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Lifetime measurements of some levels belonging to the $3p^5nd$ ($n = 4, 5, 6, 7$) configuration of ArI

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Abstract. Lifetimes of some $3p^5nd$ ($n = 4, 5, 6, 7$) levels of neutral argon have been measured by high frequency deflection technique with a delayed coincidence single photon counting arrangement. The measurements have been performed under conditions where pressure dependent effects are negligible. Lifetimes of some of the levels have been measured for the first time. The results have been compared with other experimental and theoretical values.

PACS. 32.70.Cs Oscillator strengths, lifetimes, transition moments

1 Introduction

There is a constant interest in the study of rare gases in connection with plasma physics, high temperature arcs and lasers. The knowledge of lifetimes and transition probabilities of ArI is of great value in atomic structure studies and also with regard to the above mentioned applications. There is a shortage of experimental information about the lifetimes of nd ($n = 4, 5, 6, 7$) levels of ArI. Lifetimes of some of these levels have been measured previously by some investigators [1–3], all by electron excitation delayed coincidence technique. However, for some levels the only experimental work carried out previously was by Borge and Campos [1] and some levels were investigated by Zurro and Campos [2] only. There also exist a few theoretical data on the radiative lifetimes of these levels. This situation points to the need for further experimental investigations. The results obtained in the present work have been compared with the values obtained by previous workers. For the $4d[1/2]_1$, $5d'[3/2]_1$, $7d[1/2]_0$, $7d[5/2]_3$ and $7d[7/2]_3$ levels no experimental results have been published to our knowledge until now. The wavelengths of the transitions used for this experiment ranged from 4 894 to 8 621 Å.

2 Experimental method

In the present work high frequency deflection technique has been used together with a delayed coincidence single photon counting arrangement. Details concerning the experimental setup were reported previously [4]. A pulsed beam of high energy electrons (4 keV) is used to excite the atoms to the levels of interest, the dc beam current being 2 mA. The duration of each pulse is about 2.2 ns and the repetition rate is 0.5 and 1 MHz depending on the selected time range of the time to amplitude converter. A Minuteman 0.5 meter monochromator (Model 305) with gratings having 1 200 grooves/mm blazed at 5 000 Å and 7 500 Å has been used at a resolution of 0.7 Å to select the transitions of interest. The photons are detected with a Hamamatsu R943-02 photomultiplier tube cooled to −20 °C for dark current reduction. The spectral lines were identified with the help the tables of Striganov and Sventitskii [5]. The coincidence resolving time (FWHM) of the whole system is measured by the method described by Erman [6] and is found to be 3 ns. Calibration of the system is achieved with the help of a precisely known delay line. The time delay in the coincidence set up is adjusted to 1.5 ns per channel. The measurements are performed at various target pressures from 0.4 to 2 mtorr and during each measurement a continuous gas flow is maintained. No pressure dependence of lifetime has been observed within the pressure range mentioned above. Decay curves are analyzed by a least square fit to the experimental data convoluted with the known instrumental response function [7].

3 Results and discussion

An excitation spectrum (intensity *versus* wavelength scan) has been recorded between 2 000 to 9 000 Å using the monochromator at a resolution of 0.7 Å keeping the beam energy and current at values as mentioned earlier in order to examine how well the spectral lines under investigation are separated from the other neighboring lines and to investigate the effect of cascades in our measurements.

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Table 1. Lifetimes (ns) of some $3p^5nd$ (n = 4, 5, 6, 7, 8) levels of ArI.

Level	Wavelength (Å)	Experimental values			Theoretical values		
		Present work	Borge & Campos Ref. [1]	Zurro & Campos Ref. [2]	Borge & Campos Ref. [1]	Zurro & Campos Ref. [2][a]	Gruzdev & Loginov Ref. [9] τ_{rv}, τ_{MC}
$4d[1/2]_1$	8 620.5	81.3 ± 4.9					138, 113
$4d[3/2]_2$	6 752.8	137.1 ± 8.6	147 ± 7		384		424, 372
$4d[7/2]_4$	7 372.1	201.6 ± 13.3	226 ± 20		230		436, 460
$4d'[3/2]_1$	5 912.1	71.9 ± 4.7		100 ± 7		98	1.71, 3.78
$4d'[5/2]_3$	6 604.9	176.5 ± 10.1	310 ± 10		317		374, 367
$5d[1/2]_1$	5 606.7	73.2 ± 4.7		77 ± 7		90	231, 111
$5d[5/2]_3$	6 212.5	238.3 ± 14.5	475 ± 5		592		1 050, 848
$5d'[3/2]_1$	5 073.1	87.8 ± 5.1					3.48, 0.97
$6d[7/2]_3$	5 506.1	281.4 ± 16.8	500 ± 20		572		
$7d[1/2]_0$	4 894.7	116.2 ± 7.4					
$7d[5/2]_3$	5 410.5	153.7 ± 9.3					
$7d[7/2]_3$	5 252.8	309.7 ± 18.9					
$7d[7/2]_4$	5 221.3	272.5 ± 16.2	363 ± 17	340 ± 30	353	463	

[a] The actual values of energies of the levels intervening in each transition have been used.
τ_{rv} has been calculated from the geometrical mean of the line strengths in the length and velocity approximation in single configuration approximation.
τ_{MC} has been calculated from the multiple configuration approximation.

All the lines recorded in this spectrum are found in the list given by Striganov and Sventitskii [5] for ArI. However, their list contains many more lines which are not observed in the present experiment. The spectrum is found to contain no line that appears due to repopulation from a higher level to any of the levels under investigation. The other cascading levels that decay by emitting photons with wavelengths less than 2 000 and higher than 9 000 Å cannot be examined by this way as the photomultiplier tube used is insensitive in this region. But for excitation with electrons with energy well above the threshold, we may expect the higher levels to be excited relatively less as compared to the lower levels according to the work of Massey [8]. On this count also it seems that in the present experiment where the excitation energy is 4 keV, cascade feedings from the high lying levels is negligible and does not significantly influence the lifetimes of the levels under study. In the present experiment each of the decay curves is found to be best fitted to a single exponential. A typical delayed coincidence spectrum obtained from a measurement on the radiation of wavelength 6 752.8 Å decaying from the $4d[3/2]_2$ states in ArI is shown in Figure 1.

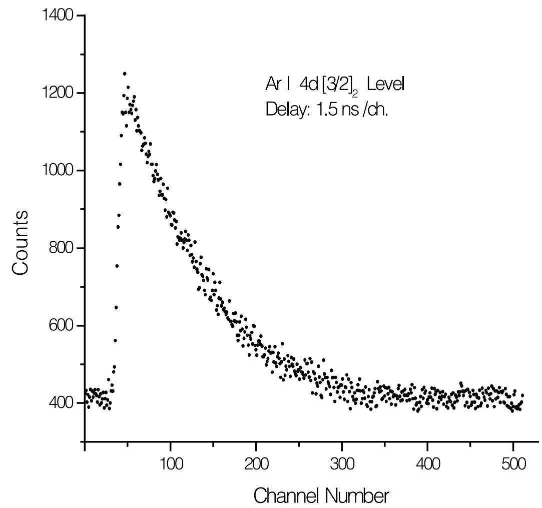

Fig. 1. The decay curve of the $4d[3/2]_2$ level of ArI measured at 6 752.8 Å (gas pressure 6×10^{-4} torr).

Our results for the lifetime measurements of some nd (n = 4, 5, 6, 7) levels in ArI are summarized in Table 1 which also shows the experimental and theoretical values obtained by other investigators. The lifetime values are the weighted average of three independent measurements for each level. The errors shown are the statistical and the systematic errors. Except for the $4d[3/2]_2$ and $4d[7/2]_4$ levels the experimentally obtained values of Borge and Campos [1] differ widely from our results. For the $5d[1/2]_1$ level the experimental value of Zurro and Campos [2] agrees well with the value obtained in the present measurement but for the $4d'[3/2]_1$ level their value is higher than our result. In both the experimental setup the spectral resolution was 5–6 Å, quite high in comparison to ours and the possibility of line blending might have been there for some levels. Moreover the duration of the beam pulse in their cases were much more higher than our value. There are different theoretical approaches by different authors. The calculations of both Borge and Campos [1] and Zurro and Campos [2] were performed in coulomb approximation and jk coupling. However, their calculated values differ from our experimental values, the deviation is less in case of jk coupling calculation of Zurro and Campos [2]. But in their calculation the possibility of configuration interaction (electron correlation) was ignored, but there may be appreciable interaction between some ArI excited configurations. The calculations of Gruzdev and Loginov [9] were based upon an intermediate coupling scheme that takes overlapping of configuration into account, using Hartree-Fock radial functions to compute the energy matrices for the electron-electron coulomb interaction and the spin orbital interaction. But the calculated values differ widely from the lifetime values obtained in the present measurement. The large discrepancies between the different forms of dipole matrix element occurring in their calculation may be due to the deficiency of the methods used for taking account of the overlap of configurations and it should be removed in order to achieve better accuracy. The inclusion of restricted set of configuration in the calculation is possibly another cause for the deviation, because drastic changes in the calculated data often occur as more and more correlation configuration are included. Thus further calculation is necessary for these levels taking into account more precisely the effect of electron correlation.

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