluorescence Yields,
 $\omega(aJ_i \rightarrow a'J_f)$.

Key Letter	$\Gamma(10^{13}/\text{Sec})$	$\omega \times 100$	$\Gamma(10^{13}/\text{Sec})$	$\omega \times 100$
Z=7			Z=8	
a	1.993(-1)	82.5	3.835(-1)	82.8
b	"	15.4	"	15.1
c	1.950(-1)	33.4	3.755(-1)	33.4
d	"	66.6	"	66.6
e	3.280(-4)	0.743	9.029(-4)	1.26
f	5.452(-5)	3.03	1.500(-4)	4.77
g	"	0.0238	"	0.0524
h	2.445(-6)	28.7	4.425(-6)	48.2
i	"	3.23	"	13.7
j	8.414	0.766	9.592	1.29
k	8.411	0.662	9.585	1.13
l	"	0.106	"	0.169
m	4.656(-2)	53.4	1.059(-1)	45.0
n	"	27.1	"	22.8
o	8.871	0.227	9.916	0.396
p	"	0.113	"	0.197
q	1.048	11.6	1.161	20.0
r	1.090	11.1	1.234	18.5
s	5.202	0.443	5.902	0.714
t	5.160	0.467	5.830	0.778
u	7.463(-6)	17.2	2.511(-5)	23.3
v	2.949(-6)	17.3	9.866(-6)	23.5
v'	2.343(-6)	0.428	4.335(-6)	0.746

Z=10			Z=16	
a	1.102	83.3	1.247(+1)	87.1
b	"	14.3	"	10.0
c	1.077	32.5	1.232(+1)	34.0
d	"	67.5	"	66.0
e	4.536(-3)	3.03	1.537(-1)	22.2
f	7.560(-4)	10.2	2.837(-2)	47.9
g	"	0.163	"	1.17
h	5.609(-5)	3.88	1.114(-2)	93.2
i	"	93.6	"	0.00497
j	1.147(+1)	3.10	1.802(+1)	22.5

(Table II Continued)

Z=10		Z=16	
k	1.145(+1)	2.79	1.802(+1)
l	"	0.339	"
m	1.463	15.4	2.498
n	"	6.80	"
o	1.030(+1)	0.252	1.578(+1)
p	"	0.131	"
q	1.519	41.1	6.229
r	1.655	36.8	6.488
s	7.008	1.48	9.584
t	6.871	1.74	9.333
u	1.681(-4)	43.4	1.409(-2)
v	6.494(-5)	44.0	5.042(-3)
v'	1.190(-5)	1.87	1.008(-4)

Z=26	
a	6.679(+1)
b	"
c	6.864(+1)
d	"
e	6.415
f	9.865(-1)
g	"
h	1.541
i	"
j	3.378(+1)
k	4.562(+1)
l	"
m	2.631(+1)
n	"
o	1.686(+1)
p	"
q	5.178(+1)
r	3.293(+1)
s	1.181(+1)
t	3.178(+1)
u	1.572
v	4.483(-1)
v'	1.334(-3)

REFERENCES

- Acton, L. W., Catura, R. C., Meyerott, A. J., Wolfson, C. J. and Culhane, J. L., 1972, Solar Physics 26, 183.
- Betz, H. D., Bell, F., Panke, H., Kalkoffen, G., Welz, M., and Evers, D., 1974 Phys. Rev. Lett. 33, 807.
- Betz, H. D., Pank, H., and Bell, F., 1975, International Conference on the Physics of Electronic and Atomic Collisions, Seattle, USA.
- Bhalla, C. P., 1975, Phys. Rev. A12, 122.
- Bhalla, C. P., Gabriel, A. H., and Presynakov, L. P. (1975), Mon. Not. R. Astr. Soc. 172, 359.
- Cheng, K., Lin, C., and Johnson, W. R. 1974, Phys. Lett. 48A, 437.
- Fischer Froese, C., 1960, Computer Phys. Commun. 1, 15L.
- Feldman, U., Doscheck, G. A., Nagel, D. J., Cowan, R. D. and Whitlock, R. R., 1974, Astroph. J., 192, 213.
- Gabriel, A. H., 1972, Mon. Not. R. Astr. Soc., 160, 99.
- Gabriel, A. H., and Jordan, C., 1972, in Case Studies in Atomic Collision Physics - II, eds., McDaniel and McDowell (North Holland).
- Gabriel, A. H., Paget, T. M., and Kunze, H. J., 1975, to be submitted to J. Phys. B.
- Goldsmith, S., 1974, J. Phys. B., 7, 2315.
- Golts, E. Ya., Zhitnik, I. A., Kononov, E. Ya., Mandelstam, S. L., and Sidelnikov, Yn. V., 1974, Report No. 4 of the Spectroscopy Institute, USSA Academy of Sciences (to be published in Soviet Physics, Doklady).
- Grineva, Yu. I., Karev, V. I., Korneyev, V. V., Krutov, V. V., Mandelstam, S. L., Vainstein, L. A., Vasilyev, B. N., and Zitnik, I. A., 1972, in Space Research XII (Akademie-Verlag, Berlin).
- Grineva, Yu. I., Karev, V. I., Korneyev, V. V., Krutov, V. V., Mandelstam, S. L., Vainstein, L. A., Vasilyev, B. N., and Zitnik, I. A., 1973, Solar Physics, 29, 441.
- Macdonald, J. R., 1975, International Conference on the Physics of Electronic and Atomic Collisions, Seattle, USA (invited talk).
- Nagel, D. J., 1974, Physica Fennica 9, Supplement S1, 403.
- Parkinson, J. H., 1972, Nature, 236, 68.
- Peacock, N. J., Hobby, M. G. and Galanti, M., 1973, J. Phys, B. 6, L298.
- Richard, P., 1975, in Atomic Inner-Shell Processes, ed, B. Crasemann (Academic Press), vol. I.
- Vainstein, L. A., and Safronova, U. I., 1972, Short Communications in Physics, 3, 40 (Lebedev Institute, Moscow).

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