Broad Structures in the VUV Argon Spectrum due to Merged A II Lines

K. Behringer and P. Thoma

Lehrstuhl für Technische Elektrophysik der TU München, West Germany

(Z. Naturforsch. **31 a**, 107–108 [1976]; received December 16, 1975)

VUV spectra from argon arc experiments, performed at 1 atm and about 20 000 K, contain broad structures around 120 nm. These are shown to consist of merged A II lines from 7f–3d electronic transitions.

Recordings of the argon vuv spectra at high plasma temperatures show some broad structures which stand out from the large number of narrow A II lines. These humps were observed in arc experiments at atmospheric pressure [1]. The arc temperatures ranged from 17 000 to 22 000 K, where the electron density is always close to $2 \cdot 10^{17}\ \mathrm{cm}^{-3}$. The most prominent structure is situated at 123 nm, near the hydrogen line Ly-α, and has a full half width of about 0.8 nm. This situation is illustrated

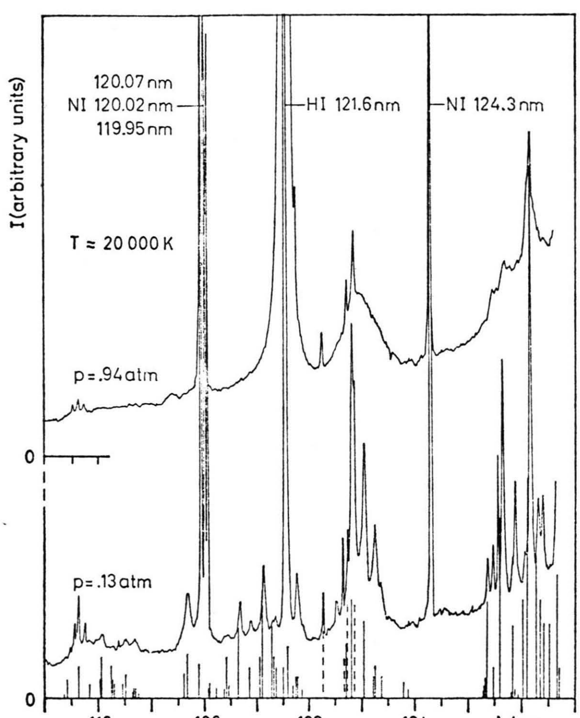

Fig. 1. Argon vuv spectrum at atmospheric pressure, the same spectrum at 0.13 atm and calculated A II lines.

Reprint requests to Dr. K. Behringer, Lehrstuhl für Technische Elektrophysik der TU München, Arcisstraße 21, *D-8000 München 2.*

in the top spectrum of Fig. 1, which also contains the usual H I and N I impurity lines above the continuous argon background. Superimposed on the broad 123 nm structure there are four narrow lines, which are not yet listed in the common spectral tables. They originate from the following transitions:

$$\text{A II}\ 3s^2 3p^4 5p\ {}^2P^0_{1/2} - 3s3p^6\ {}^2S_{1/2}\,,\quad 122.74\ \text{nm},$$
$$\text{A II}\ 3s^2 3p^4 5p\ {}^2P^0_{3/2} - 3s3p^6\ {}^2S_{1/2}\,,\quad 122.87\ \text{nm},$$
$$\text{A II}\ 3s^2 3p^4 5p\ {}^2D^0_{3/2} - 3s3p^6\ {}^2S_{1/2}\,,\quad 122.28\ \text{nm},$$
$$\text{A II}\ 3s^2 3p^4 5p\ {}^2D^0_{5/2} - 3s3p^6\ {}^2S_{1/2}\,,\quad 122.66\ \text{nm}.$$

These wavelengths are marked at the bottom of Fig. 1 by dashed lines. The last one of the four lines is much weaker in intensity than the others because of $\Delta J = 2$, but can be recognized in the spectrum. All the corresponding transitions from the 4p levels have already been observed with considerable intensity and are listed in Ref. [2], e. g.:

$$\text{A II}\ 3s^2 3p^4 4p\ {}^2P^0_{1/2} - 3s3p^6\ {}^2S_{1/2}\,,\quad 196.14\ \text{nm}.$$

Besides these lines the hump shows no apparent structure, even at the high spectral resolution of the experiment, which is about 0.015 nm. The temperature dependence of the intensity of this hump is comparable with that of other A II lines. Furthermore experiments show that this intensity does not depend on the amount of impurities in the arc plasma. In particular, though it is situated in the Ly-α wing, it has nothing to do with hydrogen admixtures. These facts lead to the presumption that high lying, strongly broadened A II multiplets with considerable transition probabilities may be responsible for the structure in the spectrum. An analysis of the A II spectral tables [2] in the range 110 to 160 nm shows that the upper levels of almost all lines have the following configuration: An f-electron is attached to the A II core ${}^3P_{0,1,2}$ or ${}^1D_2$. These f-electrons are very hydrogen-like, i. e. the multiplet splitting is very small and the energy levels can very accurately be described by Rydberg series and a small quantum defect. The latter fact makes it possible to predict the wavelengths of lines from higher principal quantum numbers n with little uncertainty.

Based upon this consideration a computer program has been set up, which calculates the $n = 6, 7, 8$ levels of 24 f-electron configurations. Then it combines these results with 18 lower A II doublet and quartet levels lying in the appropriate energy range as to produce spectral lines in the interesting wavelength region. Of course, care has been taken to fulfil the usual selection rules. A relative intensity has been attributed to these lines according to the following relation:

$$\varepsilon_L = (2J+1)\ \exp\{-E_m/kT\}\ c/\lambda\, n^3\,. \qquad (1)$$

This equation is the usual formula for line emission coefficients with the statistical weight $(2J+1)$ and the asymptotic hydrogen transition probability c/n^3, where c is an arbitrary constant. The temperature has been chosen to be 20 000 K. Of course this is still a fairly rough model, because the individual transition probabilities have not been taken into account. The results of the described calculation are represented by the solid vertical lines at the bottom of Fig. 1 for the spectral range 117 to 127 nm.

A comparison of the calculated spectrum with the top recording in Fig. 1 shows that six lines lie indeed in the range of the broad 123 nm structure, the contour of which is nicely described by the calculated line intensities. A subsequent experimental investigation of the spectrum at lowered plasma pressure (0.13 atm), the result of which is also shown in Fig. 1, absolutely proved the theory of the merged A II lines. This measurement confirmes the calculated line structure of the spectrum in an excellent manner throughout the investigated wavelength range. In particular, the broad hump at 123 nm clearly breaks up into the predicted lines. This means that it actually consists of the transitions

$$^3P_2\ 7f^0_{5/2,7/2,9/2} - 3d\ ^4D_{1/2,3/2,5/2,7/2}\,,$$

which are completely merged at atmospheric pressure and the pertinent electron density of $2 \cdot 10^{17}\ \mathrm{cm}^{-3}$. In contrast to that the four superimposed A II lines, which originate from 5p electrons, are much less affected by the Stark broadening.

We thank the Deutsche Forschungsgemeinschaft for the support of this work.

[1] K. Behringer and W. R. Ott, Proc. of the XI-th Int. Conf. on Phenomena in Ionized Gases, paper 4.5.1.1, Prague 1973.

[2] A. R. Striganov and N. S. Sventitskii, Tables of Spectral Lines of Neutral and Ionized Atoms, IFI/Plenum, New York-Washington 1968.