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SIMPLE FORMULAE FOR ESTIMATING STARK BROADENING PARAMETERS OF NEUTRAL ATOM LINES

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RESUME.- Nous avons présenté formules pour estimation de la largeur et du déplacement Stark des raies spectrales des neutres.

SUMMARY.- Simples formulae for estimating Stark width and shift of neutral atom lines are presented.

In 1978, Freudenstein and Cooper [1] suggested a simple method for evaluation of electron-impact widths of neutral atom lines, based on the simplification of GBKO [2] method. We develop here this approach further and extend its applicability to the shift calculations also.

The half-half width (w) and shift (d) of a neutral atom spectral line broadened by electron impacts are given by [2]

$$w+id=\frac{4\pi}{3} N_e\left(\frac{\hbar}{m}\right)^2 \int \frac{dv}{v} f(v)\left\{ \frac{1}{2}\tilde{\rho}^2_{min} + \sum_{i'} \vec{R}^2_{ii'}\left[a_{ii'}(z^{min}_{ii'}) - i\,\varepsilon_{ii'} b_{ii'}(\tilde{z}^{min}_{ii'})\right] + \sum_{f'} \vec{R}^2_{ff'}\left[a_{ff'}(z^{min}_{ff'}) + i\,\varepsilon_{ff'} b_{ff'}(\tilde{z}^{min}_{ff'})\right]\right\} \tag{1}$$

where $\vec{R}^2_{jj'}$ is the square of the coordinate operator matrix element, i,f denote the initial and final states, and i′,f′ are the corresponding perturbing states within the dipole approximation. $\varepsilon_{jj'}=(E_j-E_{j'})/|E_j-E_{j'}|$, where E_j and $E_{j'}$ are the energies of the corresponding states. The minimum impact parameter ρ_{min} allowed by the unitarity condition [2] is given by

$$\rho^2_{min} = \frac{2}{3}\left(\frac{\hbar}{mv}\right)^2\left|\sum_{i'} \vec{R}^2_{ii'}\left[A_{ii'}(z_{ii'}) - i\,\varepsilon_{ii'}B_{ii'}(z_{ii'})\right] + \sum_{f'} \vec{R}^2_{ff'}\left[A_{ff'}(z_{ff'}) + i\,\varepsilon_{ff'}B_{ff'}(z_{ff'})\right]\right| \tag{2}$$

where $a_{jj'}$, $b_{jj'}$, $A_{jj'}$ and $B_{jj'}$ are the GBKO [2] Stark broadening functions of the arguments $z_{jj'}$ and $\tilde{z}_{jj'}$ [2], and ρ is the impact parameter.

In order to simplify Eqs. (1) and (2), we introduce here the approximation

$$\left|\sum_{j'} \vec{R}^2_{jj'}\left[A_{jj'}+i\,\varepsilon_{jj'}B_{jj'}\right]\right| \approx \sum_{j'} \vec{R}^2_{jj'}\left|\left[A_{jj'}+i\,\varepsilon_{jj'}B_{jj'}\right]\right| \tag{3}$$

For a series of complex numbers z_j we have $|\sum z_j| \leq \sum |z_j|$, where the signe of equality holds in the case when all z_j have equal arguments. This means that $A_{jj'} \gg B_{jj'}$ which is satisfied for close collisions, high velocities or close perturbing levels, giving usually the principal contribution to the line broadening

Define $\eta_{jj'} \equiv |E_j - E_{j'}|/3kT$. Then

$$w + id \approx 1.089 N_e \pi \left(\frac{\hbar a_0}{m}\right)\left(\frac{E_H}{kT}\right)^{1/2} \left\{ \sum_{i'} \vec{R}^2_{ii'} \left[f_w(\eta_{ii'} \vec{R}_{ii'}) - \right.\right.$$
$$\left. - i\, \varepsilon_{ii'} f_d(\eta_{ii'} \vec{R}_{ii'}) \right] + \sum_{f'} \vec{R}^2_{ff'} \left[f_w(\eta_{ff'} \vec{R}_{ff'}) + \right.$$
$$\left.\left. + i\, \varepsilon_{ff'} f_d(\eta_{ff'} \vec{R}_{ff'}) \right] \right\}, \qquad (4)$$

Approximate fitted expressions for f_w and f_d are:

$$f_w(x) = e^{-1.33x} \ln\left(1+\frac{2.27}{x}\right) + \frac{0.487x}{0.153+x^{5/3}} + \frac{x}{7.93+x^3}$$

$$f_d(x) = 1.571\, e^{-2.482x} + \frac{1.295x}{0.415+x^{5/3}} + \frac{0.713x}{8.139+x^3} \qquad (5)$$

where $x = \eta_{jj'} \vec{R}_{jj'}$.

In Table 1, our results obtained using Eqs. (4) and (5) are compared with results from Ref. 3 and according to Ref. 1. We can see that in the simple case of $2p^1P$-$5s^1S$ transition, all calculations are in agreement. In the case of He I $2p^1P$-$3d^1D$ line, where we have not a dominant perturbing level, our calculations for the width agree better with BG results.

We belive that the simple formulae presented here, will be useful when astrophysicists or physicists require a large number of neutral atom line widths and shifts influenced by the Stark effect.

Table 1. - Half-half widths and shifts in Å: DK-present results; BG-results from Ref. 5 (also given in Ref. 1); FC-results calculated according to Ref. 2. $N_e = 10^{16} cm^{-3}$

T(K)	W_{DK}	W_{BG}	W_{FC}	d_{DK}	d_{BG}
He I $2p^1P$-$5s^1S$ 4438 A line					
5000	1.46	1.41	1.34	1.73	1.51
10000	1.77	1.57	1.64	1.49	1.43
20000	1.85	1.65	1.72	1.12	1.24
30000	1.79	-	-	0.924	-
40000	1.72	1.62	1.60	0.803	0.996
He I $2p^1P$-$3d^1D$ 6678 A line					
5000	0.468	0.423	0.948	0.236	0.275
10000	0.432	0.386	0.825	0.181	0.233
20000	0.428	0.349	0.696	0.135	0.196
30000	0.389	-	-	0.111	-
40000	0.364	0.318	0.573	0.096	0.161

REFERENCES

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