Lifetimes of some 6p levels of neutral argon

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Radiative lifetimes of five levels belonging to the $3p^5 6p$ configuration of Ar I have been measured by means of electron-impact excitation followed by selective pulsed-laser excitation. The present experimental values have been compared with calculations performed in an intermediate-coupling scheme employing for the radial part of the transitions the Coulomb approximation as well as with theoretical results from other authors obtained with Hartree-Fock wave functions. The agreement between the experimental values and the Hartree-Fock calculations is within 4%.

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I. INTRODUCTION

Radiative lifetimes and transition probabilities of neutral argon have been the subject of many experimental and theoretical works. There is a continuing interest in the knowledge of lifetimes and transitions probabilities of this atom in connection with plasma and atomic-structure studies.

For the 4s-4p and 4s-5p transition arrays a recent work [1] reviews the large number of lifetime and transition probability data, adds some new experimental results, and recommends reliable values for these aforementioned parameters. Nevertheless, for the $3p^5 6p$ levels, the experimental lifetime values are scarce [2] and the contribution of additional data would be desirable.

This situation has prompted the present experiment on lifetime measurement that was made by using a double excitation method [3] based on pulsed electron-impact excitation of metastable levels followed by laser excitation from them of the levels of interest. Lifetime values have been obtained from the decay of laser-induced fluorescence. The levels measured were the $6p[3/2]_1$, $6p[3/2]_2$, $6p[5/2]_2$, $6p'[3/2]_2$, and $6p'[1/2]_1$ levels using jK spectroscopic notation in the form $nl[K]_J$. For these levels no previous experimental lifetime values have been found in the literature.

The present experimental results have been compared with theoretical values from Gruzdev and Loginov [4] and from calculations carried out in the present work. The theoretical lifetimes were calculated by employing the intermediate-coupling (IC) scheme. To obtain the radial part of transition probabilities, the Hartree-Fock method was used in Ref. [4] and the Coulomb approximation was used in this work. The spectral tables of Striganov and Sventitskii [5] were used to identify the transitions, and the energy values of the levels have been taken from the compilations of Moore [6] and Bashkin and Stoner [7].

II. EXPERIMENTAL SETUP

As is well known, laser-induced fluorescence is an advantageous method for lifetime measurements. The different techniques employed, as well as the most important sources of error, have been discussed by several authors, as, for example, in Refs. [8] and [9].

The present experimental method is based on the excitation of the measured levels in two steps. The first step consists in populating the metastable levels by a pulsed electron beam. The second step is selective excitation of the 6p levels by a pulsed, tunable laser. This last step can be delayed with respect to the end of the first in the 0–50-μs range. After laser excitation, the decay of the induced fluorescence is measured.

Figure 1 shows the experimental setup. The excitation chamber had a triode structure similar to that employed in previous works [3,10]. The electron beam was directed along the chamber axis and the laser beam was perpendicular to it. Electron-impact excitation took place in the inner part of the anode, which had apertures for the laser beam and for fluorescence detection. The diameters of the electron beam and laser beam sections were 10 and 3 mm, respectively.

The electron beam was pulsed at 10 Hz frequency, the corresponding peak current was 1 mA and the pulse length was 100 μs. The electron energy could be varied in the 20–100 eV range. The beam could be pulsed at a variable delay with respect to an external triggering signal.

The dye laser was pumped by the second harmonic of a Q-switched Nd:YAG laser operating at 10 Hz frequency. The laser-pulse length was 7 ns and emission took place 170 μs after the triggering signal of the laser flash lamps. This signal triggered the electron beam at the same time. In this way the electron and laser pulses were synchronized and the laser pulse could be delayed with respect to the electron pulse in a preset time.

The dye used was Pyridin 1, having a tunable range [3] from 6700 to 7500 Å. The laser wavelength employed for level excitation was in the 3550–3390 Å range and was obtained by using a frequency doubler. The laser power at the chamber entrance was varied in the range 20–100 kW, and no dependence of experimental results on laser power was found within experimental error. The polarization of the excitation light was made parallel to the direction of the background magnetic field in the chamber, and the laser spectral resolution was 0.05 Å.

The fluorescence light from the excitation chamber was focused on the entrance slit of a 3-Å resolution monochromator that selected the transitions used to study the level population decay. The corresponding single photons were detected by means of an EMI 9813QB photomultiplier. These signals were amplified and fed a multiscaling whose start pulse was given by a fast photodiode (Monsanto MT1) that received a small part of the laser light. This start signal can be delayed in the range 0–0.5 μs with respect to the laser pulse in order to begin the measurements at different times after the end of the laser excitation. The dwell time per channel of the multiscaling was 30 ns and its full range could be selected from 0.5–1.5 μs by changing the position of the time channels. The time calibration was made with an accuracy better than 0.1%. The counting rate was low enough to prevent dead-time effects.

To tune the laser emission at resonance with the selected transitions, the optogalvanic effect was employed. For it an Ar hollow-cathode lamp received a part of the laser beam by means of a beam splitter and the amplitude of the optogalvanic signal was monitored during the measurements by an oscilloscope.

The experiment was made at different gas pressures maintaining a continuous flow of Ar into the excitation chamber. The pressure was varied in the range from 5 to 20 mTorr. Also, measurements were made varying the energy of colliding electrons in the mentioned range and the delay of the start signal of the multiscaling system in the 0.3–0.5 μs range. The results obtained by changing these experimental conditions were within the experimental errors. Figure 2 shows typical results for the deexcitation of the measured levels. The decay curves shown were obtained delaying the start of the multiscaling by

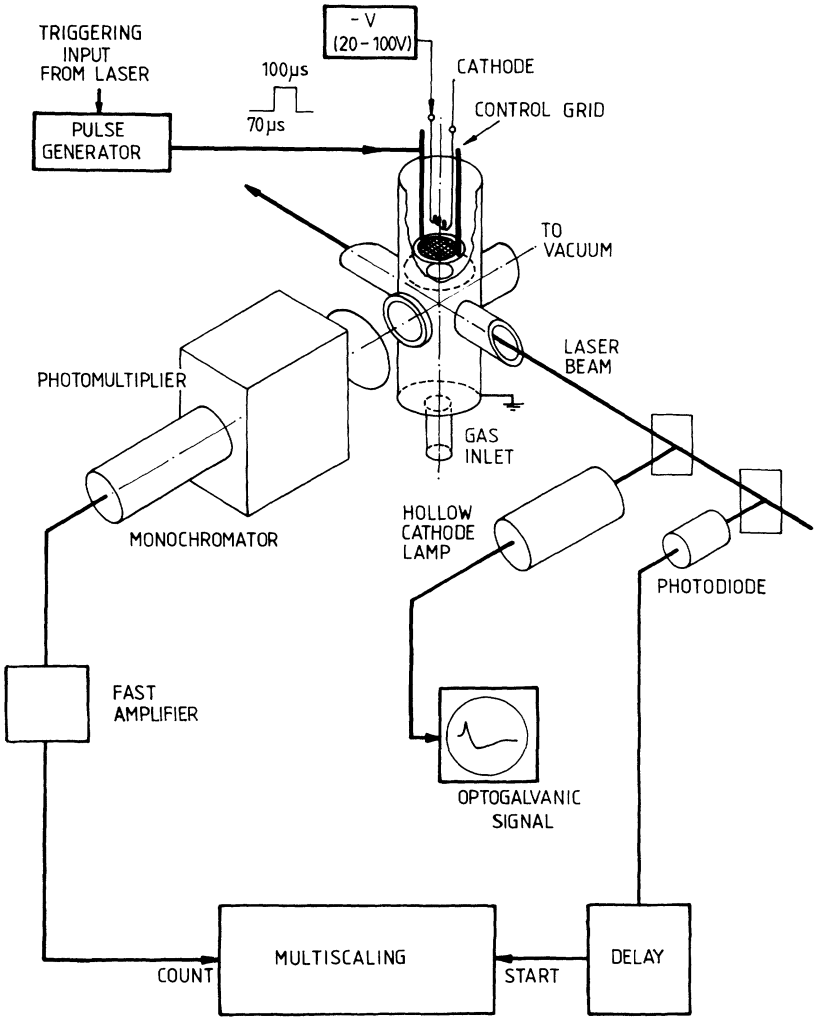

FIG. 1. Diagram of the experimental setup.

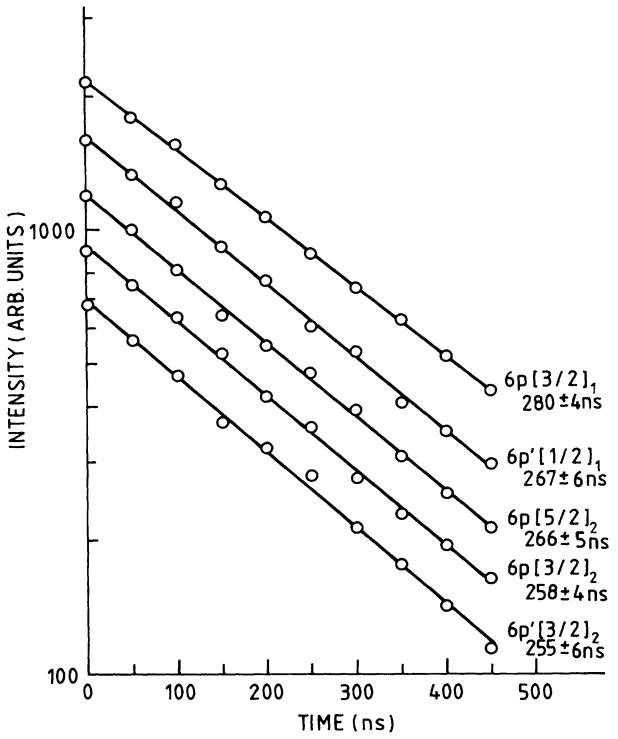

FIG. 2 Typical results obtained for the deexcitation of the $3p^5 6p$ levels of Ar I measured in the present work. The number of counts in the first channel is about 2000 for each curve. The gas pressure was 10 mTorr and the start of the multiscaling was delayed 400 ns with respect to the laser pulse. Only the $6p[3/2]_1$-level decay curve is to scale, the other curves have been vertically shifted for comparison.

400 ns and at 10 mTorr gas pressure. The number of counts in the first channel was about 2000 and the background was lower than 5%. In Fig. 2 only the $6p[3/2]_1$-level decay curve is to scale, the other curves have been vertically shifted for comparison. The statistical errors calculated from several measurements were about 1% (one standard deviation). The total errors were obtained by adding quadratically these statistical errors and the estimated systematic error (2%). This last error includes possible remaining Zeeman-quantum-beat effects due to the difficulty of making the polarization of the exciting light exactly parallel to the direction of the background magnetic field. These quantum beats have not been observed (within the numerical uncertainty of each fit) in the present experiment.

III. RESULTS AND DISCUSSION

The present results are shown in Table I together with the available theoretical data for comparison. Table II shows the Ar levels and transitions related to this experiment and includes the metastable levels and wavelengths used for excitation of the studied levels as well as the transitions and wavelengths employed for the measurement of the fluorescence decay.

In Table I the theoretical lifetime results obtained in the present work are shown. Calculations were carried out in the IC scheme and the Coulomb approximation, using the mean energy of the levels of the corresponding configurations. Deviations between these calculations and the experimental values are within 6%. Table I also shows the values obtained by Gruzdev and Loginov [4] in

TABLE I. Lifetimes of some $3p^5 6p$ levels of Ar I (ns).

Level (jK notation)	Experimental values (present work)	Theoretical Values: Present work (IC Coulomb)	Gruzdev and Loginov [4] (IC Hartree-Fock): τ_{rv}[a]	Gruzdev and Loginov [4] (IC Hartree-Fock): τ_{MC}[b]
$6p[3/2]_1$	280.4±5.9	296	293	262
$6p[3/2]_2$	257.7±5.4	257	251	230
$6p[5/2]_2$	266.1±5.4	284	272	291
$6p'[3/2]_2$	255.2±6.2	256	262	268
$6p'[1/2]_1$	266.7±6.4	250	261	276

[a]Calculated from the geometrical mean of the line strengths in the dipole-length and dipole-velocity approximations and single-configuration approximation.
[b]Multiconfigurational calculation.

TABLE II. Transitions used in the lifetime measurement of $3p^5 6p$ levels of Ar I.

Level	Excitation: Metastable level	Excitation: Wavelength (Å)	Deexcitation: Lower level	Deexcitation: Wavelength (Å)
$6p[3/2]_1$	$4s[3/2]_2$	3556.01	$4s[3/2]_1$	3634.46
$6p[3/2]_2$	$4s[3/2]_2$	3554.31	$4s[3/2]_1$	3632.68
$6p[5/2]_2$	$4s[3/2]_2$	3564.30	$4s[3/2]_1$	3643.12
$6p'[3/2]_2$	$4s[3/2]_2$	3389.85	$4s[3/2]_1$	3461.08
$6p'[1/2]_1$	$4s'[1/2]_0$	3563.29	$4s[3/2]_2$	3393.75

IC with Hartree-Fock wave functions. These authors performed calculations in dipole-length and dipole-velocity approximations and also in one-configuration and many-configuration approximations. For these levels, lifetime values that are obtained by calculating the radial parts of transition probabilities in dipole-length approximation are smaller than the results of the dipole-velocity calculations. In order to compensate for the uncertainty in the values of the radial parts, the geometrical mean of length and velocity approximations was taken to obtain transition probabilities. The corresponding lifetime results (τ_{rv}) are shown in the fourth column of Table I for the case of single-configuration approximation. The last column shows multiconfigurational results (τ_{MC}). These calculations agree with the experimental values, since for the τ_{rv} calculations, differences with experimental results are within 4%; for the τ_{MC} calculations, deviations are 10% at maximum and about 7% on average.

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