Lifetimes of some levels belonging to the $4p^5 5p$ and $4p^5 6p$ configurations of Kr I

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The lifetimes of sixteen levels of Kr I belonging to the $4p^5 5p$ and $4p^5 6p$ configurations have been measured by the delayed-coincidence method. The results are compared with other experimental values and with theoretical calculations using jK coupling and using intermediate coupling. From cascade components, lifetime values for some levels belonging to the $4p^5 4d$ configuration can be inferred.

INTRODUCTION

There are few experimental data about radiative lifetimes of Kr I levels (the noble gas last studied from this point of view). For the $4p^5 5p$ configuration the only known experimental information is given by Osherovich and Verolainen,[1] who used the delayed-coincidence method. For the $6p'(\frac{3}{2})_1$, $6p'(\frac{3}{2})_2$, $6p(\frac{1}{2})_1$, and $6p'(\frac{1}{2})_0$ levels, the only existing experimental data are those of Delgado *et al.*[2] (again using delayed coincidences). Finally, for the $5p'(\frac{1}{2})_0$ level no experimental results have been published to our knowledge. In the present experiment, radiative lifetimes of some levels belonging to the $4p^5 5p$ and $4p^5 6p$ configurations have been measured. The radiative transition wavelengths used in this experiment range from 7500 to 8300 Å and from 4300 to 4500 Å.

EXPERIMENTAL METHOD

An experimental technique based on the delayed-coincidence method that employs a time-to-amplitude converter and a multichannel pulse-height analyzer has been used in the present work. The entire experimental setup has been described by different authors in detail.[3]

A Jarrell-Ash 0.25-m monochromator of about 6 Å resolution was used to isolate lines from the atomic levels of which the spontaneous depopulation has been measured. Excitation of the levels of interest is obtained by means of an electron pulse of 0.5-mA peak current. The pulsed-electron-beam repetition rate was 50 kHz and the pulse duration 200 ns. The pulses end in less than 4 ns. Photons were detected with an EMI 9816B (S-20 response) photomultiplier, which was cooled with dry ice.

To get the given results the energy of the pulsed electron beam was always lower than 14 eV (ionization potential of Kr I) and as close to the excitation threshold of the level as was allowed by the intensity of the spectral lines. Higher energies were used for the measurements. The decay curves were observed with two time ranges: 900 and 3500 ns. The latter was used to measure as accurately as possible long cascade contributions. The measurements were performed at gas pressures lower than 10 mtorr. No lifetime changes with pressure variations were observed within the experimental error.

The decay curves have been fitted by one, two, and, in some cases, three exponential terms plus a uniform background by standard methods (least squares). The background was accumulated during the measurements in the time channels which correspond to an earlier time than the beginning of the excitation pulse, which was delayed with respect to the initial pulse of the time-to-amplitude converter. In all cases, the cascade components were less intense than the main component. Each level was measured in several steps, each one with an excitation electron energy closer to the threshold than the previous one and the intensity evolution of cascading components was followed as the excitation energy was varied. When this energy is higher than the threshold, three exponential terms are necessary to get a correct fit for the decay curves. As the excitation energy approaches threshold conditions, only two terms for the $4p^5 5p$ configuration levels and one term for the levels of the $4p^5 6p$ configuration [except the $6p(\frac{1}{2})_0$ and $6p(\frac{3}{2})_2$ levels] are needed to obtain a good fit to the experimental data. In many cases ($4p^5 5p$ configuration) the intermediate-cascading-component lifetime has been determined with a reasonable accuracy and information about lifetimes of higher populating levels can be obtained from it. For the three-component fits, the observed results for the longest component do not offer any information because in general they are due to several cascading levels.

DISCUSSION OF RESULTS

The results of the present experiment and of our theoretical calculations using pure jK coupling and

TABLE I. Lifetimes of some levels (in nano seconds) belonging to the $4p^5 5p$ and $4p^5 6p$ configurations of Kr I.

Level	λ(Å)	Experimental lifetimes: Present work	Ref. 2	Ref. 1	Other authors	Theoretical lifetimes: This work (jK)	Lilly (IC)	Murphy (IC)	Gruzdev and Loginov (IC)[a]: ζ_r	ζ_{SC} ζ_{rv}	ζ_v	ζ_{MC}
$5p(\frac{1}{2})_0$	7587	22.8±2	···	40	···	23.5	23.36	23.37	16.8	21.8	28.3	18.9
$5p(\frac{3}{2})_1$	8298	32.0±6	···	34	···	28.1	29.86	29.85	20.9	27.1	35.1	29.7
$5p(\frac{3}{2})_2$	7601	21.5±2	···	23	30.2[b]	24.5	25.23	25.31	18.1	23.4	30.3	26.3
$5p(\frac{5}{2})_3$	8113	31.0±3	···	44	28.1[b] 27[c]	28.4	28.55	···	20.7	26.8	34.7	25.9
$5p'(\frac{1}{2})_0$	7685	22.1±2	···	···	···	24.4	24.24	24.23	17.2	22.3	28.9	19
$5p'(\frac{1}{2})_1$	7854	23.5±3	···	34	···	28.3	26.17	26.29	19.3	25.0	32.4	28.6
$5p'(\frac{3}{2})_1$	8059	29.5±1	···	36	···	29.2	30.41	30.41	21.6	28.0	36.4	28.8
$5p'(\frac{3}{2})_2$	8263 5871	28.5±2	···	26	···	29.0	28.80	28.80	21.2	27.5	35.6	26.9
$6p(\frac{1}{2})_0$	4376	72 ±3	74.3±1	87	···	67.3	···	···	92.5	111	131	54.1
$6p(\frac{1}{2})_1$	4363	170 ±15	210 ±3	···	···	137.0	···	···	84	104	127	122
$6p(\frac{3}{2})_1$	4464	145 ±7	186 ±6	181	···	97.5	···	···	95	115	139	109
$6p(\frac{3}{2})_2$	4274	118 ±3	198 ±4	173	···	80.4	···	···	79.8	96.8	117	99.7
$6p(\frac{5}{2})_2$	4502	186 ±4	199 ±4	173	···	121.1	···	···	91.1	111	135	117
$6p'(\frac{1}{2})_0$	4352	93 ±4	111 ±4	···	···	80.0	···	···	83	99	117	53
$6p'(\frac{3}{2})_1$	4425	129 ±2	128 ±4	···	···	110.0	···	···	86.8	106	128	113
$6p'(\frac{3}{2})_2$	4400	129 ±3	127 ±2	···	···	190.0	···	···	84.4	103	124	105

[a] Reference 8. ζ_{SC}, lifetime from the single-configuration approximation; ζ_r, with transition integrals calculated from formulas for the length; ζ_v, from the dipole velocity; ζ_{rv}, the geometric mean of ζ_r and ζ_v; ζ_{MC}, from the multiple-configuration approximation.

[b] Reference 4.

[c] Reference 5.

TABLE II. Lifetimes of probable intense cascading levels to the $4p^5 5p$ configuration levels.

Populated level	Most likely cascading levels	Experimental results (ns)	Theoretical value jK	Theoretical value[a]: ζ_r	ζ_{SC} ζ_{rv}	ζ_v	ζ_{MC}
$5p(\frac{1}{2})_0$	$4d(\frac{3}{2})_1$	77±7	73	123	130	138	187
$5p(\frac{3}{2})_1$	$4d(\frac{5}{2})_2$	107±15	95	103	90.1	78.6	89.9
$5p(\frac{3}{2})_2$	$4d(\frac{5}{2})_3$	110±20	88	102	88.6	77.2	87.9
$5p(\frac{5}{2})_3$	$4d(\frac{7}{2})_3$	105±13	113	113	98.4	85.8	100
	$7s(\frac{3}{2})_2$		102	82.2	92.0	103	89.4
$5p'(\frac{1}{2})_0$	$4d'(\frac{3}{2})_1$	70±3	73	84	89	95	···
$5p'(\frac{1}{2})_1$	$4d'(\frac{3}{2})_1$	100±8	73	84	89	95	···
	$7s'(\frac{1}{2})_0$		100	···	···	···	···
$5p'(\frac{3}{2})_1$	$4d'(\frac{5}{2})_2$	118±8	122	104	90.8	79.6	98.0
$5p'(\frac{3}{2})_2$	$4d'(\frac{5}{2})_3$	117±8	119	111	96.5	84	111

[a] Reference 8.

using the Coulomb approximation are shown in Table I. The experimental values are compared with those given by Osherovich and Verolainen[1]; Malakhov,[4] and Landman[5]; the theoretical ones are compared with the values given by Murphy[6], Lilly,[7] and Gruzdev and Loginov.[8] In this table it is shown that for the levels of the $4p^55p$ configuration our experimental and theoretical calculations are in agreement and there is also agreement with the calculations of Refs. 6–8, performed using intermediate coupling (IC). For the measured levels belonging to the $4p^56p$ configuration, except for the $6p'(\frac{3}{2})_2$ level, the theoretical results are lower than the experimental ones.

The influence of cascading components in the measured lifetime values can be summarized as follows. For the $4p^55p$ configuration, the change in lifetime for the $5p(\frac{1}{2})_0$, $5p'(\frac{1}{2})_0$, $5p'(\frac{1}{2})_1$, and $5p(\frac{3}{2})_1$ levels, using a pulsed-electron-beam energy of 6 eV above the excitation threshold, is within the given experimental error (10%) of the close-to-threshold measurements. With the same experimental excitation conditions, the $5p(\frac{3}{2})_2$ and $5p(\frac{5}{2})_3$ levels show a higher variation (16%) while for the $5p'(\frac{3}{2})_1$ and $5p'(\frac{3}{2})_2$ levels (the last one measured by two different transitions), the influence due to cascades is less than 5%. For the $4p^56p$ configuration, the lifetime change of the $6p(\frac{1}{2})_0$, $6p(\frac{1}{2})_1$, $6p(\frac{3}{2})_1$, $6p(\frac{3}{2})_2$, and $6p(\frac{5}{2})_2$ levels, for an excitation energy 6 eV above the threshold, ranges between 5% and 9%. For the same excitation energy, the $6p'(\frac{1}{2})_0$ level presents a 16% lifetime variation, while for the $6p'(\frac{3}{2})_1$ and $6p'(\frac{3}{2})_2$ levels, even for electron energy 10 eV above the threshold, the lifetime-value change remains within the limits of the experimental error.

In Table II we present experimental lifetime values of the most likely levels which can populate some of the measured levels belonging to the $4p^55p$ configuration by radiative cascade. The lifetime values given are the decay time constants of the intermediate cascade components. These lifetimes do not appreciably change their value when the energy of the colliding electrons is varied in the threshold neighborhood and at higher energies the variation is less than 10%. The level selection has been made taking into account, first, the experimental intensity of the cascading lines as given in Ref. 9 and the closeness in energy of these levels to the populated ones and, second, the calculated lifetime values. In this way it can be deduced that the $5p$ levels are mainly populated by $4d$ levels. Nevertheless, for the $5p(\frac{5}{2})_3$ and $5p'(\frac{1}{2})_1$ levels the cascade identification is more difficult, so that two possible levels, $4d$ and $7s$, are given.

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