Broadening of the He II Line $\lambda=4686$ Å in a Plasma

P. BOGEN
European Space Research Institute, Frascati (Rome), Italy

(Z. Naturforsch. 25 a, 1151—1153 [1970]; received 11 Mai 1970)

The profile of the He II $\lambda = 4686$ Å line has been measured in a plasma with an electron density of $5.5 \times 10^{18}$ cm$^{-3}$ and a temperature of $6 \times 10^4$ K. The measured halfwidth is consistent with that predicted by the Griem and Shen theory. On the far wings the intensity approaches the value expected when ions and electrons are treated by the static theory, although the electrons are far outside the static broadening regime.

The broadening of the He II line $\lambda = 4686$ Å by the electric fields of electrons and ions in a plasma was first discussed by UNSÖLD and WULFF using the Holtsmark theory. BERG measured the half-width $\Delta h_b$ of this line emitted from a plasma of known electron density $N_e$ and electron temperature $T$, and found $\Delta h_b$ in good agreement with the calculation of GRIEM and SHEN. Recently the whole profile has been determined by EBERHAGEN and WUNDERLICH. They obtained much lower intensities on the far line wings than theoretically predicted. Their profile could be explained if the contribution of the electrons to the intensity of the wings were negligible.

Since the last result is unexpected, the profile measurements have been repeated with the aim of improving the accuracy by avoiding the main difficulties in calculating $\Delta h_b$: the correction for insufficient resolution of the spectrometer and the modification of the theoretical profiles to include doubly ionized atoms. We have achieved an improvement by choosing appropriate plasma conditions, i.e., high densities (to give broad profiles) and low temperatures (to reduce double ionization).

The plasma was produced in the following way: a quartz tube of 3.6 cm inner diameter was filled with helium at a pressure of 0.4 Torr. It was surrounded by a single turn coil of 30 cm length and 4.2 cm diameter. By discharging a 0.5 µF, 25 kV condenser into this coil, the gas was preheated. Then, by switching the main condenser bank of 1 kJoule energy, 25 kV charging voltage to the same coil, magnetic compression produced a plasma of 0.1 µs life time with $N_e = 5.5 \times 10^{17}$ cm$^{-3}$, $T = 6.0 \times 10^4$ K and a ratio of double to singly ionized atoms $N_{i+}/N_i = 15\%$.

The absolute intensity $I_1$ of the continuum at 5200 Å and of the profiles of the He II lines $\lambda = 4686$ Å and $\lambda = 3203$ Å has been measured photoelectrically with a spectrometer having 1 Å resolution. The intensity calibration was performed with a carbon arc.

Side-on and end-on observations of the $\lambda = 3203$ Å line gave equal half-widths within $\pm 5\%$. This observation justifies the assumption of an optically homogeneous plasma layer. Owing to self-absorption the 4686 Å line appears much broader end-on than side-on. By comparison of both profiles, an optical depth $\tau = 2.6$ has been found in the line centre. Thus the temperature could be derived from $I_1$ at 4686 Å by using the equation of radiative transfer for a homogeneous layer and Planck’s law:

$$I_1 = B_1(1 - e^{-\tau}) ;$$

$$B_1 = 2\frac{c^2}{\lambda^5} \cdot \left(\exp\left(\frac{h c}{\lambda k T}\right) - 1\right)^{-1}.$$

The electron density was determined from the continuum intensity at $\lambda = 5200$ Å, the ratio $N_{i++}/N_i$ from the intensity of the 3203 Å line, the temperature, and the electron density using the Saha equation. Since for $N_e = 5 \times 10^{17}$ cm$^{-3}$ thermal equilibrium for quantum states with $n \geq 2$ can be expected the Saha equation can be applied.

The full half-widths $\Delta \lambda_h$ of the 3203 Å and 4686 Å lines are related to the electron density approximately by

$$N_e = C \Delta \lambda_h^{1/4}. $$

Several theoretical and experimental C-values are summarized in Table 1. The agreement between them is surprisingly good, especially for the 3203 Å line which is not very sensitive to temperature variations.

<table>
<thead>
<tr>
<th>Author</th>
<th>$\lambda=3203$ Å</th>
<th>$\lambda=4686$ Å</th>
</tr>
</thead>
<tbody>
<tr>
<td>BERG $^3$</td>
<td>$2.2 \times 10^{15}$</td>
<td>$13.9 \times 10^{15}$ cm$^{-3}$ $\AA^{-1/4}$</td>
</tr>
<tr>
<td>EBERHAGEN and WUNDERLICH $^5$</td>
<td>$2.3 \times 10^{15}$</td>
<td>$11 \times 10^{15}$ cm$^{-3}$ $\AA^{-1/4}$</td>
</tr>
<tr>
<td>Present Paper</td>
<td>$2.3 \times 10^{15}$</td>
<td>$11.5 \times 10^{15}$ cm$^{-3}$ $\AA^{-1/4}$</td>
</tr>
<tr>
<td>GRIEM and SHEN $^4, 6$</td>
<td>$2.2 \times 10^{15}$</td>
<td>$12 \times 10^{15}$ cm$^{-3}$ $\AA^{-1/4}$</td>
</tr>
<tr>
<td>interpolated for $T=6 \times 10^4$ K, $N_e=5 \times 10^{17}$ cm$^{-3}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. C-values for the relation $N_e = C \Delta \lambda_h^{1/4}$.

The intensity of the far wings is compared with that derived from different theories and experiments by using the normalized profile:

$$S(a) = I_1 F_0/I_0 \quad \text{with} \quad a = \Delta \lambda/F_0,$$

$$F_0 = 2.61 e N_e^{1/4}, \quad I_0 = \int I_1 \, d\lambda.$$ 

The correction of $F_0$ for doubly ionized atoms has been neglected. Applying this correction the theoretical $S(a)$ curves for ion broadening would increase by about 10%, the curves including ion and electron broadening by about 5% on the far wings. The results are given in Fig. 1. Side-on and end-on observations agree at a typical a-value of $5 \times 10^{-2}$ Å/cgs unit within ± 5%. The experimental curve is compared with calculations of GRIEM and SHEN $^4, 6$. They use the static theory for the perturbing ions and a collision theory for the electrons in accordance with the prediction $^7$ that the static broadening theory is not applicable till $\Delta \lambda \approx 1300$ Å, which is far outside the wavelength range considered. From the cases they have treated those of $N_e = 10^{17}$ cm$^{-3}$, $T = 80000$ K, giving too low half-width, and $N_e = 10^{18}$ cm$^{-3}$, $T = 80000$ K, giving too high half-width, are plotted. The wing intensities given by GRIEM $^6$ at $a = 5 \times 10^{-2}$ Å/cgs unit are a factor 2.35 or 3.25 higher than calculated from the

The wings of the Balmer lines of hydrogen can be described over a wide range of a by the asymptotic formula

$$S(a) = \text{const} \, a^{-1/4}$$

considering electrons and ions as static perturbers $^8, 10$. Fig. 1 shows that this formula gives a good approximation to our experimental results for large a. When the broadening by ions only is taken...

---


$^8$ H. R. GRIEM, Comments, Atomic and Molecular Phys. 2 [1970].
into account and the field distribution function of Mozér and Baranger is used, the intensities obtained are too low.

In summary, the results indicate that the electrons give about the same contribution to the wing broadening as the ions even for values $\Delta \lambda / \Delta \lambda > 25$ where collision theory should be used for the electrons. Our results are not in good agreement with those obtained by Eberhagen and Wunderlich. The discrepancy would be partly removed if their corrections for doubly ionized atoms were omitted.

On the other hand the profile measured by Wulff agrees with our result when $N_e = 3.2 \cdot 10^{16}$ cm$^{-3}$ instead of $N_e = 3.9 \cdot 10^{16}$ cm$^{-3}$ is assumed. This correction is very favourable since it gives a much better fit to Wulff's other electron density determinations.

I thank the KFA Jülich for the loan of experimental equipment and Mr. I. Pollard and Mr. W. Wiegmann for technical help in construction and operation of the experiment.

10 P. Bogen, Z. Physik 149, 62 [1957].