Stark Broadening Parameters of Ne I 837.8 nm Spectral Line

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Abstract. The Stark broadening parameters of Ne I 837.8 nm spectral line corresponding to the transition 2p⁵3d ⁹[7/2]⁴ – 2p⁵3p ⁹[5/2], have been calculated using Sahal-Bréchot theory. The temperature dependence of the width and shift has been obtained.

1. Introduction
Stark broadening parameters of neon lines are of importance not only for laboratory plasma diagnostics and for technological plasma investigations and development but also for astrophysics. Neon is the most abundant element in the universe after hydrogen, helium, oxygen, and carbon, and it is, for example, one of the products of hydrogen and helium burning in the orderly evolution of stellar interiors. Consequently, its lines are present in stellar spectra and, for example, neon spectral lines have been used to determine its abundances in late- to mid-B stars [1]. The neon spectral line at 837.8 nm, corresponding to the transition 2p⁵3d ⁹[7/2]⁴ – 2p⁵3p ⁹[5/2], is one of the most useful for plasma diagnostics [2]. It is intensive, well isolated, and in the visible part of the spectrum. The Stark broadening of this line was theoretically investigated, for example, by Griem in [3] and experimentally by Purić et al. [4] and del Val et al. [5]. In this paper, calculations of the Stark broadening parameters of Ne I 837.8 nm for astrophysical purposes are presented.

2. Theory
In this work the semi-classical theory of Sahal-Bréchot [6,7] for Stark broadening calculations, also presented in [8], has been used.

3. Results
3.1. Atomic data
In table 1 the wavelengths of the studied neon line, along with the corresponding transition in j-L coupling scheme, the perturber energy levels, the energy values of the initial and final level of the transition, and the effective quantum number of the initial level are included.
Table 1. Basic data for the considered Ne I spectral line. Here $\lambda$ denotes wavelength, $i$ and $f$ are initial and final level of the transition (within the frame of $j$-$L$ coupling), $i'$ and $f'$ are the corresponding perturbing levels, $E_i$ and $E_f$ are the energy values, and $n^*$ is the effective quantum number of the initial level.

| $\lambda$ (nm) | Transition $(i-f)$ | $i'$ levels | $f'$ levels | $E_i$ (cm$^{-1}$) | $E_f$ (cm$^{-1}$) | $n^*$ |
|---------------|-------------------|-------------|-------------|-----------------|-----------------|------|
| 837.7         | $2p^53d' - 2p^23p^2$ | 4f, 5f,     | 3s, 4s, 5s, | 161590.3        | 149657.0        | 2.98 |

3.2. Calculations

The calculations have been oriented for the diagnostic of astrophysical objects where the perturbers are electrons, helium ions, and protons, and have been made for a set of temperatures ($2.5 - 5.0 \times 10^4$ K) at a perturber density of $10^{16}$ cm$^{-3}$. The values of the energy levels have been taken from the NIST catalogue [9]. The oscillator strengths ($j$-$L$ coupling) have been calculated within the Bates & Damgaard approximation.

3.3. Temperature dependence

The calculated results for the Stark width and shift of the examined neon spectral line are included in table 2. The contribution of the interactions between: (i) emitters and electrons ($W_e$, $d_e$); (ii) emitters and helium ions ($W_{He^+}$, $d_{He^+}$) and (iii) emitters and protons ($W_p$, $d_p$) in the Stark width and shift are given. The value of the maximum density for which the line is isolated for the corresponding perturber can be calculated using the ratio $C/W$, where $C$ is the parameter, included in table 2 and $W$ is the total width. For the ordinary stellar plasma the total Stark width $W$ and shift $d$, respectively, are approximately:

$$ W = W_e + 0.9W_p + 0.1W_{He^+} $$  (1)
$$ d = d_e + 0.9d_p + 0.1d_{He^+}. $$  (2)

Table 2. Stark broadening parameters for Ne I 837.7 nm for a perturber (electrons, helium ions and protons) density of $10^{16}$ cm$^{-3}$ and temperatures from 2500 up to 50000 K.

| Perturbers are: | Electrons | Ionized helium | Protons |
|----------------|-----------|----------------|---------|
| Transition     | $T$ (10$^3$ K) | $W_e$ (0.1 nm) | $d_e$ (0.1 nm) | $W_{He^+}$ (0.1 nm) | $d_{He^+}$ (0.1 nm) | $W_p$ (0.1 nm) | $d_p$ (0.1 nm) |
| 3d $^2[7/2]_4$- | 2.5       | 0.306          | 0.21      | 0.0788          | 0.031          | 0.918×10$^{-1}$ | 0.502×10$^{-1}$ |
| 3p $^2[5/2]_3$- | 5         | 0.35           | 0.233     | 0.0831          | 0.0386         | 0.974×10$^{-1}$ | 0.601×10$^{-1}$ |
| 837.7 nm       | 10        | 0.383          | 0.239     | 0.0868          | 0.046          | 0.104          | 0.701×10$^{-1}$ |
| C = 0.65×10$^9$| 20        | 0.417          | 0.222     | 0.0909          | 0.0535         | 0.112          | 0.806×10$^{-1}$ |
| 50             | 0.465     | 0.162          | 0.0973    | 0.064           | 0.125          | 0.956×10$^{-1}$ |

3.3.1. Width. The values of the three components of the width, corresponding to the different perturbers, and the total Stark width increase with the temperature in the examined interval (perturber density $10^{16}$ cm$^{-3}$). The temperature dependence of the electron width is illustrated in figure 1.
In ordinary stellar plasma for temperatures \((0.25 - 5) \times 10^4 \text{ K}\) and at an electron density \(10^{16} \text{ cm}^{-3}\), the contribution of the collisions between neon emitters and electrons in the total Stark width is \(77 - 79\%\), of emitters-helium ions collisions \(1 - 2\%\), and the contribution of the emitters-protons is \(19 - 20\%\).

3.3.2. Shift. The electronic component of the shift due to the collisions between the emitters and electrons increases with the temperature up to near \(10^4 \text{ K}\) and after that decreases. This dependency governs the temperature variation of the total Stark shift, as it is shown in figure 2. The values of the shift due to the collisions of the emitters with the helium ions and protons increase with the temperature in the considered temperature interval.
For ordinary stellar plasmas, for example in the temperature interval \((0.25 - 5) \times 10^4\) K and at an electron density \(10^{16} \text{ cm}^{-3}\), the contribution of the collisions between neon emitters and electrons in the total Stark shift is 64–81 \%, this one of the emitters-helium ions collisions – 1–2.5 \%, and the contribution of the emitters-protons is 17–33 \%.

A complete analysis of the obtained results and a comparison with the theoretical and experimental results available in the literature will be given in [10].

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