I R A M P
2(1), June 2011, pp. 53-55

© International Science Press
ISSN: 2229-3159

Stark Profiles of Spectral Lines Corresponding to the Transitions to Rydberg Levels of Argon: Possibilities for Diagnostics of Weak Electric Fields in Plasmas

V. P. GAVRILENKO

Center for Surface and Vacuum Research, Federal Agency on Technical Regulating and Metrology
Novatorov street 40/1, Moscow 119421, Russia
and
Moscow Institute of Physics and Technology (State University), Institutskiy per. 9
Dolgoprudniy 141700 Moscow region, Russia

ABSTRACT: Quantitative description of the Stark effect on Rydberg levels of argon atoms is given. Theoretical dependences of the shift and splitting of both allowed and forbidden spectral lines of argon atoms on the magnitude of the electric field are obtained These dependences can be used for laser-aided measurements of weak electric fields in low temperature plasmas.

Keywords: Stark effect, Rydberg atoms, measurements of electric fields.

PACS: 52.70.-m, 52.70.Kz, 32.60.+i, 32.70.Jz.

INTRODUCTION

At present laser spectroscopy of Rydberg levels of argon atoms is widely used for diagnostics of electric fields (EFs) in plasmas (see, e. g., [1-6]). For EF measurements, two main schemes of excitation in argon atoms are used. A feature of the first scheme [1-3] is a single-photon excitation from the metastable level $4s[3/2]_2$ to Rydberg $n'f$ levels ($n' >> 1$). Within the second scheme [4-6], a two-step excitation from the $4s[3/2]_J$ level to Rydberg levels $n'd$ and $(n'+2)\, s[3/2]_J$ is used, and laser-induced fluorescence-dip spectroscopy [7] is employed to detect the Stark spectra (see Fig. 1). As an intermediate level, the np level is used, where $n = 4$ or 5. Experiments performed with the use of this scheme (see [4-6]) revealed a very complicated structure of Stark spectra of argon.

In the present work, we give a quantitative description of the Stark effect for argon atoms within the excitation scheme employed in Refs. [4-6]. The results, obtained in the present work, can be used for laser-aided measurements of weak electric fields in plasmas.

THEORETICAL CALCULATIONS AND RESULTS

The wave functions and the positions of energy levels of Rydberg states of argon atoms are determined from the following Schrödinger equation:

$$H\psi = \varepsilon\psi, \quad H = H_0 + ezF. \tag{1}$$

Here H_0 is the unperturbed Hamiltonian of an argon atom, and ezF is the operator of the electric dipole interaction of the argon atom with the electric field $\vec{F}$. It is assumed that the z-axis is chosen parallel to the direction of the vector $\vec{F}$.

We solved Eq. (1) by performing numerical diagonalization of the matrix $H = H_0 + ezF$. We assume that the vector of polarization of the laser radiation having the wavelength λ_2 (cf. Fig. 1) is parallel to the vector $\vec{F}$. In our

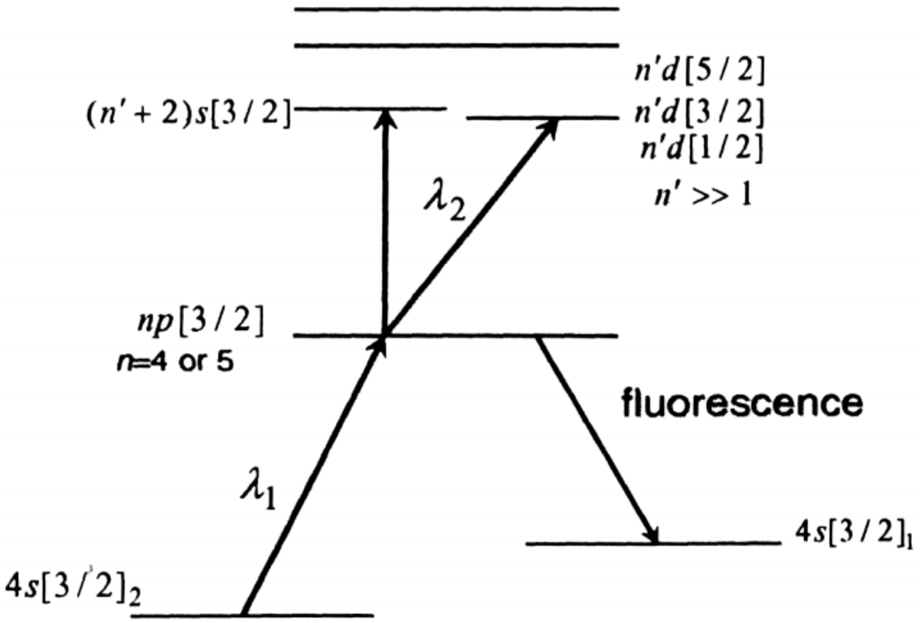

Figure 1: Partial scheme of energy Levels of an argon atom. Two-step excitation scheme is used to populate rydberg Levels of argon. It is assumed that the stark spectrum is recorded using laser-induced fluorescence-dip spectroscopy

numerical code that calculates the Stark spectra corresponding to the excitation of the transitions to Rydberg levels n' of argon, the following Rydberg levels of argon are taken into account: $n'l$ ($l = 2, 3,..., n'-1$), $n' - 1, l$ ($l = 2, 3,..., n' - 2$), $n' + 1, l$ ($l = 0, 1, 2,..., n'$), $(n' + 2)s$, $(n' + 2)p$, and $(n' + 3)s$.

Theoretical Stark spectra of argon atoms calculated for the excitation to levels of $n' = 25$ are shown in Fig. 2. For rather weak electric field $F = 70$ V/cm, the spectrum consists of three intense allowed lines corresponding to the transitions from the $np[3/2]$ level to the levels $25d[3/2]_2$, $25d[5/2]_J$ ($J = 2;3$), $27s[3/2]_2$. Two weak forbidden lines corresponding to the transitions to the $26p$ and $27p$ levels can also be seen. For sufficiently strong electric field, the Stark spectra of argon consist of many components. The positions of most of these components depend strongly on the strength of the electric field.

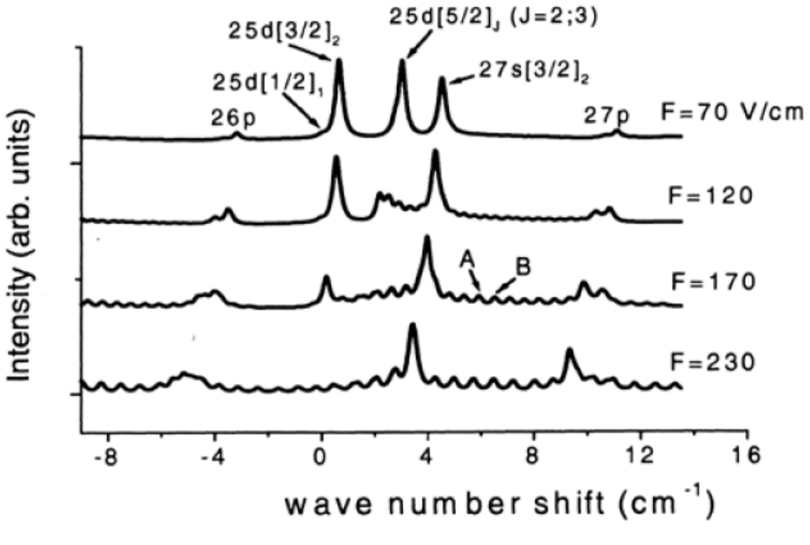

Figure 2: Theoretical stark spectra of argon atoms for the excitation scheme shown in Fig. 1.

For measurements of moderate electric fields, it is convenient to use the separation between the closely spaced spectral lines that are indicated in Fig. 2 by letters **A** and **B.** When the electric field is weak and the separation between these lines cannot be measured accurately, the strength of the electric field can be deduced from the Stark shift of the allowed spectral line corresponding to the transition $np[3/2] \rightarrow 27s[3/2]_2$, as well as of the forbidden spectral lines corresponding to the transitions $np[3/2] \rightarrow 26p$ and $np[3/2] \rightarrow 27p$, where $n = 4$ or 5. Figure 3 (curves 1-3) shows the theoretical dependence of the Stark shift of these lines on the electric field strength. The curve 4 in Fig. 3 shows the experimental dependence of the shift of the line $4p[3/2] \rightarrow 26p$ obtained in Ref. [4]. One can see that there is a reasonable agreement between the experimental and theoretical dependencies of the Stark shift of the line $4p[3/2] \rightarrow 26p$ on the electric field strength.

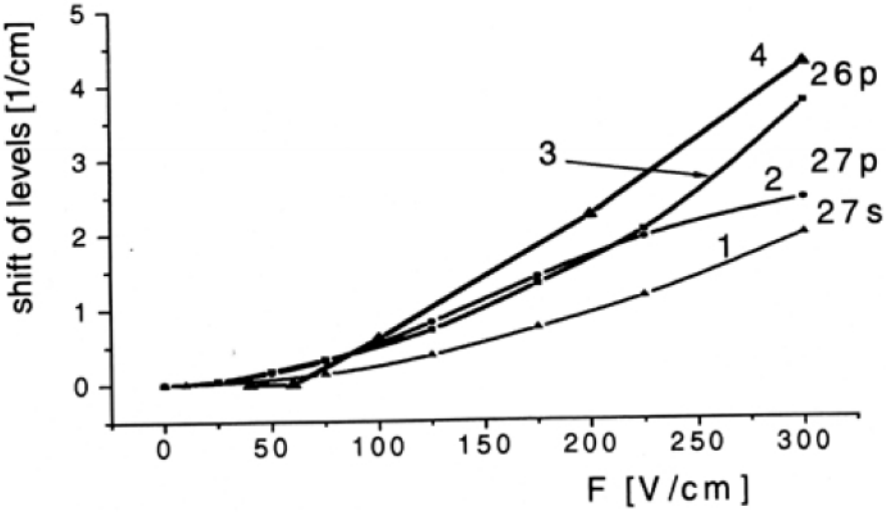

Figure 3: Stark shift of spectral lines corresponding to the transitions $np[3/2] \rightarrow 27s[3/2]_2$, $np[3/2] \rightarrow 27p$, and $np[3/2] \rightarrow 26p$, Respectively, versus the magnitude of the electric field *F*. Curves 1 ($np[3/2] \rightarrow 27s[3/2]2$), 2 ($np[3/2] \rightarrow 27p$) and 3 ($np[3/2] \rightarrow 26p$) Show the theoretical dependences of the shift on *F*, *n* being either 4, or 5. Curve 4 shows the experimental shift of the transition against the magnitude of the electric field *F*, obtained in Ref. [4]

Acknowledgements

This work was partially supported by the Russian Foundation for Basic Research (project No 06-02-17011).

References

[1] J. B. Kim, K. Kawamura, Y. W. Choi, M. D. Bowden, K. Muraoka, and V. Helbig, *IEEE Trans. Plasma Sci*. **26,** 1556, (1998).

[2] V. P. Gavrilenko, H. J. Kim, T. Ikutake, J. B. Kim, Y. W. Choi, M. D. Bowden, and K. Muraoka, *Phys. Rev. E* **62,** 7201, (2000).

[3] V. P. Gavrilenko, H. J. Kim, T. Ikutake, J. B. Kim, M. D. Bowden, and K. Muraoka, *Phys. Rev. E* **63,** 047401, (2001).

[4] K. Takizawa, K. Sasaki, and K. Kadota, *Jpn. J. Appl. Phys*. **41,** L1285, (2002).

[5] K. Takizawa, K. Sasaki, and A. Kono, *Appl. Phys. Lett*. **84,** 185, (2004).

[6] E. V. Barnat and G. A. Hebner, *Appl. Phys. Lett.* **85,** 3393, (2004).

[7] U. Czarnetzki, D. Luggenhölscher, and H.F. Döbele, *Phys. Rev. Lett*. **81,** 4592, (1998).