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Temperature dependence of non hydrogenic atom-lines Stark widths

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Abstract. Our objective here is to demonstrate that sometimes used dependence $T^{-1/2}$ for scaling with temperature is often inadequate, particularly for Stark broadening of neutral emitter lines.

Key words. Stark broadening- plasma spectroscopy- Line widths

1. Introduction

In order to compare experimental data for Stark width of non hydrogenic atom-, and ion-lines obtained at various plasma conditions, different methods for scaling with temperature are used. Among them, sometimes is used that the Stark width w depends on T as $T^{-1/2}$, which is often good for ionized atoms. However, the use of such dependence without additional checks might be inadequate, especially for spectral lines of neutral atoms. For example, in Konjević (1999), empirical relations for Stark width dependence on temperature, different from $T^{-1/2}$, are obtained for a number of particular cases of neutral atom spectral lines. In order to demonstrate the deviations from the $T^{-1/2}$ dependence, we will derive here temperature dependence for two particular cases, starting from the simplified formula of Freudenstein, & Cooper (1978).

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2. Theory

According to Freudenstein, & Cooper (1978), Stark half-half width (w) of an isolated, non-hydrogenic, neutral atom spectral line, for the case of one dominant perturbing level for the initial (i) state and one for the final (f) state of the considered transition, may be expressed as

$$w = \frac{c_0}{\sqrt{T}}[R_{ii}^2 f_w\,(\eta_{ii'} R_{ii'}) + R_{ff}^2 f_w(\eta_{ff'} R_{ff'})], \quad (1)$$

where i' and f' are the corresponding closest perturbing levels,

$$c_0 = \left(\frac{32}{27}\right)^{\frac{1}{2}} N_e \pi \left(\frac{E_H}{k}\right)^{\frac{1}{2}} \left(\frac{\hbar a_0}{m}\right) \quad (2)$$

E_H is the hydrogen atom ionization energy, N_e electron density and

$$R_{jj}^2 = \frac{n_j^{*2}}{2Z^2}\left[5n_j^{*2} + 1 - 3\ell_j(\ell_j + 1)\right], j = i, f. \quad (3)$$

Here, n_j^* and ℓ_j are effective principal, and orbital quantum numbers of the atomic energy level j and Z charge "seen" by the optical electron ($Z = 1$ for neutrals, 2 for singly charged ions ...). The dipole matrix element ${R_{jj'}}^2 = f_{jj'} \times \frac{\lambda_{jj'}(\text{Å})}{303.7}$, where $f_{jj'}$ is the oscillator strengths between levels j and j', $\lambda_{jj'}$ the corresponding wavelength and $\eta_{jj'} = |E_j - E_{j'}|/3kT$, E_j, $E_{j'}$ being energies of the corresponding atomic levels.

For ηR much larger than one or

$$T << R_{jj'}|E_j - E_{j'}|/3k, \quad (4)$$

the function $f_w(\eta_{jj'}R_{jj'})$ may be approximated as (Freudenstein, & Cooper 1978)

$$f_w(\eta_{jj'}R_{jj'}) = \frac{1}{2}[3\pi^2/32(\eta_{jj'}R_{jj'})^2]^{1/3} \quad (5)$$

For such a case f_w may be expressed explicitly as a function of T

$$f_w = B_{jj'}T^{2/3} \quad (6)$$

$$B_{jj'} = \frac{1}{2}(\frac{27}{32})^{1/3}(\pi k/|E_j - E_{j'}|R_{jj'})^{2/3}. \quad (7)$$

Finally, w may be expressed as an explicit function of T as

$$w = CT^{1/6} \quad (8)$$

$$C = c_0(B_{ii'}R_{ii}^2 + B_{ff'}R_{ff}^2). \quad (9)$$

Similarly, for ηR much smaller than one or

$$T >> R_{jj'}|E_j - E_{j'}|/3k, \quad (10)$$

the function $f_w(\eta_{jj'}R_{jj'})$ may be approximated as (Freudenstein, & Cooper 1978)

$$f_w(\eta_{jj'}R_{jj'}) = \ln(2.27/\eta_{jj'}R_{jj'}). \quad (11)$$

For this case one can also express explicitly the dependence of w on T, since

$$f_w = \ln(D_{jj'}T) \quad (12)$$

$$D_{jj'} = 2.27 \times 3k/|E_j - E_{j'}|R_{jj'}, \quad (13)$$

and

$$w = T^{-1/2}[F_1 + F_2\ln(T)]. \quad (14)$$

$$F_1 = c_0[R_{ii}^2\ln(D_{ii'}) + R_{ff}^2\ln(D_{ff'})]. \quad (15)$$

$$F_2 = c_0(R_{ii}^2 + R_{ff}^2). \quad (16)$$

Dimitrijević, & Konjević (1986) generalized the formula of Freudenstein, & Cooper (1978) for the case of more than one important perturbing level and also derrived analogous formula for the shift. According to Dimitrijević, & Konjević (1986), Eq. (1) becomes

$$w = \frac{c_0}{\sqrt{T}}[\sum_{i' \neq i} R_{ii'}^2 f_w(\eta_{ii'}R_{ii'}) + \sum_{f' \neq f} R_{ff'}^2 f_w\left(\eta_{ff'}R_{ff'}\right)] \quad (17)$$

For this case, the temperature dependence described by Eqs. (8) and (14) is also valid, but the corresponding quantities C, F_1 and F_2 become

$$C = c_0(\sum_{i' \neq i} B_{ii'}R_{ii'}^2 + \sum_{f' \neq f} B_{ff'}R_{ff'}^2). \quad (18)$$

$$F_1 = c_0[\sum_{i' \neq i} R_{ii'}^2\ln(D_{ii'}) + \sum_{f' \neq f} R_{ff'}^2\ln(D_{ff'})]. \quad (19)$$

$$F_2 = c_0(\sum_{i' \neq i} R_{ii'}^2 + \sum_{f' \neq f} R_{ff'}^2). \quad (20)$$

3. Conclusion

Within the simplified theory of Freudenstein, & Cooper (1978) for determination of Stark width of an isolated, non-hydrogenic, neutral atom spectral line, we have derived the explicit temperature dependence for the cases when T is much larger and much smaller than $R_{jj'}|E_j - E_{j'}|/3k$, and demonstrated that it is different from $T^{-1/2}$. The obtained relations are also generalized for the case of more than one perturbing level (Dimitrijević, & Konjević 1986).

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