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Extended Analysis of Ar III and Ar IV

Mónica Raineri [1,*], Roberto E. Mejia Castellanos [2], Mario Gallardo [1] and Jorge Reyna Almandos [1]

1 Centro de Investigaciones Ópticas, M. B. Gonnet, P. O. Box 3, La Plata 1897, Argentina; mogallardo38@gmail.com (M.G.); jreyna@ciop.unlp.edu.ar (J.R.A.)
2 Departamento de Materia Condensada, Escuela de Física, Universidad Nacional Autónoma de Honduras, Tegucigalpa 11101, Honduras; rexar.ingenieria@gmail.com
* Correspondence: monicar@ciop.unlp.edu.ar

Received: 18 July 2018; Accepted: 16 August 2018; Published: 21 August 2018

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Abstract: A pulsed discharge light source was used to study the two and three times ionized argon (Ar II, Ar III) spectra in the 480–6218 Å region. A set of 129 transitions of Ar III and 112 transitions of Ar IV were classified for the first time. We extended the analysis of Ar III to five new energy levels belonging to $3s^23p^34d$, $3s^23p^35s$ odd configurations. For Ar IV, 10 new energy levels of the $3s^23p^23d$ and $3s^23p^24p$ even and odd configurations, respectively, are presented. For the prediction of energy levels, line transitions, and transition probabilities, relativistic Hartree–Fock calculations were used.

Keywords: atomic spectra; energy levels; capillary pulsed-discharge; relativistic Hartree–Fock calculations

1. Introduction

Spectral analysis of several ions of argon has implications in different fields. In astrophysics [1–3], argon spectral lines are important in determining the chemical abundance of elements and estimating radiative transfer through stellar plasmas. Argon plasma sources are also applied in various fields of industry and research [4–7].

A compilation of energy levels and observed spectral lines of all ionization stages of Ar was reported in [8]. Many of the papers published on the spectra of two and three times ionized argon (Ar III, Ar IV) are cited in this work [8]. The report by Hansen and Persson [9] that presented a revised and extended analysis of the optical spectrum of Ar III is noteworthy. They used hollow cathode and theta-pinch sources analyzing the $3s^23p^4$, $3s3p^5$, $3p^6$, $3s^23p^34s$, $3s^23p^34p$, and $3s^23p^33d$ configurations. Improved energy levels in this ion resulting from the best wavelengths in the literature in the range between 508 Å and 4183 Å were presented by Kaufman and Whaling [10]. For Ar IV, Bredice et al. [11] reanalyzed the $3s^23p^3$, $3s3p^4$, $3s^23p^2$ (3d + 4s) configurations to obtain new energy levels and classify new transitions. A more recent paper [12] presented an analysis of beam-foil and beam-gas excited spectrum of argon observed in the wavelength region 2965–3090 Å. New transitions in the spectrum of Ar III and Ar IV were also identified.

In the last few decades [13–18], there has been intense research on determining and compiling the transition probabilities of ionized argon. In the work of Burger et al. [19], transition probabilities were presented for 38 Ar III and 14 Ar IV spectral lines from the wavelength interval 2400–3080 Å. These were compared to other papers reporting theoretical values [15,17]. In [15], Luna et al. used the Cowan code [20] carried out according to the relativistic Hartree–Fock (HF) approach.

To continue the study of the two and three times ionized argon spectra, a new spectral analysis of these ions is presented in this work. We used our experimental data of the argon spectrum covering the wavelength range 480–6218 Å for the visible ultraviolet (VUV) region. A set of 129 transitions of Ar III and 112 transitions of Ar IV were classified for the first time. Five new energy levels belonging to $3s^23p^34d$, $3s^23p^35s$ odd configurations of Ar III and 10 new energy levels of the $3s^23p^23d$ and

$3s^23p^24p$ even and odd configurations, respectively, of Ar IV are presented. Theoretical predictions of the configuration structure and transition probabilities for the spectral lines were obtained from the computer code developed by Cowan [20]. The energy matrix was calculated using energy parameters adjusted to fit the experimental energy levels.

2. Experimental Methods

The experimental data for argon were obtained at Centro de Investigaciones Opticas (CIOp). In order to excite the spectra, a capillary-pulsed discharge was used. It consisted of a Pyrex tube about 100 cm long, with an inner diameter of 0.5 cm. The electrodes, placed 80 cm apart, were made of tungsten and covered with indium. Gas excitation was produced by discharging a bank of low-inductance capacitors between 20 and 280 nF and charged up to 20 kV. To study the VUV region, one end of the tube was connected to a vacuum spectrograph and in this way a continuous flow of gas between the gas inlet and the spectrograph was established. Light emitted axially was recorded in the VUV and in the visible regions. In the VUV region, the light was analyzed using a 3 m normal incidence vacuum spectrograph with a concave diffraction grating with 1200 lines/mm and plate factor 2.77 Å/mm in the first diffraction order. To record the spectra, Ilford Q plates were used and known lines of carbon, nitrogen, oxygen, and different noble gas ions served as wavelength standards. The wavelength range above 2000 Å was observed using a diode array detector coupled to a 3.4 m Ebert plane-grating spectrograph with 600 lines/mm and a plate factor of 5 Å/mm in the first diffraction order. Photographic plates were used to record the spectra in the first, second, and third diffraction orders. Thorium lines from an electrodeless discharge were superimposed on the spectrograms and served as reference lines. To distinguish between different states of ionization, the gas pressure, discharge voltage, and number of discharges were varied. Wavelengths above 2000 Å were tabulated in air using the Edlén formula (Sections 1–4 in Reference [20]). The spectrograms were measured with a photoelectric semiautomatic Grant comparator, and the uncertainty in the determination of the wavelength of unperturbed lines was estimated to be $\pm$0.02 Å in the VUV region and $\pm$0.01 Å in the visible region. Energy level values derived from the observed lines were determined by means of an iterative procedure, which took into account the wave numbers of the lines, weighted by their estimated uncertainties. The uncertainty of the adjusted experimental energy level values was assumed to be lower than 2 cm^{-1}.

3. Results and Discussion

In the present work, we used Cowan's atomic structure package [20], with corrections to the code made by Kramida [21] due to an error in Cowan's atomic structure theory, to calculate the solution for relativistic Hartree–Fock (HF) equations including configuration interaction for Ar III and Ar IV. We adjusted the values of energy parameters to the experimental energy levels of these ions by means of a least squares calculation. With the adjusted values, we calculated the energy and composition of the levels, as well as the weighted transition probability rate gA [15,20], where g is the statistical weight 2J + 1 of the upper level. We present a revised and extended analysis of $3s^23p^34d$, $3s^23p^35s$ odd configurations for Ar III and of $3s^23p^23d$ and $3s^23p^24p$ even and odd configurations for Ar IV. The configuration sets used were $3s^23p^4$, $3s^23p^3$ (4p,5p,6p), $3s^23p^3$ (4f,5f), $3s3p^43d$, $3p^6$, $3s^23p^23d^2$ and $3s3p^5$, $3s^23p^3$ (3d,4d,5d,6d), $3s^23p^3$ (4s,5s,6s,7s) for Ar III even and odd parities, respectively, and $3s^23p^3$, $3s^23p^2$ (4p,5p), $3p^5$, $3s3p^33d$, $3s^23p^24f$, $3s^23p3d^2$ and $3s3p^4$, $3s^23p^2$ (3d,4d), $3s^23p^2$ (4s,5s), $3s3p^23d^2$, $3p^43d$ for Ar IV odd and even parities, respectively.

Tables 1 and 2 show the new and calculated energy level values for these ions with the percentage composition in LS notation. We report three new energy levels belonging to $3s^23p^34d$ and two to $3s^23p^35s$ configurations of Ar III, and in Ar IV five new energy levels for $3s^23p^23d$ and five for $3s^23p^24p$ configurations. The calculated energy level values were obtained by least squares fit [20]. Our calculations included all the energy levels experimentally known.

Table 1. New Ar III energy levels.

Configuration	Term	J	Exp Level (cm^{-1})	Fitted [a] (cm^{-1})	Composition [b]
$3s^23p^3$ ($^2D^o$) 4d	$^1S^o$	0	267,275.7	267,244	98
$3s^23p^3$ ($^2P^o$) 4d	$^1F^o$	3	286,381.9	286,375	78 $3s^23p^3$ ($^2P^o$) $4d^1F^o$ + 8 $3s^23p^3$ ($^2D^o$) $5d^1F^o$
$3s^23p^3$ ($^2P^o$) 4d	$^1P^o$	1	292,090.9	292,122	63 $3s^23p^3$ ($^2P^o$) $4d^1P^o$ + 18 $3s^23p^3$ ($^2D^o$) $5d^1P^o$
$3s^23p^3$ ($^2D^o$) 5s	$^1D^o$	2	272,655.2	272,636	57 $3s^23p^3$ ($^2D^o$) $5s^1D^o$ + 34 $3s^23p^3$ ($^2D^o$) $4d^1D^o$
$3s^23p^3$ ($^2P^o$) 5s	$^1P^o$	1	286,878.2	286,845	97

[a] Calculated energy level values obtained using the fitted energy parameters. [b] Percentages below 5% have been omitted.

Table 2. New Ar IV energy levels.

Configuration	Term	J	Exp Level (cm^{-1})	Fitted [a] (cm^{-1})	Composition [b]
$3s^23p^2$ (^1D) 3d	^2F	$^5/_2$	185,795.6	185,870	46 $3s^23p^2$ (^1D) 3d ^2F + 39 $3s^23p^2$ (^3P) 3d ^2F
$3s^23p^2$ (^1D) 3d	^2F	$^7/_2$	186,451.8	186,591	44 $3s^23p^2$ (^1D) 3d ^2F + 31 $3s^23p^2$ (^3P) 3d ^2F
$3s^23p^2$ (^1D) 3d	^2P	$^1/_2$	245,175.2	245,287	57 $3s^23p^2$ (^1D) $3d^2P$ + 21 $3s^23p^2$ (^3P) 3d ^2P
$3s^23p^2$ (^1S) 3d	^2D	$^5/_2$	261,761.1	261,946	58 $3s^23p^2$ (^1S) 3d ^2D + 30 $3s^23p^2$ (^3P) 3d ^2D
$3s^23p^2$ (^1S) 3d	^2D	$^3/_2$	262,626.1	262,735	55 $3s^23p^2$ (^1S) 3d ^2D + 31 $3s^23p^2$ (^3P) 3d ^2D
$3s^23p^2$ (^3P) 4p	$^2S^o$	$^1/_2$	282,726.0	282,596	98
$3s^23p^2$ (^1D)4p	$^2P^o$	$^1/_2$	311,018.3	310,973	87 $3s^23p^2$ (^1D) $4p^2P^o$ + 10 $3s^23p^2$ (^3P) $4p^2P^o$
$3s^23p^2$ (^1D)4p	$^2P^o$	$^3/_2$	311,276.3	311,201	76 $3s^23p^2$ (^1D) $4p^2P^o$ + $123s^23p^2$ (^3P) $4p^2P^o$
$3s^23p^2$ (^1S)4p	$^2P^o$	$^1/_2$	327,113.4	327,126	96
$3s^23p^2$ (^1S)4p	$^2P^o$	$^3/_2$	327,388.9	327,333	96

[a] Calculated energy level values obtained using the fitted energy parameters. [b] Percentages below 5% have been omitted.

Tables 3 and 4 show 23 and 53 new classified lines for Ar III and Ar IV, respectively, that were classified with the new levels presented in this work. We also present 106 and 59 new spectral lines for Ar III and Ar IV, respectively, corresponding to transitions with previously known levels. In these tables we also present gA transition probabilities to compare with the experimental intensity of the new observed lines. In the last columns of these tables we compare the values of gA with those of reference [16]. The observed differences could be due to the fact that weighted values of the energy parameters were used in our work and the calculations presented in reference [16] are *ab initio*, therefore the composition percentages of the experimental levels are different; besides, the set of configurations used is not exactly the same and there are effects of cancellation factors in our calculations (Sections 14 and 15 in Reference [20]).

Table 3. New classified lines of Ar III.

Rel. Int.	Observed Wavelength Vac (Å)	Wavenumber (cm^{-1}) σ_{obs}	Lower Level Conf.	Term	J	Upper Level Conf.	Term	J	gA (s^{-1})	gA (s^{-1}) Reference [16]
3	764.09	130,875	$3s^23p^4$	^1D	2	$3s^23p^3$ ($^4S^o$) 3d	$^5D^o$	1	4.12×10^4	2.20×10^5
4	790.77	126,459	$3s3p^5$	$^3P^o$	2	$3s^23p^3$ ($^2P^o$) 4p	^3D	2	1.74×10^7	3.22×10^7
8	797.48	125,395	$3s3p^5$	$^3P^o$	2	$3s^23p^3$ ($^2P^o$) 4p	^3S	1	1.77×10^8	4.35×10^8
6	797.75	125,353	$3s3p^5$	$^3P^o$	1	$3s^23p^3$ ($^2P^o$) 4p	^3D	1	1.96×10^7	3.64×10^7
7	803.88	124,397	$3s3p^5$	$^3P^o$	1	$3s^23p^3$ ($^2P^o$) 4p	^3S	1	1.60×10^8	3.95×10^8
2	807.32	123,867	$3s3p^5$	$^3P^o$	0	$3s^23p^3$ ($^2P^o$) 4p	^3S	1	6.66×10^7	3.52×10^7
1	817.90	122,264	$3s3p^5$	$^3P^o$	2	$3s^23p^3$ ($^2D^o$) 4p	^1D	2	1.18×10^6	
2	855.01	116,958	$3s3p^5$	$^3P^o$	1	$3s^23p^3$ ($^2D^o$) 4p	^3P	0	8.33×10^7	2.18×10^8
6	855.94	116,831	$3s3p^5$	$^3P^o$	1	$3s^23p^3$ ($^2D^o$) 4p	^3P	1	3.96×10^7	1.21×10^8
3	887.30	112,702	$3s3p^5$	$^3P^o$	2	$3s^23p^3$ ($^2D^o$) 4p	^3F	3	1.25×10^7	9.22×10^6
7	896.02	111,605	$3s3p^5$	$^3P^o$	2	$3s^23p^3$ ($^2D^o$) 4p	^3D	3	5.62×10^7	1.78×10^8
3	896.37	111,561	$3s3p^5$	$^3P^o$	1	$3s^23p^3$ ($^2D^o$) 4p	^3F	2	2.82×10^6	
6	906.18	110,353	$3s3p^5$	$^3P^o$	1	$3s^23p^3$ ($^2D^o$) 4p	^3D	2	2.65×10^7	9.18×10^7
2	910.22	109,864	$3s3p^5$	$^3P^o$	2	$3s^23p^3$ ($^2D^o$) 4p	^1P	1	8.82×10^3	
2	1019.59	98,079	$3s^23p^3$ ($^4S^o$) 3d	$^3D^o$	1	$3s^23p^3$ ($^2P^o$) 4p	^1S	0	1.13×10^6	
6	1048.67	95,359 *	$3s^23p^3$ ($^4S^o$) 3d	$^5D^o$	2	$3s^23p^3$ ($^2D^o$) 4p	^3D	2	1.85×10^5	
6	1048.67	95,359 *	$3s^23p^3$ ($^4S^o$) 3d	$^5D^o$	3	$3s^23p^3$ ($^2D^o$) 4p	^3D	2	9.23×10^3	
3	1143.62	87,442	$3s^23p^3$ ($^4S^o$) 3d	$^3D^o$	3	$3s^23p^3$ ($^2P^o$) 4p	^1D	2	3.14×10^5	

Table 3. *Cont.*

Rel. Int.	Observed Wavelength Vac (Å)	Wavenumber (cm^{-1}) σ_{obs}	Lower Level Conf.	Term	J	Upper Level Conf.	Term	J	gA (s^{-1})	gA (s^{-1}) Reference [16]
8	1151.15	86,870	$3s^23p^3\ (^4S^\circ)\ 3d$	$^5D^\circ$	1	$3s^23p^3\ (^2D^\circ)\ 4p$	^3P	0	2.96×10^4	
3	1152.92	86,736	$3s^23p^3\ (^4S^\circ)\ 3d$	$^5D^\circ$	2	$3s^23p^3\ (^2D^\circ)\ 4p$	^3P	1	7.69×10^4	
4	1156.63	86,458	$3s^23p^3\ (^4S^\circ)\ 3d$	$^5D^\circ$	1	$3s^23p^3\ (^2D^\circ)\ 4p$	^3P	2	6.57×10^4	
1	1225.27	81,615	$3s^23p^3\ (^4S^\circ)\ 3d$	$^5D^\circ$	2	$3s^23p^3\ (^2D^\circ)\ 4p$	^3F	3	5.61×10^4	
6	1226.52	81,532	$3s^23p^4$	^1S	0	$3s3p^5$	$^3P^\circ$	1	2.33×10^5	
2	1227.88	81,441	$3s^23p^3\ (^4S^\circ)\ 4p$	^5P	1	$3s^23p^3\ (^2P^\circ)\ 5s$	$^3P^\circ$	2	2.80×10^5	
1	1231.13	81,226	$3s^23p^3\ (^4S^\circ)\ 4p$	^5P	2	$3s^23p^3\ (^2P^\circ)\ 5s$	$^3P^\circ$	1	2.36×10^3	
9	1232.52	81,135	$3s3p^5$	$^1P^\circ$	1	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	1	9.26×10^7	
1	1246.07	80,252	$3s^23p^3\ (^4S^\circ)\ 3d$	$^5D^\circ$	3	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	2	9.23×10^3	
1	1287.22	77,687	$3s^23p^3\ (^4S^\circ)\ 4p$	^3P	1	$3s^23p^3\ (^2P^\circ)\ 5s$	$^1P^\circ$	1	5.26×10^5	
4	1294.84	77,232	$3s^23p^3\ (^4S^0)\ 4p$	^3P	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1F^\circ$	3	3.74×10^5	
9	1308.25	76,438	$3s^23p^3\ (^2D^\circ)\ 3d$	$^3F^\circ$	2	$3s^23p^3\ (^2P^\circ)\ 4p$	^3S	1	9.63×10^5	
2	1382.71	72,322	$3s^23p^3\ (^4S^\circ)\ 4p$	^3P	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3F^\circ$	3	1.03×10^5	
6	1461.38	68,428	$3s^23p^3\ (^2D^\circ)\ 4p$	^1P	1	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1P^\circ$	1	1.90×10^8	
1	1478.87	67,619	$3s^23p^3\ (^4S^\circ)\ 4p$	^5P	1	$3s^23p^3\ (^2D^\circ)\ 5s$	$^3D^\circ$	2	3.02×10^3	
1	1479.33	67,598	$3s^23p^3\ (^4S^\circ)\ 4p$	^5P	2	$3s^23p^3\ (^2D^\circ)\ 5s$	$^3D^\circ$	3	1.19×10^5	
1	1498.21	66,746	$3s^23p^3\ (^4S^\circ)\ 3d$	$^3D^\circ$	2	$3s^23p^3\ (^2D^\circ)\ 4p$	^1P	1	1.56×10^7	
7	1498.38	66,739	$3s^23p^3\ (^4S^\circ)\ 3d$	$^3D^\circ$	2	$3s^23p^3\ (^2D^\circ)\ 4p$	^1P	1	8.52×10^7	
1	1501.77	66,588	$3s^23p^3\ (^2P^\circ)\ 3d$	$^3P^\circ$	1	$3s^23p^3\ (^2P^\circ)\ 4p$	^1S	0	1.92×10^3	
3	1517.15	65,913	$3s^23p^3\ (^4S^\circ)\ 4s$	$^5S^\circ$	2	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	3	4.39×10^6	
1	1551.71	64,445	$3s^23p^3\ (^4S^\circ)\ 4p$	^5P	1	$3s^23p^3\ (^2D^\circ)\ 4d$	$^3D^\circ$	2	2.90×10^5	
2	1565.07	63,895	$3s^23p^3\ (^4S^\circ)\ 4s$	$^3S^\circ$	1	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	2	2.47×10^7	3.17×10^7
2	1583.54	63,150	$3s^23p^3\ (^2D^\circ)\ 4p$	^1P	1	$3s^23p^3\ (^2P^\circ)\ 5s$	$^1P^\circ$	1	3.88×10^7	
1	1584.74	63,102	$3s^23p^3\ (^4S^\circ)\ 4p$	^3P	2	$3s^23p^3\ (^2D^\circ)\ 5s$	$^3D^\circ$	3	1.63×10^6	
2	1621.91	61,656	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	1	$3s^23p^3\ (^2P^\circ)\ 5s$	$^1P^\circ$	1	6.94×10^6	
3	1641.85	60,907	$3s^23p^3\ (^2D^\circ)\ 3d$	$^1S^\circ$	0	$3s^23p^3\ (^2D^\circ)\ 4p$	^1P	1	1.96×10^8	
1	1646.50	60,735	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	2	$3s^23p^3\ (^2P^\circ)\ 5s$	$^3P^\circ$	1	2.50×10^7	
2	1654.12	60,455	$3s^23p^3\ (^2D^\circ)\ 4p$	^1P	1	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3D^\circ$	1	2.16×10^4	
2	1657.39	60,336	$3s^23p^3\ (^2D^0)\ 4p$	^3P	0	$3s^23p^3(^2P^\circ)\ 4d$	$^1P^\circ$	1	7.81×10^5	
2	1670.10	59,877	$3s^23p^3\ (^2D^0)\ 4p$	^3F	3	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1F^\circ$	3	3.57×10^4	
3	1674.09	59,734	$3s^23p^3\ (^2D^0)\ 4p$	^3F	4	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1F^\circ$	3	4.57×10^4	
1	1756.05	56,946	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	1	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3P^\circ$	2	3.39×10^6	
1	1758.89	56,854	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3P^\circ$	1	4.34×10^3	
2	1784.86	56,026	$3s^23p^3\ (^2D^0)\ 4p$	^1D	2	$3s^23p^3(^2P^\circ)\ 4d$	$^1P^0$	1	6.97×10^5	
1	1818.15	55,001	$3s^23p^3\ (^2P^\circ)\ 3d$	$^3P^\circ$	1	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	1	3.07×10^7	4.91×10^7
2	1821.26	54,907	$3s^23p^3\ (^2P^\circ)\ 3d$	$^3P^\circ$	2	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	2	2.59×10^8	3.19×10^8
2	1833.45	54,542	$3s^23p^3\ (^2D^\circ)\ 4p$	^3P	2	$3s^23p^3\ (^2P^\circ)\ 5s$	$^3P^\circ$	1	1.12×10^7	
1	1877.34	53,267	$3s^23p^3\ (^2D^\circ)\ 3d$	$^3G^\circ$	4	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	3	1.39×10^8	3.84×10^7
1	1885.05	53,049	$3s^23p^3\ (^2D^\circ)\ 3d$	$^3G^\circ$	3	$3s^23p^3\ (^2D^\circ)\ 4p$	^3D	2	4.94×10^7	1.79×10^7
3	1925.40	51,939	$3s^23p^3(^2P^\circ)\ 4p$	^3D	1	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1P^\circ$	1	1.54×10^7	
1	1967.80	50,818	$3s^23p^3\ (^2D^\circ)\ 4p$	^1D	2	$3s^23p^3\ (^2P^\circ)\ 5s$	$^1P^0$	1	3.98×10^7	
	Observed Wavelength Air (Å)									
6	2041.2	48,991	$3s^23p^3\ (^2D^0)\ 4p$	^1P	1	$3s^23p^3\ (^2D^\circ)\ 5s$	$^1D^\circ$	2	1.67×10^9	
1	2339.23	42,736.0	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	1	$3s^23p^3\ (^2P^\circ)\ 5s$	$^3P^\circ$	1	1.73×10^8	
2	2351.80	42,521	$3s^23p^3\ (^2P^\circ)\ 4p$	^1D	2	$3s^23p^3\ (^2P^\circ)\ 5s$	$^1P^\circ$	1	1.30×10^9	
5	2378.82	42,024.7	$3s^23p^3\ (^2P^\circ)\ 4p$	^1D	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1F^\circ$	3	5.30×10^9	
2	2394.85	41,743.6	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3P^\circ$	1	1.46×10^6	
4	2572.92	38,854.7	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	1	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3P^\circ$	1	1.24×10^8	
1	2628.26	38,036.6	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3F^\circ$	2	5.33×10^6	
1	2710.09	36,888.2	$3s^23p^3\ (^4S^\circ)\ 4p$	^3P	2	$3s23p^3\ (^4S^\circ)4d$	$^5D^\circ$	3	1.39×10^6	
2	2710.36	36,884.5	$3s^23p^3\ (^2P^\circ)\ 4p$	^1S	0	$3s^23p^3\ (^2P^\circ)\ 4d$	$^1P^\circ$	1	4.38×10^8	
9	2767.39	36,124.5	$3s^23p^3\ (^2D^\circ)\ 4p$	^1D	2	$3s^23p^3\ (^2D^\circ)\ 5s$	$^3D^\circ$	2	1.42×10^7	
3	2771.92	36,065.4	$3s^23p^3\ (^2D^\circ)\ 4p$	^1D	2	$3s^23p^3\ (^2D^\circ)\ 5s$	$^3D^\circ$	1	1.58×10^6	
4	2804.36	35,648.3	$3s^23p^3\ (^2D^\circ)\ 4p$	^3P	1	$3s^23p^3\ (^2D^\circ)4d$	$^1S^\circ$	0	1.51×10^6	
4	2891.46	34,574.5	$3s^23p^3\ (^2P^\circ)\ 4s$	$^3P^\circ$	2	$3s^23p^3\ (^2P^\circ)\ 4p$	^1P	1	2.61×10^7	
2	3037.25	32,914.9	$3s^23p^3\ (^2D^\circ)\ 4p$	^1D	2	$3s^23p^3\ (^2P^\circ)\ 4d$	$^3D^\circ$	1	2.00×10^6	
9	3048.47	32,793.8	$3s^23p^3\ (^2P^\circ)\ 3d$	$^3D^\circ$	1	$3s^23p^3\ (^2P^\circ)\ 4p$	^1D	2	7.18×10^6	
1	3075.70	32,503.5 *	$3s^23p^3\ (^2P^\circ)\ 4p$	^3S	1	$3s^23p^3\ (^2D^\circ)4d$	$^3P^0$	0	6.26×10^4	
1	3075.70	32,503.5 *	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	1	$3s^23p^3\ (^2D^\circ)\ 5s$	$^1D^\circ$	2	6.94×10^5	
3	3089.03	32,363.2	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	3	$3s^23p^3\ (^2D^\circ)\ 5s$	$^1D^\circ$	2	4.64×10^3	
2	3120.41	32,037.8	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	1	$3s^23p^3\ (^2D^\circ)5s$	$^3D^0$	2	5.91×10^6	
4	3132.13	31,917.9	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	1	$3s^23p^3\ (^2D^\circ)4d$	$^3S^\circ$	1	6.40×10^5	
1	3137.82	31,860.0	$3s^23p^3\ (^2P^\circ)3d$	$^3D^\circ$	1	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	2	1.12×10^6	1.04×10^7
6	3140.30	31,834.9	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	2	$3s^23p^3\ (^2D^\circ)\ 4d$	$^1D^\circ$	2	1.30×10^7	
7	3199.08	31,250.0	$3s^23p^3\ (^2P^\circ)\ 4p$	^3D	2	$3s^23p^3\ (^2D^\circ)\ 4d$	$^3P^\circ$	2	1.04×10^5	
6	3245.58	30,802.3	$3s^23p^3\ (^2P^\circ)\ 3d$	$^3D^\circ$	2	$3s^23p^3\ (^2P^\circ)\ 4p$	^1P	1	4.11×10^7	1.58×10^7
2	3290.37	30,383.0	$3s^23p^3\ (^2P^\circ)\ 4p$	^1P	1	$3s^23p^3\ (^2D^\circ)\ 5s$	$^3D^\circ$	2	1.33×10^7	
8	3300.95	30,285.6	$3s^23p^3\ (^2P^\circ)\ 4p$	^1P	1	$3s^23p^3\ (^2D^\circ)\ 4d$	$^1D^\circ$	2	4.58×10^7	
8	3352.49	29,820.0	$3s^23p^3\ (^2P^\circ)\ 4p$	^3S	1	$3s^23p^3\ (^2D^\circ)\ 4d$	$^3D^\circ$	2	2.00×10^6	
2	3356.47	29,784.7	$3s^23p^3\ (^2P^\circ)\ 4p$	^3S	1	$3s^23p^3\ (^2D^\circ)4d$	$^3D^\circ$	1	5.91×10^5	
2	3373.35	29,635.6	$3s^23p^3\ (^2P^\circ)3d$	$^1D^\circ$	2	$3s^23p^3\ (^4S^\circ)\ 4p$	^3P	2	1.34×10^2	
7	3387.85	29,508.8	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	1	$3s^23p^3\ (^2D^\circ)\ 5s$	$^1D^\circ$	2	1.14×10^6	
2	3420.12	29,230.4	$3s^23p^3\ (^2P^\circ)\ 4p$	^3P	2	$3s^23p^3\ (^2D^\circ)\ 5s$	$^1D^\circ$	2	7.43×10^5	

Table 3. *Cont.*

Rel. Int.	Observed Wavelength Vac (Å)	Wavenumber (cm^{-1}) σ_{obs}	Lower Level Conf. Term, J			Upper Level Conf. Term, J			gA (s^{-1})	gA (s^{-1}) Reference [16]
4	3442.18	29,043.0	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 5s$	$^3D^\circ$	2	1.59×10^7	
1	3445.79	29,012.6	$3s^23p^3 (^2P^\circ) 4p$	^1S	0	$3s^23p^3 (^2P^\circ) 4d$	$^3D^\circ$	1	1.81×10^6	
3	3449.32	28,982.9	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 5s$	$^3D^\circ$	1	8.36×10^6	
2	3453.61	28,946.9	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 4d$	$^1D^\circ$	2	2.18×10^7	
5	3456.48	28,922.9	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 4d$	$^3S^\circ$	1	2.61×10^7	
2	3463.81	28,861.7	$3s^23p^3 (^2P^\circ) 4p$	^3D	1	$3s^23p^3 (^2D^\circ) 4d$	$^3D^\circ$	2	5.00×10^6	
6	3467.98	28,827.0 *	$3s^23p^3 (^2P^\circ) 4p$	^3D	1	$3s^23p^3 (^2D^\circ) 4d$	$^3D^\circ$	1	1.83×10^7	
6	3467.98	28,827.0 *	$3s^23p^3 (^2P^\circ) 4p$	^3P	2	$3s^23p^3 (^2D^\circ) 5s$	$^3D^\circ$	3	4.58×10^7	
7	3482.15	28,709.7	$3s^23p^3 (^2P^\circ)4p$	^3D	3	$3s^23p^3 (^2D^\circ) 4d$	$^3D^\circ$	3	5.48×10^7	
6	3490.12	28,644.1	$3s^23p^3 (^2P^\circ) 4p$	^3P	2	$3s^23p^3 (^2D^\circ) 4d$	$^3S^\circ$	1	2.71×10^7	
2	3501.57	28,550.5	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 4d$	$^3P^\circ$	0	8.20×10^6	
3	3504.54	28,526.3	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 4d$	$^3P^\circ$	1	7.90×10^5	
1	3524.86	28,361.8	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 4d$	$^3P^\circ$	2	3.55×10^6	
7	3532.92	28,297.1	$3s^23p^3 (^2P^\circ) 4p$	^1D	2	$3s^23p^3 (^2D^\circ) 5s$	$^1D^\circ$	2	6.12×10^7	
6	3546.52	28,188.6	$3s^23p^3 (^2P^\circ) 3d$	$^3D^\circ$	2	$3s^23p^3 (^2P^\circ) 4p$	^3S	1	1.13×10^7	
7	3557.68	28,100.2	$3s^23p^3 (^4S^\circ) 4p$	^3P	2	$3s^23p^3 (^2P^\circ) 3d$	$^1P^\circ$	1	1.27×10^4	
8	3559.94	28,082.3 *	$3s^23p^3 (^2P^\circ) 4p$	^3P	2	$3s^23p^3 (^2D^\circ) 4d$	$^3P^\circ$	2	6.00×10^6	
8	3559.94	28,082.3 *	$3s^23p^3 (^2P^\circ) 4p$	^3S	1	$3s^23p^3 (^2D^\circ)4d$	$^1S^\circ$	0	6.15×10^5	
1	3604.60	27,734.4	$3s^23p^3 (^2P^\circ) 4p$	^1D	2	$3s^23p^3 (^2D^\circ) 4d$	$^1D^\circ$	2	1.72×10^7	
3	3618.28	27,629.6	$3s^23p^3 (^2P^\circ) 3d$	$^3D^\circ$	1	$3s^23p^3 (^2P^\circ) 4p$	^3S	1	3.69×10^6	
8	3632.13	27,524.2	$3s^23p^3 (^2P^\circ)4p$	^3D	2	$3s^23p^3 (^2D^\circ) 4d$	$^3G^\circ$	3	7.87×10^5	
2	3674.63	27,205.9	$3s^23p^3 (^2P^\circ)4p$	^1P	1	$3s^23p^3 (^2D^\circ) 4d$	$^3D^\circ$	2	2.00×10^4	
2	3787.06	26,398.2	$3s^23p^3 (^2P^\circ) 4p$	^1D	2	$3s^23p^3 (^2D^\circ) 4d$	$^1P^\circ$	1	2.28×10^7	
2	3908.78	25,576.2	$3s^23p^3 (^2P^\circ) 4p$	^3P	2	$3s^23p^3 (^2D^\circ) 4d$	$^3D^\circ$	3	1.22×10^6	
5	3978.72	25,126.6	$3s^23p^3 (^2P^\circ) 3d$	$^1D^\circ$	2	$3s^23p^3 (^4S^\circ) 4p$	^5P	2	4.49×10^2	
3	3989.35	25,059.7	$3s^23p^3 (^2P^\circ) 3d$	$^3D^\circ$	2	$3s^23p^3 (^2D^\circ) 4p$	^1D	2	2.21×10^6	
3	3998.77	25,000.6	$3s^23p^3 (^2P^\circ)4s$	$^1P^\circ$	1	$3s^23p^3 (^2D^\circ) 4p$	^1D	2	5.83×10^6	9.23×10^6
4	4012.31	24,916.3	$3s^23p^3 (^2D^\circ) 4p$	^1P	1	$3s^23p^3 (^2D^\circ) 4d$	$^3F^\circ$	2	5.69×10^4	
7	4143.38	24,128.1	$3s^23p^3 (^2P^\circ) 4p$	^3P	1	$3s^23p^3 (^2D^\circ) 4d$	$^1S^\circ$	0	5.46×10^6	
1	4520.87	22,113.4	$3s^23p^3 (^2D^\circ)3d$	$^3P^\circ$	2	$3s^23p^3 (^2D^\circ) 4p$	^1D	2	1.47×10^6	
6	4553.69	21,954.1	$3s^23p^3 (^2D^\circ)3d$	$^3D^\circ$	1	$3s^23p^3 (^4S^\circ) 4p$	^3P	1	5.49×10^6	1.68×10^8
7	4693.06	21,302.1	$3s^23p^3 (^2D^\circ)3d$	$^3D^\circ$	2	$3s^23p^3 (^4S^\circ) 4p$	^3P	1	1.33×10^7	4.83×10^8
1	5587.80	17,891.2	$3s^23p^3 (^4S^\circ)4s$	$^3S^\circ$	1	$3s^23p^3 (^4S^\circ) 4p$	^5P	1	4.62×10^5	
9	5869.96	17,031.2	$3s^23p^3 (^2P^\circ)3d$	$^3D^\circ$	3	$3s^23p^3 (^2D^\circ) 4p$	^1F	3	1.21×10^6	
9	5976.62	16,727.2	$3s^23p^3 (^2P^\circ)3d$	$^1D^\circ$	2	$3s^23p^3 (^2D^\circ) 4p$	^1D	2	3.59×10^7	
9	6054.43	16,512.3	$3s^23p^3 (^2D^\circ) 4p$	^1D	2	$3s^23p^3 (^4S^\circ) 5s$	$^3S^\circ$	1	4.23×10^3	
7	6167.05	16,210.6	$3s^23p^3 (^2D^\circ) 4p$	^1D	2	$3s^23p^3 (^4S^\circ) 4d$	$^3D^\circ$	1	3.17×10^4	
8	6187.84	16,156.3	$3s^23p^3 (^2D^\circ)3d$	$^1P^\circ$	1	$3s^23p^3 (^2D^\circ)4p$	^1D	2	1.14×10^7	
3	6217.65	15,940.4	$3s^23p^3 (^2D^\circ) 3d$	$^3D^\circ$	3	$3s^23p^3 (^4S) 4p$	^5P	2	4.48×10^4	

* Double classification.

Table 4. New classified lines of Ar IV.

Rel. Int.	Observed Wavelength Vac (Å)	Wavenumber (cm^{-1}) σ_{obs}	Lower Level Conf. Term, J			Upper Level Conf. Term, J			gA (s^{-1})	gA (s^{-1}) Reference [16]
1	480.61	208,068	$3s3p^4$	^4P	$^1/_2$	$3s^23p^2 (^1S) 4p$	$^2P^\circ$	$^1/_2$	2.30×10^4	
4	491.01	203,662	$3s^23p^3$	$^2D^\circ$	$^3/_2$	$3s^23p^2 (^3P) 3d$	^2D	$^3/_2$	5.87×10^9	
3	499.48	200,208	$3s^23p^3$	$^2D^\circ$	$^3/_2$	$3s^23p^2 (^3P) 3d$	^4P	$^3/_2$	4.41×10^7	
2	500.75	199,700	$3s^23p^3$	$^2D^\circ$	$^3/_2$	$3s^23p^2 (^3P) 3d$	^4P	$^5/_2$	1.97×10^7	
5	501.09	199,565	$3s^23p^3$	$^2D^\circ$	$^5/_2$	$3s^23p^2 (^3P) 3d$	^4P	$^5/_2$	1.53×10^8	
1	520.90	191,975	$3s3p^4$	^4P	$^1/_2$	$3s^23p^2 (^1D) 4p$	$^2P^\circ$	$^1/_2$	5.91×10^3	
7	536.08	186,539	$3s^23p^3$	$^2D^\circ$	$^5/_2$	$3s^23p^2 (^1D) 3d$	^2G	$^7/_2$	4.11×10^7	2.48×10^7
2	564.06	177,286	$3s3p^4$	^4P	$^3/_2$	$3s^23p^2 (^3P) 4p$	$^2P^\circ$	$^1/_2$	5.73×10^5	
3	596.65	167,602	$3s^23p^3$	$^2D^\circ$	$^3/_2$	$3s^23p^2 (^3P) 3d$	^4D	$^1/_2$	9.99×10^6	6.18×10^6
2	599.11	166,912	$3s3p^4$	^4P	$^1/_2$	$3s^23p^2 (^3P) 4p$	$^4D^\circ$	$^1/_2$	3.00×10^7	1.05×10^7
3	604.76	165,355	$3s3p^4$	^2D	$^3/_2$	$3s^23p^2 (^1D) 4p$	$^2P^\circ$	$^3/_2$	7.34×10^8	
2	605.06	165,273	$3s3p^4$	^2D	$^5/_2$	$3s^23p^2 (^1D) 4p$	$^2P^\circ$	$^3/_2$	8.37×10^8	
2	627.10	159,464	$3s^23p^3$	$^2D^\circ$	$^5/_2$	$3s^23p^2 (^3P) 3d$	^4F	$^3/_2$	3.00×10^5	
6	632.95	157,990	$3s3p^4$	^2D	$^5/_2$	$3s^23p^2 (^1D) 4p$	$^2F^\circ$	$^7/_2$	3.95×10^8	
2	686.52	145,662	$3s3p^4$	^2D	$^5/_2$	$3s^23p^2 (^3P) 4p$	$^2D^\circ$	$^5/_2$	1.43×10^6	6.31×10^7
2	694.89	143,907	$3s3p^4$	^2D	$^3/_2$	$3s^23p^2 (^3P) 4p$	$^4P^\circ$	$^5/_2$	1.05×10^5	
2	695.27	143,830	$3s^23p^2 (^3P)3d$	^2P	$^1/_2$	$3s^23p^2 (^1D) 4p$	$^2P^\circ$	$^3/_2$	6.60×10^7	
2	698.33	143,199	$3s3p^4$	^2D	$^3/_2$	$3s^23p^2 (^3P) 4p$	$^4P^\circ$	$^1/_2$	4.33×10^5	
2	716.50	139,567	$3s^23p^2 (^3P)3d$	^4D	$^5/_2$	$3s^23p^2 (^1S) 4p$	$^2P^\circ$	$^3/_2$	1.62×10^4	
7	773.31	129,314	$3s^23p^2 (^3P)3d$	^2P	$^3/_2$	$3s^23p^2 (^3P) 4p$	$^2P^\circ$	$^1/_2$	2.53×10^8	3.82×10^8
8	779.07	128,358	$3s^23p^2 (^3P)3d$	^2P	$^1/_2$	$3s^23p^2 (^3P) 4p$	$^2P^\circ$	$^3/_2$	2.96×10^8	4.56×10^8
1	806.55	123,985	$3s^23p^2 (^3P)3d$	^4D	$^1/_2$	$3s^23p^2 (^1D) 4p$	$^2P^\circ$	$^3/_2$	6.66×10^5	
7	844.39	118,429	$3s^23p^2 (^3P)3d$	^4D	$^3/_2$	$3s^23p^2 (^1D) 4p$	$^2D^o$	$^5/_2$	2.74×10^6	
3	847.68	117,969	$3s3p^4$	^2S	$^1/_2$	$3s^23p^2 (^3P) 4p$	$^2P^\circ$	$^3/_2$	1.78×10^6	1.98×10^7
1	848.39	117,870	$3s^23p^2 (^1D) 3d$	^2F	$^5/_2$	$3s^23p^2 (^1D) 4p$	$^2F^\circ$	$^5/_2$	1.01×10^9	
2	850.80	117,537	$3s^23p^2 (^1D) 3d$	^2F	$^7/_2$	$3s^23p^2 (^1D) 4p$	$^2F^\circ$	$^7/_2$	1.20×10^9	
2	853.14	117,214	$3s^23p^2 (^1D) 3d$	^2F	$^7/_2$	$3s^23p^2 (^1D) 4p$	$^2F^\circ$	$^5/_2$	1.17×10^8	
3	859.34	116,368	$3s^23p^2 (^3P) 3d$	^2P	$^3/_2$	$3s^23p^2 (^3P) 4p$	$^2S^\circ$	$^1/_2$	1.04×10^9	1.21×10^9

Table 4. *Cont.*

Rel. Int.	Observed Wavelength Vac (Å)	Wavenumber (cm^{-1}) σ_{obs}	Lower Level Conf. Term, J			Upper Level Conf. Term, J			gA (s^{-1})	gA (s^{-1}) Reference [16]
3	860.82	116,168	3s^{2}3p^2 (^{3}P) 3d	^{4}D	5/2	3s^{2}3p^2 (^{1}D) 4*p*	^{2}F°	7/2	6.59 × 10^6	
3	863.24	115,843	3s^{2}3p^2 (^{3}P) 3d	^{4}D	5/2	3s^{2}3p^2 (^{1}D) 4*p*	^{2}F°	5/2	5.20 × 10^7	
1	903.25	110,711	3s^{2}3p^2 (^{3}P) 3d	^{4}F	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}S°	3/2	3.94 × 10^4	
9	922.68	108,380	3s^{2}3p^2 (^{3}P) 3d	^{4}D	1/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	1/2	3.80 × 10^6	
2	945.05	105,814	3s^{2}3p^2 (^{3}P) 3d	^{4}P	3/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	1/2	5.74 × 10^5	
1	953.37	104,891	3s3p^4	^{2}S	1/2	3s^{2}3p^2 (^{3}P) 4p	^{2}S°	1/2	2.79 × 10^6	
1	957.32	104,457	3s^{2}3p^2 (^{1}D) 3d	^{2}F	5/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	3/2	3.01 × 10^9	2.53 × 10^9
6	958.34	104,347	3s^{2}3p^2 (^{3}P) 3d	^{4}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{4}S°	3/2	2.57 × 10^7	7.19 × 10^7
6	959.10	104,264	3s^{2}3p^2 (^{3}P) 3d	^{4}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	5/2	9.61 × 10^6	2.01 × 10^7
5	962.27	103,921	3s^{2}3p^2 (^{3}P) 3d	^{4}D	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}S°	3/2	4.76 × 10^7	4.93 × 10^7
2	982.76	101,754	3s^{2}3p^2 (^{1}D) 3d	^{2}F	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	7/2	1.19 × 10^7	8.94 × 10^7
7	986.07	101,413	3s^{2}3p^2 (^{3}P) 3d	^{4}D	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	3/2	2.15 × 10^9	2.07 × 10^9
1	987.70	101,245	3s^{2}3p^2 (^{3}P) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	3/2	1.05 × 10^9	
1	989.12	101,100	3s^{2}3p^2 (^{1}D) 3d	^{2}F	7/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	7/2	4.13 × 10^8	3.11 × 10^8
2	990.57	100,952	3s^{2}3p^2 (^{1}D) 3d	^{2}F	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	5/2	3.03 × 10^7	2.48 × 10^8
1	997.06	100,295	3s^{2}3p^2 (^{1}D) 3d	^{2}F	7/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	5/2	8.36 × 10^7	4.77 × 10^7
2	1019.73	98,065	3s^{2}3p^2 (^{1}D) 3d	^{2}G	7/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	5/2	2.07 × 10^7	
1	1114.60	89,718	3s^{2}3p^2 (^{3}P) 3d	^{4}P	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	1/2	8.89 × 10^5	
4	1118.70	89,390	3s^{2}3p^2 (^{3}P) 3*d*	^{4}P	1/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	1/2	1.26 × 10^5	
1	1127.19	88,716	3s^{2}3p^2 (^{1}D) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	3/2	7.89 × 10^7	
1	1132.00	88,339	3s^{2}3p^2 (^{1}D) 3d	^{2}D	3/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	3/2	8.98 × 10^6	
1	1135.56	88,062	3s3p^4	^{2}P	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	1/2	2.95 × 10^7	
1	1135.56	88,062	3s^{2}3p^2 (^{1}D) 3d	^{2}D	3/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	1/2	2.34 × 10^7	
1	1146.02	87,259	3s3p^4	^{2}P	1/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	3/2	5.06 × 10^7	
2	1217.88	82,115	3s^{2}3p^2 (^{1}D) 3d	^{2}P	1/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	3/2	2.70 × 10^7	
5	1218.52	82,067	3s^{2}3p^2 (^{1}D) 3d	^{2}G	7/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	5/2	3.34 × 10^5	
6	1232.37	81,145	3s^{2}3p^2 (^{3}P) 3*d*	^{2}D	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	3/2	1.23 × 10^7	
5	1233.47	81,072	3s^{2}3p^2 (^{3}P) 3*d*	^{2}D	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	5/2	1.71 × 10^7	
5	1254.87	79,690	3s^{2}3p^2 (^{1}D) 3d	^{2}G	9/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	7/2	2.68 × 10^5	
7	1254.97	79,683	3s^{2}3p^2 (^{3}P) 3*d*	^{2}D	5/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	5/2	4.47 × 10^7	
4	1307.41	76,487	3s^{2}3p^2 (^{3}P)4s	^{4}P	3/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	3/2	1.05 × 10^5	
2	1312.11	76,213	3s^{2}3p^2 (^{3}P)4s	^{4}P	3/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	1/2	1.00 × 10^5	
1	1333.06	75,015	3s^{2}3p^2 (^{3}P) 3*d*	^{4}P	5/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	3/2	4.31 × 10^6	
7	1372.75	72,847	3s3p^4	^{2}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	3/2	8.47 × 10^7	3.83 × 10^7
1	1377.35	72,603	3s^{2}3p^2 (^{1}D) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	3/2	3.15 × 10^8	
2	1407.94	71,026	3s^{2}3p^2(^{3}P) 4s	^{2}P	1/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	1/2	2.21 × 10^7	
8	1410.89	70,877	3s^{2}3p^2 (^{3}P) 3*d*	^{4}P	5/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	5/2	3.09 × 10^7	3.61 × 10^7
7	1421.24	70,361	3s^{2}3p^2 (^{3}P) 3*d*	^{4}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	5/2	1.62 × 10^7	2.10 × 10^7
1	1433.28	69,770	3s^{2}3p^2 (^{3}P) 4s	^{2}P	3/2	3s^{2}3p^2 (^{1}S) 4p	^{2}P°	1/2	1.26 × 10^7	
4	1439.58	69,465	3s^{2}3p^2 (^{3}P) 3*d*	^{4}P	5/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	3/2	1.20 × 10^7	2.83 × 10^7
2	1453.74	68,788	3s3*p*^{4}	^{2}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{4}S°	3/2	7.27 × 10^6	1.88 × 10^7
7	1487.51	67,226	3s^{2}3p^2 (^{1}D) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	3/2	5.18 × 10^7	
5	1489.10	67,155	3s^{2}3p^2 (^{1}D) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	5/2	1.19 × 10^9	
3	1494.59	66,908	3s^{2}3p^2 (^{3}P) 3d	^{2}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	5/2	2.47 × 10^7	
7	1497.60	66,774	3s^{2}3p^2 (^{1}D) 3d	^{2}D	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	5/2	1.04 × 10^8	
2	1512.87	66,101	3s^{2}3p^2 (^{1}D) 3d	^{2}P	1/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	3/2	2.96 × 10^7	
2	1538.63	64,993	3s^{2}3p^2 (^{1}D) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}D) 4p	^{2}F°	5/2	1.58 × 10^7	
1	1636.69	61,099	3s^{2}3p^2 (^{3}P) 3*d*	^{4}P	1/2	3s^{2}3p^2 (^{3}P) 4p	^{2}S°	1/2	2.48 × 10^3	8.40 × 10^6
1	1646.84	60,722	3s^{2}3p^2 (^{1}D) 3d	^{2}P	1/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D°	3/2	2.32 × 10^7	
1	1795.85	55,684	3s^{2}3p^2 (^{3}P) 4s	^{4}P	1/2	3s^{2}3p^2 (^{1}D) 4p	^{2}D^o	3/2	1.11 × 10^7	
2	1887.01	52,992	3s^{2}3p^2 (^{1}D) 3d	^{2}D	5/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	5/2	7.60 × 10^7	3.22 × 10^7
1	1953.12	51,200	3s^{2}3p^2 (^{1}D) 3d	^{2}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	3/2	4.88 × 10^7	2.45 × 10^7
1	1975.10	50,630	3s^{2}3p^2 (^{1}D) 3d	^{2}P	1/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	3/2	1.18 × 10^7	1.29 × 10^7
2	1980.41	50,495	3s^{2}3p^2 (^{1}D) 3d	^{2}P	1/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	1/2	1.51 × 10^6	1.83 × 10^6
	Observed Wavelength Air (Å)									
3	2311.05	43,257.1	3s^{2}3p^2(^{1}D) 4s	^{2}D	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}P°	1/2	8.16 × 10^8	
1	2319.82	43,093.6	3s^{2}3p^2 (^{3}P) 3d	^{2}F	7/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	5/2	2.00 × 10^7	
6	2385.63	41,904.1	3s^{2}3p^2 (^{1}S) 3d	^{2}D	5/2	3s^{2}3p^2 (^{1}D) 4p	^{2}F°	5/2	4.40 × 10^6	
1	2435.91	41,040.0	3s^{2}3p^2 (^{1}S) 3d	^{2}D	3/2	3s^{2}3p^2 (^{1}D) 4p	^{2}F°	5/2	3.48 × 10^7	
4	2451.42	40,780.3	3s^{2}3p^2 (^{1}D) 3d	^{2}P	1/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	1/2	9.44 × 10^3	
3	2906.13	34,400.0	3s^{2}3p^2 (^{3}P) 4s	^{2}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{4}S°	3/2	4.97 × 10^5	
4	2936.85	34,040.1	3s^{2}3p^2 (^{1}S) 3d	^{2}D	5/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	3/2	7.71 × 10^7	6.40 × 10^8
3	3013.45	33,174.9	3s^{2}3p^2 (^{1}S) 3d	^{2}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	3/2	8.83 × 10^6	9.85 × 10^7
8	3025.44	33,043.4	3s^{2}3p^2 (^{1}S) 3d	^{2}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}P°	1/2	3.77 × 10^7	3.57 × 10^8
2	3074.86	32,512.4	3s^{2}3p^2 (^{3}P) 4s	^{4}P	1/2	3s^{2}3p^2 (^{3}P) 4p	^{2}S°	1/2	3.05 × 10^6	
3	3141.25	31,825.2	3s^{2}3p^2 (^{3}P) 4s	^{4}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}S°	1/2	5.81 × 10^6	4.22 × 10^6
4	3143.89	31,778.3	3s^{2}3p^2 (^{3}P) 4s	^{2}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	1/2	4.74 × 10^6	
1	3317.29	30,136.4	3s^{2}3p^2 (^{3}P) 4s	^{2}P	1/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	3/2	1.02 × 10^6	
4	3399.88	29,404.4	3s^{2}3p^2 (^{3}P) 4s	^{2}P	3/2	3s^{2}3p^2 (^{3}P) 4p	^{4}D°	5/2	1.83 × 10^6	
2	3561.57	28,069.5	3s^{2}3p^2 (^{1}S) 3d	^{2}D	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	5/2	1.33 × 10^6	
4	3618.61	27,627.0	3s^{2}3p^2 (^{1}S) 3d	^{2}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{2}D°	3/2	1.23 × 10^7	6.96 × 10^7
1	3639.09	27,471.6	3s^{2}3p^2 (^{1}S) 3d	^{2}D	5/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	3/2	1.29 × 10^5	
2	3674.93	27,203.7	3s^{2}3p^2 (^{1}S) 3d	^{2}D	3/2	3s^{2}3p^2 (^{3}P) 4p	^{4}P°	5/2	5.55 × 10^4	

Table 4. *Cont.*

Rel. Int.	Observed Wavelength Vac (Å)	Wavenumber (cm^{-1}) σ_{obs}	Lower Level Conf. Term, J			Upper Level Conf. Term, J			gA (s^{-1})	gA (s^{-1}) Reference [16]
1	3752.79	26,639.2	$3s^23p^2$ (^3P) 4s	^2P	$^1/_2$	$3s^23p^2$ (^3P) 4p	$^2S^\circ$	$^1/_2$	1.07×10^8	6.94×10^7
2	4000.64	24,988.9	$3s^23p^2$ (^1S) 3d	^2D	$^5/_2$	$3s^23p^2$ (^3P) 4p	$^4D^\circ$	$^5/_2$	1.73×10^3	
9	4168.14	23,984.8	$3s^23p^2$(^1D) 4s	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^4S^\circ$	$^3/_2$	7.90×10^2	
8	4178.81	23,923.5	$3s^23p^2$(^1D) 4s	^2D	$^5/_2$	$3s^23p^2$ (^3P) 4p	$^2D^\circ$	$^5/_2$	9.64×10^7	8.11×10^7
6	4182.41	23,902.9	$3s^23p^2$(^1D) 4s	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^2D^\circ$	$^5/_2$	1.01×10^8	
6	4044.85	22,511.9	$3s^23p^2$(^1D) 4s	^2D	$^5/_2$	$3s^23p^2$ (^3P) 4p	$^2D^\circ$	$^3/_2$	6.02×10^6	
3	4285.01	23,330.6	$3s^23p^2$ (^1S) 3d	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^4D^\circ$	$^1/_2$	1.19×10^4	
8	4444.96	22,491.1	$3s^23p^2$ (^1D) 4s	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^2D^\circ$	$^3/_2$	4.58×10^7	3.85×10^7
6	4525.46	22,091.0	$3s^23p^2$ (^1D) 4s	^2D	$^5/_2$	$3s^23p^2$ (^3P) 4p	$^4P^\circ$	$^5/_2$	3.52×10^6	
3	4529.64	22,070.6	$3s^23p^2$ (^1D) 4s	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^4P^\circ$	$^5/_2$	4.37×10^5	
4	4655.59	21,473.5	$3s^23p^2$ (^1D) 4s	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^4P^\circ$	$^3/_2$	7.00×10^5	
2	4680.08	21,361.2	$3s^23p^2$ (^1D) 4s	^2D	$^3/_2$	$3s^23p^2$ (^3P) 4p	$^4P^\circ$	$\frac{1}{2}$	5.39×10^3	

* Double classification.

The least squares calculation results are shown in Tables 5–8 for Ar III and Ar IV. In Tables 5 and 6, we show the radial parameters for the even and odd parity configurations of Ar III. In this calculation we also included the illegal-k effective-operator parameters F^k (i,j) and G^k (i,j) (Section 16-7 in Reference [20]). In the case of $3s^23p^33d$ configuration for the odd parity, we set free the G^2 (3p, 3d) parameter (there is no HF value for this parameter). The fitted value is in agreement with that published in [10]. In these tables, all the adjusted parameters that were set free are in good agreement with the scaled HF values. The parameter α was left free in the calculation and then fixed to its optimized value. The strong configuration interactions for the even parity (Table 5) between $3s^23p^4$–$3s3p^43d$ and $3s^23p^4$–$3p^6$ configurations were optimized and fixed at 90%, 85%, and 70% of their HF values, respectively. For the odd parity (Table 6), the interaction integrals between $3s3p^5$–$3s^23p^33d$ and $3s^23p^33d$–$3s^23p^34d$ configurations were set free in the calculation. In the energy adjustment of Ar III, the standard deviation was 101 and 339 cm^{-1} for the even and odd parities, respectively.

Table 5. Energy parameters (cm^{-1}) for the studied even parity configurations of Ar III. HF, Hartree–Fock.

Configuration	Parameter	HF Value	Fitted Value	Fitt/HF [a]
$3s^23p^4$	E_{av}		22,421 ± 52	
	F^2 (3p, 3p)	68,558	57,745 ± 203	0.84
	α		69 (FIX)	
	ζ_{3p}	1005	1096 ± 98	1.09
$3s^23p^34p$	E_{av}	219,988	227,971 ± 20	1.04
	F^2 (3p, 3p)	72,040	56,805 ± 117	0.79
	α		100 (FIX)	
	ζ_{3p}	1114	1659 ± 142	1.49
	ζ_{4p}	150	143 (FIX)	0.95
	F^2 (3p, 4p)	14,694	14,240 ± 214	0.97
	G^0 (3p, 4p)	3979	3343 ± 22	0.84
	G^2 (3p, 4p)	4556	3441 ± 118	0.75
Configuration Interaction (CI) Integrals				
$3s^23p^4$–$3s3p^43d$	R^1 (3s3p, 3p3d)	80,053	72,047 (FIX)	0.90
$3s^23p^4$–$3s3p^43d$	R^1 (3s3p, 3d 3p)	59,375	50,469 (FIX)	0.85
$3s^23p^4$–$3p^6$	R^1 (3s3s, 3p3p)	94,238	65,967 (FIX)	0.70

[a] Parameters omitted from this table: direct and exchange integrals and spin-orbit ζ parameters set to 85% and 95% of their HF values, respectively; CI integrals were set to 85% of their HF values. The standard deviation for the energy adjustment was 101 cm^{-1}.

Table 6. Energy parameters (cm^{-1}) for the studied odd parity configurations of Ar III.

Configuration	Parameter	HF Value	Fitted Value	Fitt/HF [a]
$3s3p^5$	E_{av}	147,157	150,084 ± 398	1.02
	ζ_{3p}	1008	1008 ± 399	1.00
	G^1 (3s, 3p)	94,422	77,710 ± 2155	0.82
$3s^23p^33d$	E_{av}	173,498	181,366 ± 145	1.04
	F^2 (3p, 3p)	69,680	54,348 ± 481	0.78
	α		248 (FIX)	
	ζ_{3p}	1046	1176 ± 207	1.12
	ζ_{3d}	25	24 (FIX)	0.95
	F^2 (3p, 3d)	54,654	49,263 ± 597	0.90
	G^1 (3p, 3d)	68,216	57,194 ± 626	0.84
	G^2 (3p, 3d)		5394 ± 463	
	G^3 (3p, 3d)	40,866	32,109 ± 601	0.78
$3s^23p^34s$	E_{av}	189,895	197,135 ± 122	1.04
	F^2 (3p, 3p)	71,619	54,250 ± 561	0.76
	α		240 (FIX)	
	ζ_{3p}	1104	1049 (FIX)	0.95
	G^1 (3p, 4s)	5735	4923 ± 284	0.86
$3s^23p^34d$	E_{av}	261,115	268,449 ± 122	1.03
	F^2 (3p, 3p)	71,954	57,693 ± 483	0.80
	α		119 (FIX)	
	ζ_{3p}	1109	1949 ± 415	1.76
	ζ_{4d}	6	6 (FIX)	1.00
	F^2 (3p, 4d)	11,486	10,068 ± 1375	0.88
	G^1 (3p, 4d)	8905	7143 ± 601	0.80
	G^3 (3p, 4d)	5982	5085 (FIX)	0.85
$3s^23p^35s$	E_{av}	264,555	272,420 ± 114	1.03
	F^2 (3p, 3p)	72,136	57,347 ± 631	0.79
	α		86 (FIX)	
	ζ_{3p}	1117	1299 ± 297	1.16
	G^1 (3p, 5s)	1714	1467 ± 299	0.85
		Configuration Interaction Integrals		
$3s3p^5$–$3s^23p^33d$	R^1 (3p3p, 3s3d)	78,625	61,091 ± 605	0.78
$3s^23p^33d$–$3s^23p^34d$	R^2 (3p3d, 3p4d)	16,765	12,132 ± 1046	0.72
$3s^23p^33d$–$3s^23p^34d$	R^1 (3p3d, 4d 3p)	23,116	24,234 ± 1142	1.05
$3s^23p^33d$–$3s^23p^34d$	R^3 (3p3d, 4d 3p)	14,594	18,936 ± 2310	1.30

[a] Parameters omitted from this table: direct and exchange integrals, and spin-orbit ζ parameters set to 85% and 95% of their HFR values, respectively; CI integrals were set to 85% of their HFR values. The standard deviation for the energy adjustment was 339 cm^{-1}.

In Tables 7 and 8, we show the radial parameters for the odd and even parity configurations of Ar IV. The adjusted parameters in these tables are in accordance with the scaled HF values. The parameter α was left free in the calculation and then fixed to its optimized value, except for the $3s^23p^24s$ configuration, which was left fixed at the value of zero. The configuration interactions were set to 85% of their HF values. These values are omitted in Tables 7 and 8. For the even configurations, the integral of interaction between $3s3p^4$ and $3s^23p^23d$ is significant, as it was seen in reference [11]. The standard deviation was 266 and 242 cm^{-1} for the odd and even parities, respectively.

It should be mentioned that the accuracy in our calculations of the fitted values of the previously known energy levels are given according to the standard deviation for each of the parities in Ar III and Ar IV.

Table 7. Energy parameters (cm^{-1}) for the studied odd parity configurations of Ar IV.

Configuration	Parameter	HF Value	Fitted Value	Fitt/HF [a]
$3s^2 3p^3$	E_{av}		27,428± 135	
	F^2 (3p, 3p)	72,352	66,464 ± 775	0.92
	α		−281 (FIX)	
	ζ_{3p}	1123	1292 ± 253	1.15
$3s^2 3p^2 4p$	E_{av}	285,513	297,973 ± 64	1.04
	F^2 (3p, 3p)	75,485	61,386 ± 380	0.81
	α		74 (FIX)	
	ζ_{3p}	1235	1045 ± 194	0.85
	ζ_{4p}	232	221(FIX)	0.95
	F^2 (3p, 4p)	19,068	15940 ± 407	0.84
	G^0 (3p, 4p)	5396	4064 ± 91	0.75
	G^2 (3p, 4p)	6186	4272 ± 404	0.69

[a] Parameters omitted from this table: direct and exchange integrals, and spin-orbit ζ parameters set to 85% and 95% of their HF values, respectively; CI integrals were set to 85% of their HF values. The standard deviation for the energy adjustment was 266 cm^{-1}.

Table 8. Energy parameters (cm^{-1}) for the studied even parity configurations of Ar IV.

Configuration	Parameter	HF value	Fitted Value	Fitt/HF [a]
$3s3p^4$	E_{av}	151,175	176,374 ± 134	1.17
	F^2 (3p, 3p)	72,202	63,402 ± 574	0.88
	α		−490 (FIX)	
	ζ_{3p}	1124	1154 ± 262	1.03
	G^1 (3s, 3p)	98,569	87,487 ± 327	0.89
$3s^2 3p^2 3d$	E_{av}	196,615	220,619 ± 74	1.12
	F^2 (3p, 3p)	73,023	75,396 ± 1781	1.03
	α		−774 (FIX)	
	ζ_{3p}	1153	1371 ± 148	1.19
	ζ_{3d}	38	36 (FIX)	0.95
	F^2 (3p, 3d)	63,295	54,769 ± 645	0.86
	G^1 (3p, 3d)	79,280	68,405 ± 234	0.86
	G^3 (3p, 3d)	48,285	30,970 ± 805	0.64
$3s^2 3p^2 4s$	E_{av}	248,237	260,502 ± 104	1.05
	F^2 (3p, 3p)	75,073	60,250 ± 923	0.80
	α		0 (FIX)	
	ζ_{3p}	1224	1299 ± 206	1.06
	G^1 (3p, 4s)	6979	5956 ± 226	0.85

[a] Parameters omitted from this table: direct and exchange integrals, and spin-orbit ζ parameters set to 85% and 95% of their HF values, respectively; CI integrals were set to 85% of their HF values. The standard deviation for the energy adjustment was 242 cm^{-1}.

4. Conclusions

In this work we studied the Ar III and Ar IV spectra covering the wavelength range 480–6218 Å for the visible ultraviolet region using a pulsed electrical discharge. A set of 129 transitions of Ar III and 112 transitions of Ar IV were classified. Five new energy levels belonging to $3s^2 3p^3 4d$, $3s^2 3p^3 5s$ and 10 new energy levels of $3s^2 3p^2 3d$, $3s^2 3p^2 4p$ for Ar III and Ar IV, respectively, were presented. Relativistic Hartree–Fock calculations were used. We considered optimized values of the energy parameters using least squares technique where we adjusted the theoretical parameter values to fit the experimental levels.

Author Contributions: Investigation, Writing-Original Draft Preparation, Conceptualization and Atomic calculation, M.R.; Software, R.E.M.C.; Formal Analysis, M.G.; Methodology and Investigation, J.R.A.

Funding: This research received no external funding.

Acknowledgments: This research was supported by the Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina. The Comision de Investigaciones Científicas de la Provıncia de Buenos Aires (CIC), where M. Raineri is a researcher, is also gratefully acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

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